THE PALYNOLOGY OF TWO WHANGAREI CRATERS,
NORTHLAND, NEW ZEALAND.

A thesis presented in partial fulfillment of the requirements for the degree of
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in
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The Swamp Forest in Maungatapere Crater, Whangarei
Photographer; R. Stewart 2011-12-08.

ABSTRACT

Whangarei lies within the Puhipuhi-Whangarei Volcanic Field, one of two fields located in Northland. The purpose of this project was to use a palynological study to provide information on the minimum ages of the young Whangarei cones, their vegetation history, and the approximate date of human arrival. Wetlands in the craters of the Maungatapere and Rawhitiroa basaltic cones were selected for this study since they both occupy discrete areas which only collect sediment from within their respective cones. A single peat core from each wetland was processed for fossil pollen and radiocarbon dating.

Radiocarbon dating was performed by the University of Waikato, providing minimum ages for the volcanoes. The date for the base of the Maungatapere core was 10530 ± 136 cal. yr BP, and an age of 2775 ± 52 cal. yr BP was determined for the basal peat from Rawhitiroa. K-Ar dating performed previously indicated that these cones were about 0.30 my old.

The pollen data indicated that a kauri-conifer-broadleaved forest was consistently present around Whangarei during the Holocene. At Maungatapere the arrival of Maori at c. 1360 AD was inferred from the marked decrease in *Dacrydium cupressinum* and the appearance of new species. This was an important horticultural site and was not repeatedly burned. At Rawhitiroa, the arrival of Maori possibly at *c*. 1200 AD was indicated by a decline in forest trees and the increased abundance of *Pteridium esculentum* and charcoal fragments. This occurred prior to the deposition of the Kaharoa Tephra, the presence of which was noted in the Rawhitiroa core.

The Maungatapere wetland is currently a fertile swamp forest while the Rawhitiroa wetland is an infertile bog dominated by *Sphagnum* and sedges. The difference in the fertility of the two wetlands can be partially attributed to the activities of humans. Repeated forest fires at Rawhitiroa increased waterlogging and stimulated the growth of herbaceous wetland vegetation, causing the rapid build-up of peat and infertile conditions. The forest at Maungatapere was not repeatedly burned and the wetland became drier over time, maintaining its fertility.

The incomplete core of peat infill at Maungatapere was a limitation of this project.

ACKNOWLEDGEMENTS

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Thanks are also expressed to Mrs. J. Hooker, and Mr. and Mrs. G. Hooker for access and permission to core the Rawhitiroa crater swamp, and to Mr. and Mrs. Peter and Judith Grove for access across their farm to the Maungatapere cone.

Information provided by Mr. B. Cathcart and Mrs. L. Forester, Northland Regional Council, and Mrs. J. Maingay, Department of Conservation, is gratefully acknowledged. Maureen E. Young is thanked for permission to include in this thesis, the species list for Maungatapere as published in the *Auckland Botanical Society Journal Vol. 66(2).* The Geoscience Society of New Zealand is thanked for supporting this work financially through the S.J. Hastie Student Scholarship.

The coring of Maungatapere cone was only made possible through permission from the Department of Conservation and the Ngatiwai Trust.

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CHAPTER ONE

INTRODUCTION

1.1 General Introduction

Palynological studies have been undertaken at a number of sites in Northland, especially in the area north of Whangarei (e.g. Elliot *et al*. 1995 and 1997; Horrocks *et al.* 2001 and 2007; Newnham 1992; Newnham *et al*. 2004). Most of the studies have focused on swamps and lakes associated with coastal dune systems (e.g. Elliot *et al*. 1995 and 1997; Horrocks *et al.* 2001 and 2007; Kershaw & Strickland 1988), but one centered on events following the formation of a lake during volcanic activity near Kaikohe (Elliot *et al.* 1998). There are a number of young volcanic cones in the Whangarei area. The craters of most of these have been breached, but two cones - Maungatapere and Rawhitiroa – have craters containing wetlands (Ferrar *et al.* 1925; Rollin 1991). While the crater at Rawhitiroa currently contains a wetland colonised by species such as *Sphagnum* moss and sedges, the swamp in the Maungatapere crater is much drier, with a swamp forest dominated by *Syzygium maire* and *Dacrycarpus dacrydioides.* Neither of these wetlands has been studied for palynological purposes previously. A possible explanation for the formation of these two very different wetlands will be the focus of this thesis.

K-Ar dating on the Whangarei basalts has indicated an age of 0.29 ± 0.05 my for the Maungatapere scoria cone, and 0.31 ± 0.15 my for the cluster of cones at Kamo which includes Rawhitiroa (Smith *et al.* 1993, quoted in Sporli and Hayward 2002). Fossil pollen extracted from cores of the crater wetlands should provide a history of changes in the composition of the vegetation and climate since sediments began accumulating in the craters after they were formed. One of the dominant climatic signals over this time has been glacial and interglacial periods with a periodicity of about 100,000 years. The Last Interglacial climaxed about 125 ka (Henderson-Sellers and Robinson 1986). If Maungatapere and Rawhitiroa volcanic cones are about 300,000 years old they are likely to have experienced a time span which included three glacial periods. This should be reflected in the sedimentological record of each crater and composition of the vegetational record as preserved by the fossil pollen. The initial colonisation of a new crater floor will be affected by such factors as the cooling period for the hot volcanic rocks and subsequent soil formation. Currently the weathering of rock to form soil and clay proceeds rapidly in Northland's warm, moist climate (Ballance and Williams 1992; Cathcart 1988; Newnham 1999), but would be expected to have occurred more slowly during glacial periods. In turn the time taken for clay to form an impermeable layer as may have occurred at Rawhitiroa (Rollin 1991) or plugs in the vesicular Maungatapere basalt (French 1980), will influence the speed of wetland formation and thus the retention of fossil pollen. Palynological studies and the interpretation of pollen diagrams can be used to identify climatic and ecological changes over time since a volcanic cone's emplacement, but only provide a minimum age for its formation.

Several palynological studies in Northland have attributed a marked change in the composition of vegetation in the late Holocene due to deforestation and burning to the early Polynesians, with later changes caused by agricultural development by the European settlers (e.g. Elliot *et al.* 1995 and 1998; Horrocks *et al.* 2007*;* Newnham *et al.* 2004). Unfortunately this information was not available from the two pollen sites closest to Whangarei, which are McEwan's Bog on the coast near the mouth of the Whangarei Harbour (Kershaw and Strickland 1988), and the Otakairangi Swamp (Newnham 1992). Archaeological reports record the presence of Maori pits and a terrace and platform on the crater rim of the Maungatapere cone and of the Pukeatua Pa lying below, but there is no estimate of age (NZAA 1982). There is also a documented archaeological site on the Hurupaki cone which lies within two kilometres of Rawhitiroa, but again there is no estimate of age. The current study will provide additional information on the presence of any volcanic ash and of changes in the vegetation as recorded by fossil pollen and charcoal fragments; this may not only assist with the dating of the volcanoes but also determine when the Polynesian settlers first arrived in the area.

1.2 Selection of Study Sites and Aim of Project

The purpose of this project is to use a palynological study to provide information on the minimum age and vegetation history of two late Quaternary basaltic volcanoes in the Whangarei area. As noted above although a similar study was undertaken at the Tauanui volcanic centre in the Bay of Islands (Elliot *et al*. 1998), it has not been conducted previously in the Whangarei area.

Five potential study sites were identified and considered for the study. These consisted of the Maungatapere volcanic cone, a nearby raupo swamp in the Maungatapere area, the Rawhitiroa volcanic cone, a nearby swamp on Church Road, and Lake Ora all in the Kamo area. The locations of these are shown in Figure 1.1.

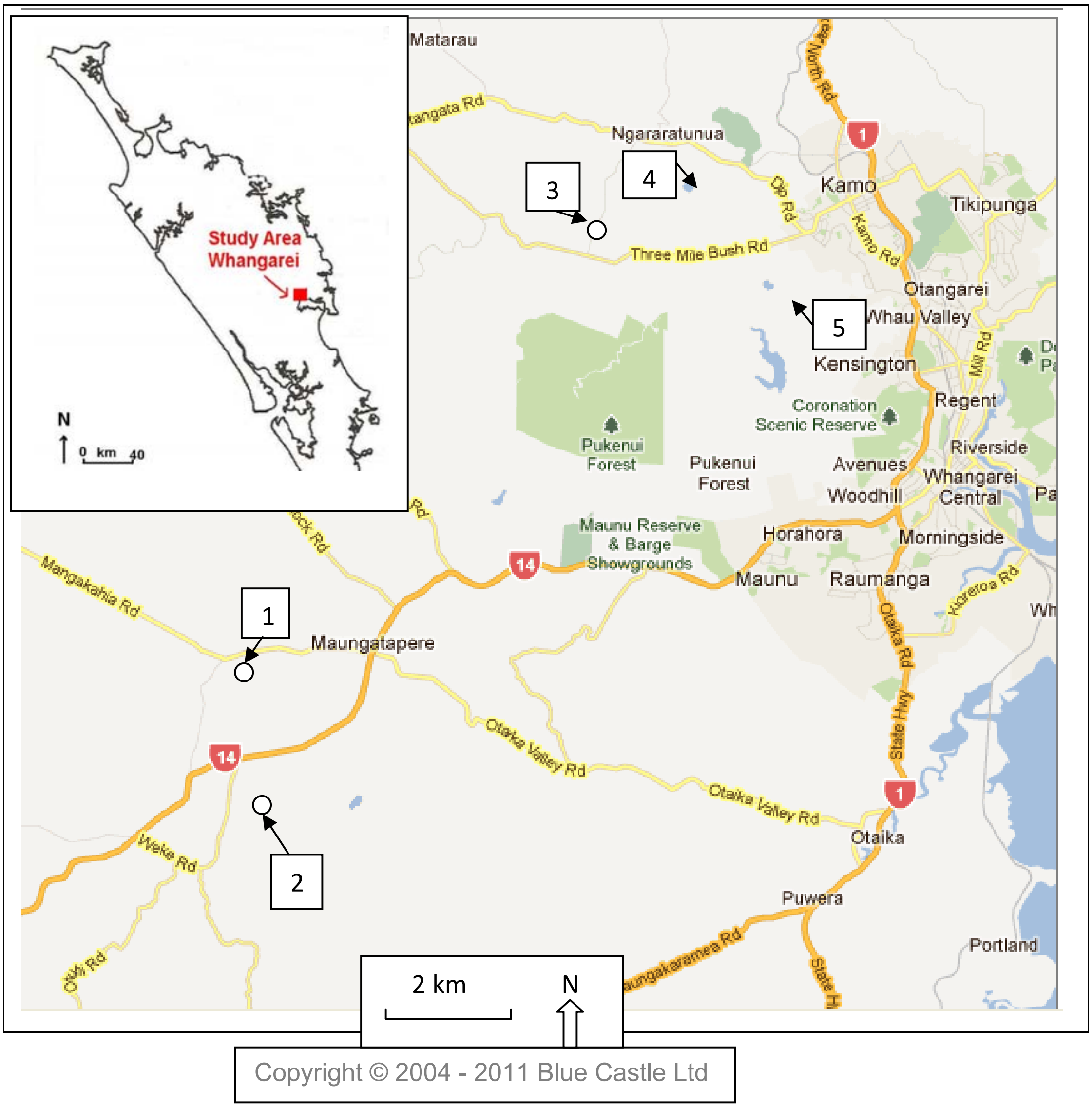

Figure 1.1: Map showing the possible sampling sites west of central Whangarei, Northland, New Zealand.

Insert map shows the location of the study area.

Key to locations on map above;

1. Raupo swamp, Mangakahia Rd.
2. Maungatapere volcanic cone
3. Swamp, Church Rd.
4. Rawhitiroa volcanic cone
5. Lake Ora

The Maungatapere and Rawhitiroa crater swamps were selected because they are the most suitable sites for this study covering discrete areas which only collect sediment from inside the cones, and where there are no natural outlet streams for drainage. Also, permission for coring was readily available.

Accordingly this study has five aims;

- To collect cores of sediment to enable the identification of fossil pollen and sediment trapped in the crater swamps of Maungatapere and Rawhitiroa volcanic cones
- To use information derived from the pollen profiles and radiocarbon dating to provide a minimum age for the volcanoes
- To reconstruct the vegetation history and palaeoecology of the area, and identify changes in climate over the time represented
- To seek evidence of human impact
- To compare the projected vegetation history of the Maungatapere and Rawhitiroa volcanic cones with each other and with other study sites of a similar age in Northland.

This account will commence with an introduction to the New Zealand environment in Chapter Two. The relationships between climate and vegetation patterns, and between vegetation composition and pollen rain will be discussed, including the problem of separate species with indistinguishable pollen. This will provide a basic understanding of the inter-relationship between some factors which influence interpretation of pollen profiles. The geology, landforms and ancient geological processes which helped to create the current geomorphology of Northland are described in Chapter Three. The focus of Chapter Four revolves around previous studies undertaken in mid-Northland. This includes palynological studies, dating of lava flows, and the impact of humans on the environment, thus providing background information for the current study which is introduced in Chapter Five, Whangarei Study Sites.

Chapter Five commences with a brief over-view of the geology of Whangarei City and the surrounding area, followed by a more detailed description of the Maungatapere and Rawhitiroa cones. Field and laboratory methods are introduced in Chapter Six. The collection of cores is described, and contour maps of the sites attached. The longest core from Maungatapere (3MT) and the core from Rawhitiroa were selected for detailed study, and the processing of cores within the laboratory is described. The stratigraphic columns are also included. Results of the study appear in Chapter Seven. This includes the radiocarbon dating and palynology of each site, and the analysis of the clay and tephra from the Rawhitiroa core. A detailed interpretation of the palynology appears in Chapter Eight. The various factors that may have affected the vegetation history and results for each site are discussed fully, and minimum ages for the volcanic cones provided. A summary of results and conclusions appears in Chapter Nine, where limitations affecting this report are outlined and further studies suggested.

A number of appendices are attached;

- Appendix 1 provides a summary of Northland sites where pollen studies have identified anthropogenic-induced environmental changes and approximate dates of when these first occurred.
- Appendix 2 is a summary of vegetation and climate changes for the three sites from mid-Northland reviewed in Chapter 4 – Otakairangi Swamp, Tauanui Volcanic Centre, and McEwan's Bog.
- Appendix 3 consists of the species lists for Maungatapere and Rawhitiroa.

- Appendix 4 provides detailed descriptions of the Maungatapere (3MT) and Rawhitiroa cores.
- Appendix 5 contains the reports for the radiocarbon dating.
- Appendix 6 contains the original-counts data for the species, reference *Lycopodium* and charcoal fragments from Maungatapere and Rawhitiroa wetlands.

CHAPTER TWO

INTRODUCTION TO THE NEW ZEALAND ENVIRONMENT

2.1 Climate

The New Zealand climate is dominated by a strong westerly circulation characterized by cycles of eastward-moving anticyclones alternating with troughs of low pressure; each cycle usually lasts between six and ten days. Changes in the direction of the gradient airflow, and the presence and orientation of mountain ranges have a marked effect on local climates and weather (McGlone *et al*. 1993; Salinger 1980a and b).

A warm to cool-temperate oceanic climate currently prevails over most of the country (McGlone *et al*. 1993; Salinger 1980a and b). However, during the Last Glacial Maximum (26.5 – 19.0 ka, as defined by Clark *et al*. 2009) there was extensive glaciation in the mountainous areas of the South Island and also along the coastal lowlands of central Westland. The North Island remained relatively free of permanent ice although small valley glaciers formed on some of the high peaks of central and southern areas (McGlone *et al*. 1993).

The climate, especially temperature and precipitation patterns, play a major role in determining the vegetation pattern of an area (Burns and Leathwick 1996). These patterns also affect the weathering of rocks and soil formation (Ballance and Williams 1992; Cathcart 1988; Newnham 1999).

2.2 Vegetation Patterns

During the Last Glacial Maximum (26.5 – 19.0 ka), grass or shrub-dominated communities covered New Zealand in areas south of Auckland. Grassland was most common in the east with shrubland in the west. Small pockets of forest survived in favourable sites (refugia) especially in the North Island. With climatic amelioration in the late-glacial period, afforestation was rapid even in upland areas (McGlone *et al*. 1993). It was suggested by Newnham (1992) that *Nothofagus* subgenus *Fuscospora* (*Fuscospora*) forest and shrub-grassland covered Northland during the Last Glacial Maximum. Newnham *et al.* (2012) state that there was extensive forest cover only from Auckland northwards. In the far north this consisted of a podocarp-broadleaved forest, and the occasional *Agathis australis,* with more open forest dominated by *Nothofagus* and shrubs elsewhere.

The pollen records from Auckland maars have indicated the occurrence of three major climatic events during the late Pleistocene to early Holocene, with time planes derived from local tephra deposits (Alloway *et al.* 2007). The first was a cool event which occurred at about the time of the Poihipi Tephra deposition (*c.* 27,237 ± 587 cal. yr BP) when there was a decline in biological productivity accompanied by the expansion of grassland (Alloway *et al*. 2007). The second event occurred just prior to the deposition of the Rerewhakaaitu Tephra at about 17,625 ± 425 cal. yr BP. This indicated a marked change in climate from cool to warmer conditions, accompanied by an expansion of the lowland forest. As podocarps had maintained a presence in the vegetation during the preceeding cool period, they were able to take advantage of warmer conditions which was accompanied by a reduction in seasonal climatic extremes. Thus, vegetation previously dominated by beech forest, shrubs and grasses was rapidly replaced by tall podocap forest. There may have also been an increase in rainfall and a decrease in windiness during this period (Alloway *et al*. 2007).

Further warming and increased biological productivity took place about the time the Poronui Tephra (11,190 ± 80 cal. yr BP) and Opepe Tephra (10,075 ± 155 cal. yr BP) were deposited. During the initial period of Holocene warming (*c.* 11,000 – 10,000 cal. yr BP) some changes in the composition of the podocarp forests occurred, including an expansion of angiosperm trees, especially *Metrosideros* (Alloway *et al*. 2007).

Most of New Zealand was covered in evergreen forest prior to the arrival of humans during the late Holocene. The main exception was central Otago which lacked complete forest cover (McGlone *et al*. 1993). There were four floristic elements - podocarps, broadleaved trees, *Nothofagus* and *Agathis australis*. The tall podocarp conifers usually dominated the canopy of podocarp- broadleaved forests, while the broadleaved species comprised all non-*Nothofagus* angiosperms ranging in size from tall trees to small shrubs. While *Nothofagus* grows throughout New Zealand, currently it is mostly found in the mountainous areas of the South Island and on the lower North Island ranges. *Agathis australis* is now restricted to the warmer regions of the northern North Island (McGlone *et al*. 1993). During the Holocene shrubby, bog-communities in many North Island areas were replaced with dense swamp forests containing *Syzygium maire* and *Dacrycarpus dacrydioides,* while raised bogs formed on the poorly drained flood-plains in the Waikato area (McGlone 1988). Tall podocarp–broadleaved forest was usually the dominant vegetation in lowland and montane areas such as in Northland prior to deforestation (McGlone *et al*. 1993).

2.3 Vegetation Patterns and the Pollen Rain

Various factors must be taken into consideration when interpreting a pollen profile: these include factors which affect the composition of the pollen rain, and the problem of indistinguishable pollen produced by different species. These are now considered further.

2.3.1 Factors Affecting the Composition of Pollen Rain

The composition of pollen rain is often not an accurate reflection of the parent vegetation due to differences in pollen production, dispersal, and preservation. Some species are usually over-represented in pollen rain, while other species are under-represented even when they are abundant in the host area (Faegri and Iverson 1989). Taxa that are usually over-represented in New Zealand include wind-pollinated trees such as *Nothofagus* and podocarps as they produce abundant pollen which is readily dispersed, while insect- and bird-pollinated species typically produce less pollen and are under-represented (McGlone *et al.* 1993). *Beilschmiedia* (taraire and tawa) pollen is usually absent even when *Beilschmiedia* is a dominant component of the vegetation (McGlone *et al*. 1993). Some important entomophilous and ornithophilous canopy trees, such as *Metrosideros* and *Weinmannia* do produce abundant pollen, but have limited dispersal (McGlone 1988), while *Agathis* pollen is only dispersed locally (Ogden *et al.* 1992) and is often poorly preserved (Mildenhall 2001).

Most New Zealand trees and shrubs are pollinated by insects or birds, but there are also a large number of wind-pollinated taxa (McGlone *et al.* 1993). Pollen from wind-pollinated species can travel great distances, and inclusion in a pollen spectrum does not necessarily indicate the presence of host trees in a local study site (McGlone 1988). The under-representation of entomophilous species in the pollen spectra is further exacerbated by restricted pollen movement within the dense structure of conifer-broadleaved forests (McGlone 1988).

2.3.2 Indistinguishable Pollen Produced by Different Species

The correct interpretation of a pollen spectrum could potentially be compromised by the presence of indistinguishable pollen produced by separate species with different ecological preferences. Such species are present in the New Zealand flora. Examples include *Podocarpus* and *Phyllocladus* which contain species with preferences for either warm or cold conditions. *Metrosideros* species grow throughout New Zealand and range in size from large canopy trees to vines. Two *Metrosideros* trees commonly found in Northland are *Metrosideros robusta,* the northern rata, and the coastal pohutukawa tree, *Metrosideros excelsa* (Newnham *et al.* 1993). Thus when considering the history of a site, interpretation should be based on the ecological preferences of the vegetation as a whole, rather than focusing on individual taxa. This may also provide a clue as to the likely identity of individual species when differentiation based on pollen morphology makes this impossible.

2.4 The Human Impact on the Environment

Lowe *et al*. (2002) correlated scientific and oral history data with information derived from various dating techniques in an attempt to determine the origin and timing of the earliest Polynesian settlement in New Zealand. They suggested that the Polynesian settlers originated from central Eastern Polynesia, and that they arrived in New Zealand between *c.* AD 1250 and 1300 at the earliest.

One of the most important markers for dating is the widespread Kaharoa Tephra (Lowe *et al*. 2002), which was erupted from Tarawera volcano in the Okataina Volcanic Centre (Newnham *et al*. 2004) and was distributed over large areas of the North Island including Northland. This has a precise radiocarbon age of AD 1314 ± 12, derived from the provisional dendrochronological “wiggle-matching” of a carbonized *Phyllocladus* sp. tree killed by the eruption (Hogg *et al.* 2003)*.* The Kaharoa Tephra is a critical ‘settlement layer’ datum because no known cultural remains or artefacts have been found beneath it; however, an increase in *Pteridium* spores occurred just before its deposition probably *c.* AD 1280 (Lowe *et al*. 2002). Claims that temporary and small increases in bracken and other seral taxa indicate an earlier arrival by the Polynesians are disputed by Lowe *et al*. (2002) who state such disturbances are indistinguishable from natural background events. McGlone and Wilmshurst (1999) consider Maori deforestation began between 1200 and 1400 AD, stating that radiocarbon dates used to substantiate claims of an earlier arrival were all derived from swamps and lakes, which are subject to contamination from the inwash of old carbon and by hard water effects. They claim silty sediments are especially subject to contamination, while macrofossils and peat from bogs are the least vulnerable. Contamination by ‘old carbon’ is particularly important, as only a small percentage of old carbon is required to potentially introduce a large error into the apparent radiocarbon age of a sample (McGlone and Wilmshurst 1999).

The earliest presence of the Pacific rat (*Rattus exulans*) has been used by Wilmshurst *et al*. (2008) to determine the time humans arrived in New Zealand. The Pacific rat was distributed around the Pacific by early humans. It rapidly multiplied once introduced into the previously rat-free environment in New Zealand, living on a diet which included native birds and seeds. Wilmshurst *et al.* (2008) used accelerator mass spectrophotometry radiocarbon dating on the rat bones found in the roost sites of the extinct laughing owl (*Sceloglaux albifacies*) and on rat-gnawed seeds found in sediments. This indicated that the Pacific rat arrived in both the main islands of New Zealand at about 1280 AD, thus corroborating the date for the arrival of the Polynesians.

CHAPTER THREE

NORTHLAND GEOLOGY AND CLIMATE

3.1 Geology and Landforms

Northland is the northernmost part of New Zealand, consisting of a long narrow peninsula about 300 kilometres in length (Newnham 1999) and about 100 kilometres across at its widest point (Cathcart 1988).

In Northland, rocks and landforms form a mosaic of units with different lithologies, ages and origin, the reflection of a turbulent history since the early Miocene (see Figure 3.1; A simplified geological map of Northland).

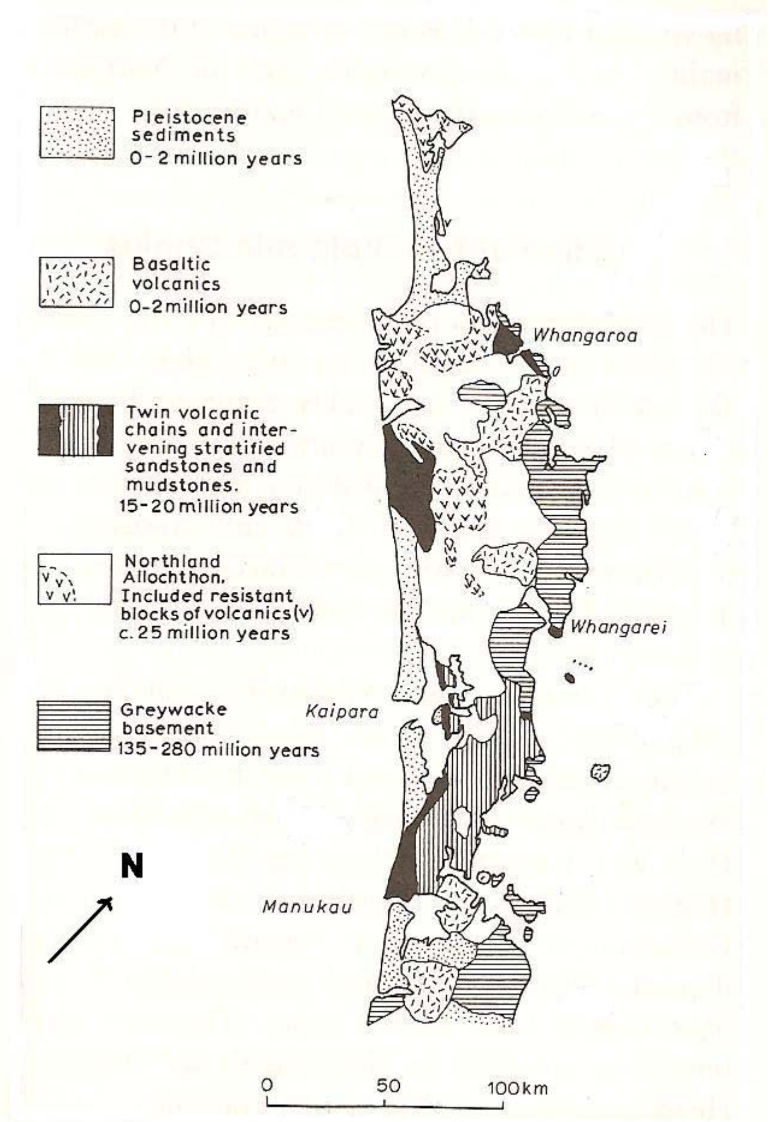

Figure 3.1: **A simplified geological map of Northland, reproduced and modified from Ballance and Williams in Soons and Selby (ed), 1992.**

Ballance and Williams (1992) attribute the geomorphological features seen in Northland to key events;

- The emplacement of the Northland Allochthon which occurred about 25 million years ago, when several sheets of marine sediments and ocean-floor material were emplaced across Northland. The sheets were deposited in reverse order of age, the uppermost sheet consisting of old sea floor volcanic rocks which now form prominent ranges such as the Tangihua Volcanics (Ballance and Williams 1992). The Allochthon is considered to have been created by a subduction zone which then lay north to south beneath Northland (Sporli and Hayward 2002).

- Eruption of twin volcanic chains took place between 22 - 15 million years ago. These have largely eroded away, but remnants remain near the Whangaroa and Whangarei Harbours, while sheets of solid lava form a plateau in the Waipoua Forest area (Ballance and Williams 1992).

- Block faulting and tilting occurred 15 million years ago, when the western side of Northland was depressed while the eastern side was raised and broken into westward tilted blocks. The younger Tertiary rocks have been largely eroded off the tilted eastern blocks exposing the underlying Mesozoic greywacke (Ballance and Williams 1992).

- Formation of volcanic fields during the Pliocene – Recent (Ballance and Williams 1992). About 2 million years ago the subduction zone moved away from Northland, but this was followed by back-arc volcanism probably associated with lithospheric extension. Two volcanic fields were formed in Northland – (1) the Kaikohe-Bay of Islands Volcanic Field and (2) the Puhipuhi-Whangarei Volcanic Field (Sporli and Hayward 2002). These will be discussed further in Section 3.2.

Northland has been geologically stable during the Quaternary (Cathcart 1988; Newnham 1999). Coastal sand dunes have developed near the entrance to the Whangarei Harbour, and along the west coast (Ballance and Williams

1992), while a tombolo links off-shore islands to the mainland in the far north (Ballance and Williams 1992; Kear and Hay 1961). Impeded drainage during the Pleistocene and Holocene has led to the formation of peat swamps or bogs in many areas of Northland. These are often associated with dune systems, as for example around the Whangarei Harbour (Kershaw and Strickland 1988), or have occurred as a result of volcanic activity such as the Tauanui Volcanic Centre (Elliot *et al.* 1998) and the Otakairangi Swamp (Newnham 1992).

Palynological studies have been carried out on a number of the Northland peat swamps or bogs, but only those of Kershaw and Strickland (1988) and Newnham (1992) have focused on areas close to Whangarei City.

3.2 Intra-plate Volcanic Fields in Northland

The two Miocene-Recent intra-plate basaltic volcanic fields of Northland are located in the Kaikohe-Bay of Islands and Puhipuhi-Whangarei districts (Figure 3.2). A more detailed map of the Whangarei Volcanic Field (Figure 3.3) by Sporli and Hayward (2002) shows the distribution of Late Pliocene-Quaternary scoria cones and lava flows, with the location of the Maungatapere and Rawhitiroa cones noted on this map.

Neither of Northland's volcanic fields can be considered extinct, but the spacing of previous events makes it impossible to predict the likely timing of future events (White and Perrin 2003). For example although the Puhipuhi-Whangarei Volcanic Field has an age range of 9 million years to 300,000 years (Edbrooke and Brook 2009) it appears that some eruptions in Whangarei were clustered with several occuring less than 500,000 years ago (White and Perrin 2003). Rawhitiroa and Maungatapere volcanic cones, the focus of this study, have both been dated at about 300,000 years old (Smith *et* *al.* 1993, in Sporli and Hayward 2002). They form part of the monogenetic Kerikeri Volcanic Group, the distribution of which in the Whangarei area is thought to be partially related to the underlying fault pattern (Edgebrooke and Brook 2009).

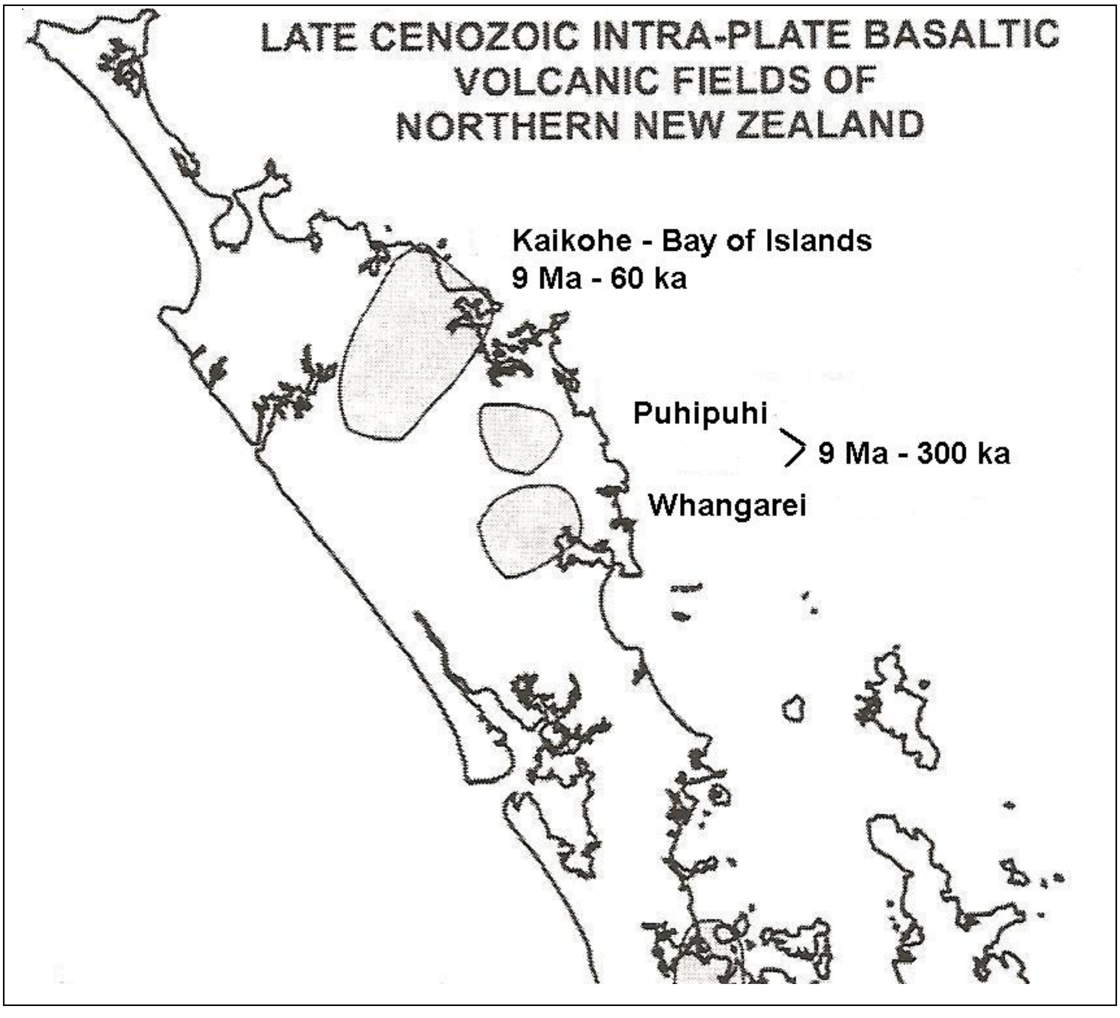

Figure 3.2: **Miocene-Recent intra-plate basaltic volcanic fields of Northland,** (adapted from Sporli and Hayward (2002)).
Ages of the volcanic fields obtained from Edbrooke and Brook (2009).

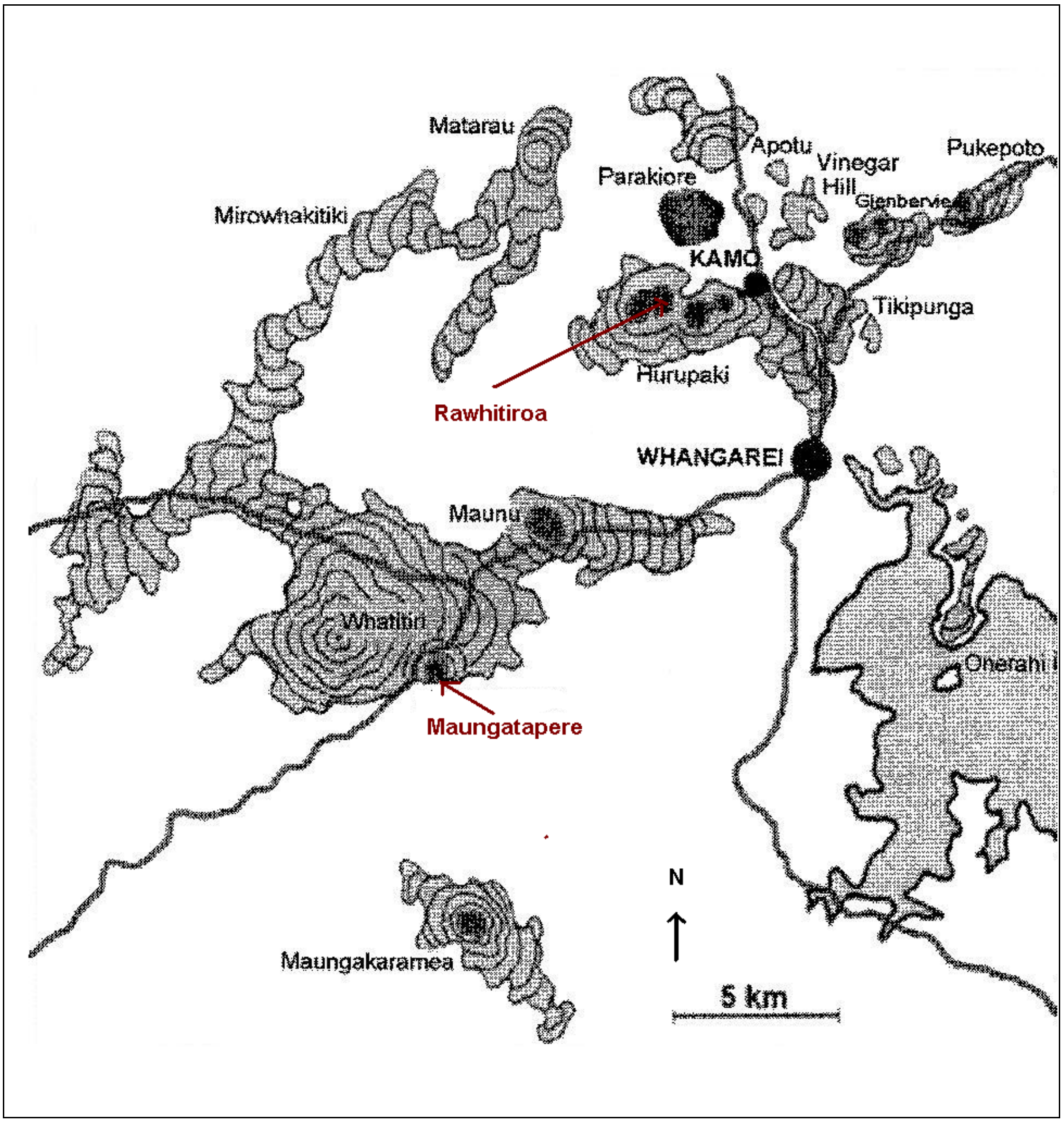

Figure 3.3: **A detailed map of the late Pliocene and Quaternary Whangarei basalt volcanic field.** The unit is the Whangarei Volcanic Field in the Edbrooke and Brook Q-map.

Map shows the location of scoria cones and lava flows**.**

Adapted from Sporli and Hayward (2002).

3.3 Climate and Soils

Northland has a mild, humid climate and is relatively windy. Winters are mild, usually with only a few light frosts, while summers tend to be humid and warm. Rainfall is usually plentiful with most areas receiving a minimum of 1500 mm per year as may be seen in Figure 3.4 (Moir *et al*. 1986). Rainfall is most abundant in the winter, while dry spells often occur in summer and autumn. Occasionally there are periods of high-intensity rainfall and severe gales (Moir *et al.* 1986), as for example, as occurred in 2007 when there was severe flooding (McKerchar 2007). These are often associated with the passage of depressions with a tropical origin. Most Northland areas receive about 2000 hours of sunshine annually (Moir *et al*. 1986). Mean annual temperature range from 15.5 - 16°C in the east and far north, to 14 - 15.5°C in the west and south (Moir *et al*. 1986; Newnham 1999).

While there are a variety of soil types, most Northland soils are strongly leached with poor fertility, thin top soils and deep clay subsoils. This is due to the combination of a warm, moist climate and rocks rich in augite and feldspar which are readily broken down to form clay (Ballance and Williams 1992; Cathcart 1988; Newnham 1999). Exceptions are young soils forming on unstable slopes, volcanic scoria cones, and alluvial deposits (Cathcart 1988). The weathering of basaltic rock results in the formation of red and brown loams. These loams have formed over a considerable time period and range in age from the younger free-draining Papakauri and Kiripaka clay loams to the mature Okaihau friable clay. Mature soils contain iron nodules with aluminium oxides (Gibbs *et al.* 1967).

The geomorphology, rock types, climate and human impact are all important factors influencing vegetation patterns in Northland.

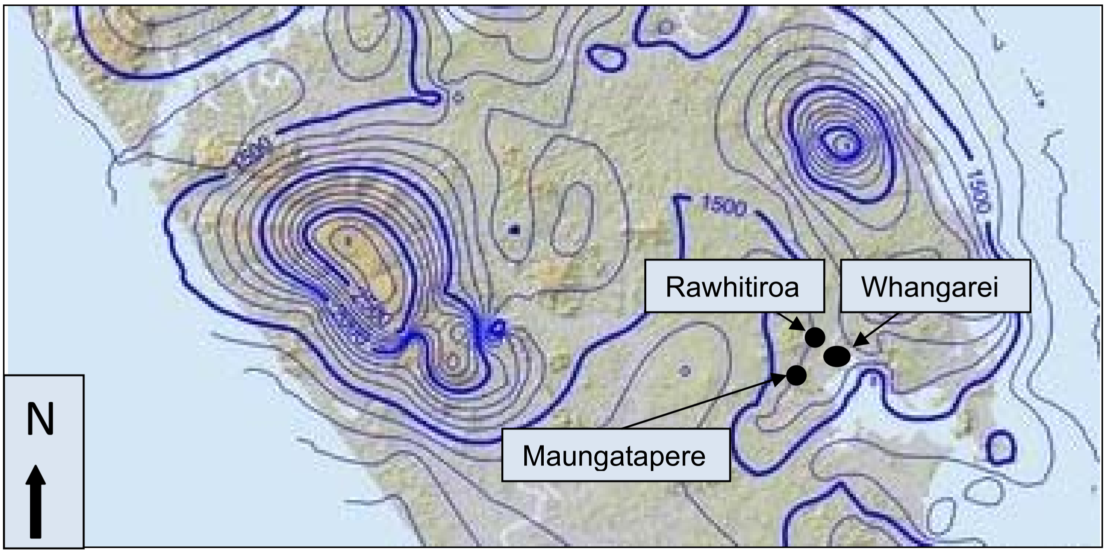

Figure 3.4: **Map of the Whangarei area showing mean annual rainfall distribution.**
Rainfall is recorded in mm per year.
Map provided by Northland Regional Council, 2008.

3.4 Vegetation Patterns

The natural climax forest in non-coastal Northland is the kauri-podocarp-broadleaf forest (Beever 1981), although areas of scrubland also exist. In a study of vegetation-environment relationships at the Waipoua Forest, Burns and Leathwick (1996) noted that vegetation patterns are linked to variation in soil fertility and physiography, while altitude determined temperature, rainfall and soil moisture. Conifers tended to congregate on infertile soils such as those often found on the ridges, while broadleaved species were dominant on the more fertile soils of the lower slopes and gullies.

The inverse relationship between the abundance of *Agathis australis* and *Nothofagus* (*Fuscospora*) has been used as an indicator of climate change. Although both species tend to occupy high ridges or areas with infertile soils, *Agathis australis* prefers warm moist conditions and is largely replaced with *Nothofagus* (*Fuscospora*) when the climate cools (Elliot *et al.* 1997 and 2005; Murray and Grant-Mackie 1989; Newnham *et al.* 2004.)

CHAPTER FOUR

PREVIOUS STUDIES

4.1 Palynological Studies

Three of the palynological studies which have been conducted previously in central Northland will now be described. These consist of the Otakairangi Swamp lying north of Whangarei (Newnham 1992), Lake Tauanui in the Bay of Islands (Elliot *et al*. 1998), and McEwan's Bog (Kershaw and Strickland 1988) on the coastline near the Whangarei Harbour. (See Figure 4.1).

The pollen profile of the core from the Otakairangi Swamp is the longest and covers an age range of between *c.* 30,000 years BP to 2,000 years BP (Newnham 1992). Although there were problems with the radiocarbon chronology Newnham assumed the radiocarbon dates to be correct and divided the pollen assemblages into three age groups - last glacial or older, late glacial-to-earliest post-glacial, and post-glacial or Holocene. His findings are summarised below.

Pollen from the last glacial period indicated the presence of a mixed conifer-angiosperm forest. The conifers formed a diverse group which included *Agathis australis* and the frost-tolerant *Lagarostrobos colensoi.* Prominent angiosperms included *Metrosideros, Nestegis,* and also *Ascarina* on occasions. The cool climate species, *Nothofagus menziesii,* was however absent. Although Poaceae pollen is dominant in the last-glacial pollen spectra over nearly all of New Zealand, it formed less than 5% of the pollen spectra at Otakairangi (Newnham 1992). The radiocarbon dates suggested that a marked change in dryland vegetation occurred in the late glacial with evidence of burning and a significant reduction in the conifer–angiosperm forest. Canopy gaps were colonised by opportunist species such as *Pteridium,* Poaceae, and Asteraceae, while *Nothofagus* (*Fuscospora*) (?*Nothofagus* *truncata*) dominated the forest. Newnham noted that while an increase in burning indicated drier conditions it occurred during a period of growth in restiad peat bog communities suggestive of a wetter and maybe a cooler climate. A suggested explanation was that the fires may have been associated with dry summer conditions caused by increased seasonality.

The early post-glacial was a period of change at Otakairangi. Burning ceased suggesting an increase in rainfall. A marked decline in Poaceae and *Nothofagus* (*Fuscospora*) pollen coincided with increased levels of pollen from *Dacrydium cupressinum, Dacrycarpus dacrydioides* and *Syzygium maire* with the formation of a swamp forest. Dryland vegetation consisted of a mixed conifer - angiosperm forest where *Dacrydium, Phyllocladus,* and *Metrosideros* were dominant taxa. *Agathis australis* was always present in the pollen spectra except when *Nothofagus* was abundant. Newnham (1992) suggested that *A. australis* may be especially susceptible to fire as reduced population levels coincided with high levels of charcoal. The record for the last 2000 years has disappeared, probably because the swamp has been burnt and drained (Newnham 1992).

When discussing the results of his pollen data Newnham (1992) suggested that the radiocarbon dating of the apparent last glacial and late glacial period may have been erroneous, and that the sediments were possibly contaminated by either old or young carbon. Thus the *Nothofagus* (*Fuscospora*) forest may have been associated with the Last Glacial Maximum rather than the late glacial period (Newnham 1992). He preferred this interpretation as it was more consistent with the pollen data recorded elsewhere in New Zealand.

The pollen profiles from both Lake Tauanui and McEwan's Bog cover the mid-to-late Holocene. Lake Tauanui was formed about 5500 years ago following volcanic activity in the area (Elliot *et al*. 1998). A volcanosere developed where tree ferns, especially *Cyathea,* were early colonisers. Later this was replaced by a mixed conifer-angiosperm forest dominated by *Dacrydium cupressinum,* while *Agathis australis* was consistently present. At *c.* 4000 yr BP the climate became cooler and drier, resulting in fires which destroyed some of the forest and caused erosion. Forest disturbance continued, intensifying around *c.* 1850 years BP causing fluctuations in the abundance of many species including *Ascarina lucida, A. australis*, and *D. cupressinum* (Elliot *et al*. 1998). As noted in the following section, marked vegetation changes occurred following the arrival of humans after *c.* 1100 years BP (Elliot *et al*. 1998).

McEwan's Bog formed in a small interdune depression about 6500 years ago (Kershaw and Strickland 1988). A mixed conifer-hardwood forest surrounded the area, and *Dacrydium cupressinum* was the dominant species. Over time the *Dacrydium* decreased in abundance relative to *Podocarpus* and *Nothofagus* (*Fuscospora*). *Agathis australis* was consistently present, and was particularly abundant between 3500 - 3000 years BP, but this was followed by a marked decline with evidence of burning. The upper sequence was too condensed for the authors to determine whether this decline was initiated by humans. Kershaw and Strickland (1988) proposed a wet, warm climate between 6500 - 4000 years BP, but as also noted by Elliot *et al.* (1998), this was followed by a drier, cooler period after 4000 years BP. A cooler, wetter period commenced at around 3400 years BP (Kershaw and Strickland 1988).

4.2 Radiometric Dating

Volcano	Description	K-Ar Age	Field
Whatitiri shield volcano & Titoki flows (Wairua Falls)	The Wairau River drains the Otakairangi Swamp	0.5 - 0.6 ± 0.1 my	Puhipuhi-Whangarei
Hurupaki	Part of a cluster of 4 scoria cones with flows – includes Rawhitiroa	0.31 ± 0.15 my	Puhipuhi-Whangarei
Maunu	Scoria cone	0.32 ± 0.09 my	Puhipuhi-Whangarei
Maungatapere	Scoria cone	0.29 ± 0.05 my	Puhipuhi-Whangarei
Whangarei Flow	Two possible vents	0.30 ± 13 my	Puhipuhi-Whangarei
Maungakaramea	Scoria cone	0.30 ± 0.06 my	Puhipuhi-Whangarei
Tauanui	Scoria cone and lava flow	0.06 my Dating method not stated - ? K-Ar.	Kaikohe-Bay of Islands

Table 4.1: **K-Ar ages of some younger basaltic volcanoes in the Puhipuhi-Whangarei and Kaikohe-Bay of Islands Fields**.
Dates of volcanoes in Puhipuhi-Whangarei Field from Smith *et al.* 1993, in Sporli and Hayward (2002).
Date of the Tauanui cone is from Hayward and Smith (2002) and Rollin (1991).

Contrary to the K-Ar date of about 300,000 years as listed for the Whangarei lava flow (Table 4.1), Cox (1973) quoted a radiocarbon age of 35,500 - 36,000 years BP (Edgebrooke and Brook 2009) for carbonized wood found below the lava flow. Rollin (1991) suggested that a possible explanation for the large difference between the K-Ar and radiocarbon dates was that they were at the extreme of the valid dating ranges for both methods, and thus uncertainties may be greater than quoted. However, based on palynological studies Elliot *et al.* (1998) estimated the age of the Tauanui Volcanic Centre as 5,500 years and Newnham (1992) estimated the age of the Otakairangi Swamp as over 30,000 years while the listed K-Ar ages are 60,000 (Hayward and Smith 2002; Rollin 1991) and between 500,000 and 600,000 years (Smith *et al.* 1993, in Sporli and Hayward 2002) respectively.

Williams *et al*. (1998) quote a dating range for potassium-argon dating ($^{40}K \rightarrow ^{40}Ar$) as 0.5 Ma to 1000 Ma, and also state results can be biased by original Ar in young lavas. This suggests that some of the lavas associated with the Whangarei Volcanic Field are far too young to be accurately dated by K-Ar and thus reported ages may be inaccurate.

4.3 Human Impact

Various workers have used evidence of burning, deforestation and erosion to indicate the presence of Polynesian settlers and in particular, to record their arrival at a particular site in Northland. Examples of these studies will now be discussed.

Elliot *et al*. (1995) contend that anthropogenic-induced environmental change first occurred at *c.* 900 yr BP (800 cal. yr BP) around Lake Taumatawhana, Aupouri Peninsula, in Northland: this was based on radiocarbon dating. However, this earlier dating was queried by McGlone and Wilmshurst (1999), who note that the section of lake sediment on which this was based contained a peak of sand-sized particles. This suggests forest clearance was associated with erosion and the inwash of material possibly contaminating the sample with old carbon (McGlone and Wilmshurst 1999). Tephra deposits could have provided confirmatory dating evidence but none were recorded.

Elliot *et al*. (1998) attribute a decline in tree and shrub pollen and an increase in *Pteridium esculentum* and charcoal fragments in the Lake Tauanui catchment to anthropogenic disturbance. This was dated by radiocarbon probably at between 980 - 1240 AD. Elliot *et al.* (1998) do not record the presence of Kaharoa Tephra at Tauanui. However, 14 tephra layers were noted in cores from Lake Omapere (Newnham *et al.* 2004). The presence of the Kaharoa Tephra near the top of the core enabled Newnham *et al*. (2004) to determine that the modern lake was formed about 600 - 700 years ago. It is possible that the lake was formed when Polynesian deforestation caused accelerated erosion which resulted in the obstruction of drainage outlets. There is no evidence of the human impact on the environment at Otakairangi Swamp as the record for the last 2000 years has been lost (Newnham 1992). The upper section of the sequence at McEwan's Bog was too condensed to demonstrate any anthropogenic influence on the environment (Kershaw and Strickland 1988).

At Wharau Road Swamp, BOI, there is evidence that Polynesian deforestation and soil erosion occurred about 600 yr BP (Elliot *et al.* 1997). In back dune swamps at Rangihoua Bay, also in the Bay of Islands, Horrocks *et al.* (2007) noted major anthropogenic changes with deforestation and drainage of the wetlands to enable Polynesian agriculture. However, errors in the radiocarbon and tephra chronologies and reworked sediments precluded accurate dating. Anthropogenic-induced, widespread deforestation and increased erosion occurred either between or after 700 – 430 cal. yr BP at Whangape Harbour on the west coast of Northland (Horrocks *et al.* 2001).

A map of Northland showing the location of pollen sites where anthropogenic changes have been recorded is presented in Figure 4.1.

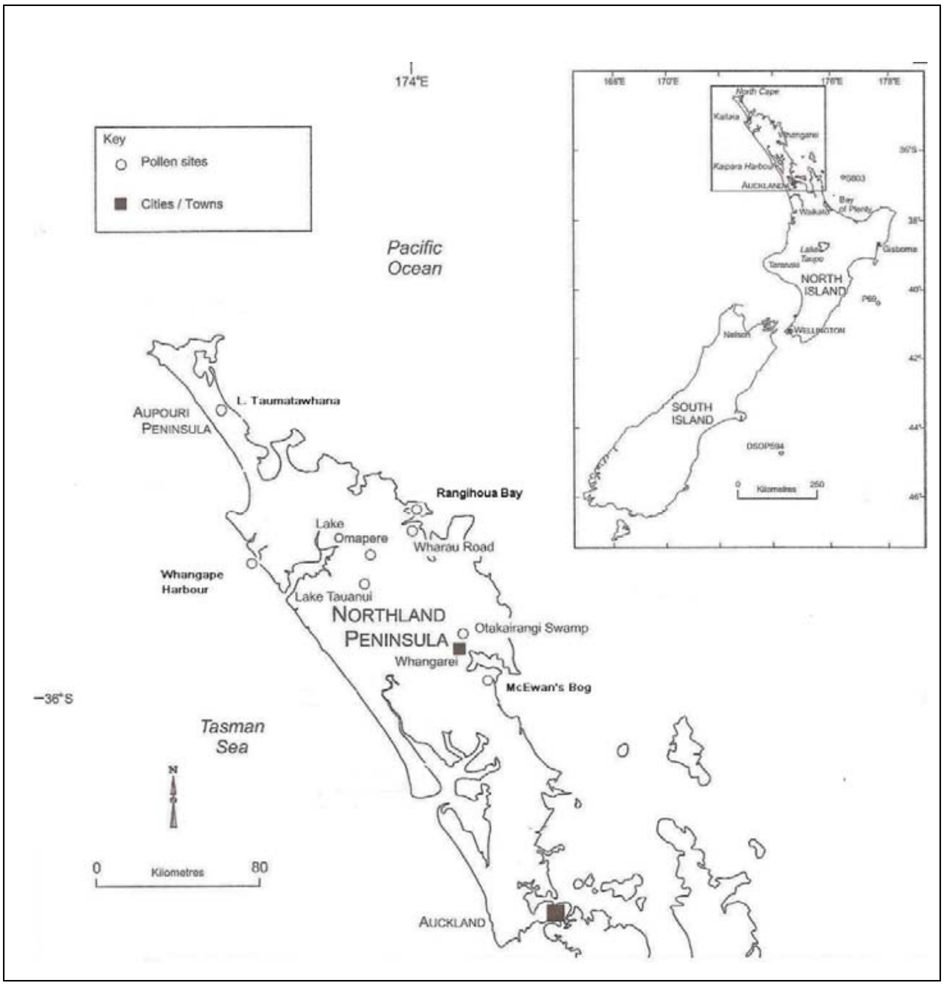

Figure 4.1: **Map of Northland showing the location of the pollen sites with recorded anthropogenic changes**.
Adapted from Elliot *et al.* (2005).

Archaeological records supplied by the Department of Conservation, and documented as NZAA NZMS 1 Site Numbers N20/49 and N20/91, provide evidence of the lifestyle and activities of early Maori in the Maungatapere area. Site N20/49 is situated on the north-east rim of the Maungatapere crater, where there are 23 open pits, a terrace and a building platform. Site N20/91 is the Pukeatua Pa which lies on a volcanic ridge below the mountain (see Figure 4.2). Information included in the reports states that 200 acres of land around the mountain were cleared of stones and forest for old Maori cultivations. When settled by European farmers in 1840 the open land was covered with *Danthonia*, flax and unspecified species of tussock. Other than the 200 acres of cleared land and part of another block, the Maungatapere area was covered in thick forest. The pa is described as being the largest in the country, but had not been used for hundreds of years. It is suggested that the pa must have been very important once since it was surrounded by extensive cultivations, and isolated in thick broadleaved forest (NZAA 1982).

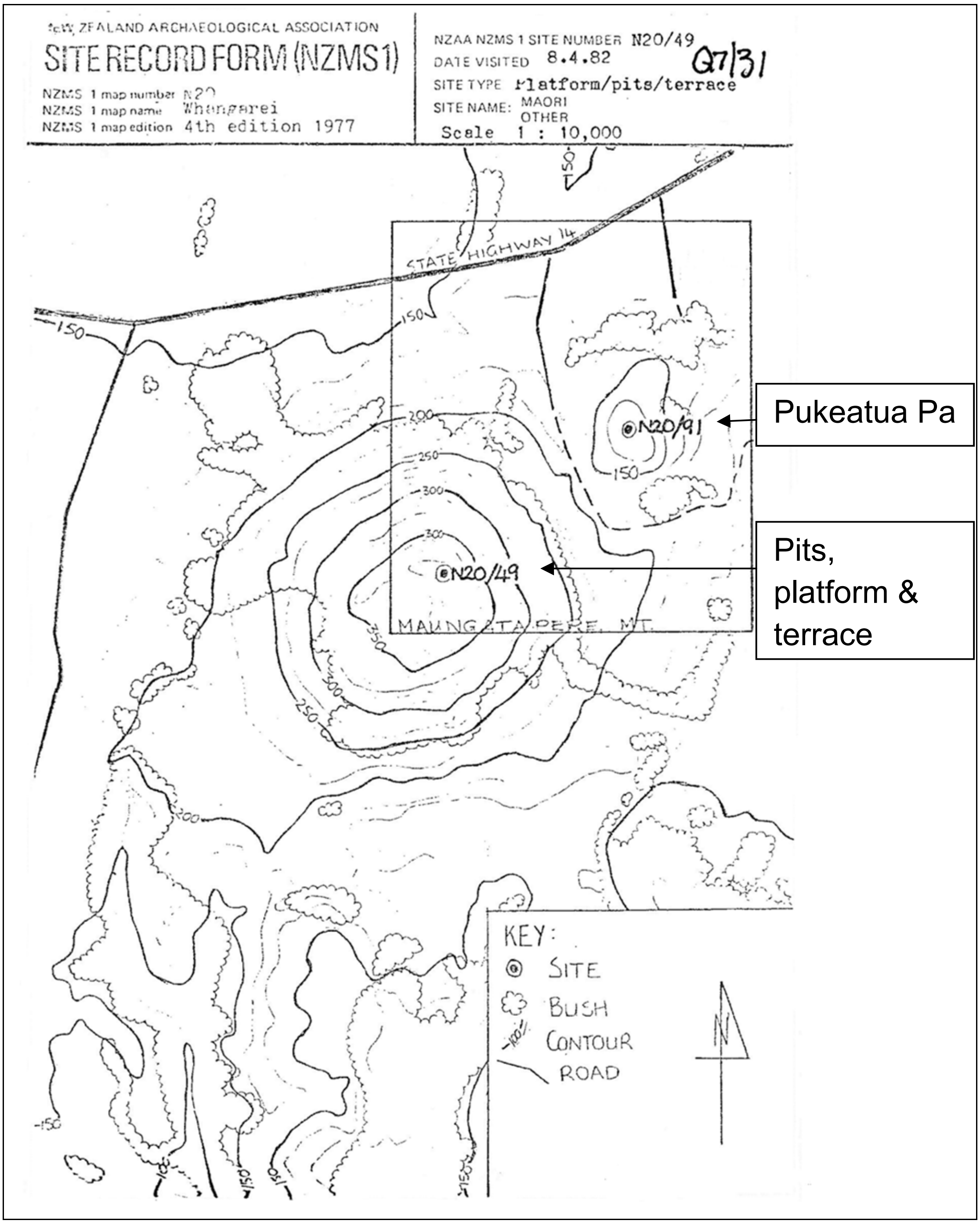

Figure 4.2: Archaeological Record - NZAA NZMS 1 Site Number N20/4 (1982).

The map indicates the location of the Maori pits, terrace and platform on the crater rim of Maungatapere Mountain (N20/49) and the Pukeatua Pa situated on a volcanic spur immediately beneath (N20/91). Information provided by the Department of Conservation.

Although there is no recorded pa site on the Rawhitiroa cone, a pa on the nearby Hurupaki cone confirms the presence of Maori settlers (Figure 4.3). This pa was defended with five ditches, and there are 82 recorded pits. It is documented as the archaeological site, Hurupaki Pa, N20/5 – Q06/208.

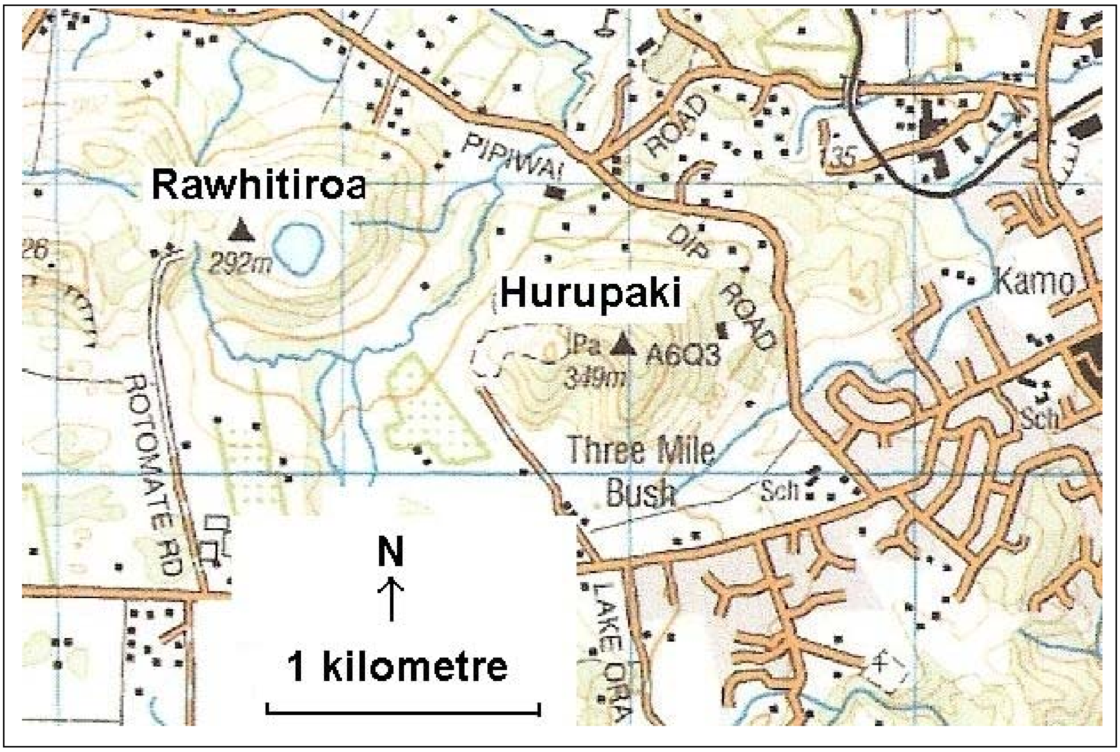

Figure 4.3: **Map showing the relative location of Rawhitiroa and Hurupaki volcanic cones.**
From *NZMS Topo50 Map Sheet AX30 – Whangarei.*

4.4 Significance of Charcoal

Caution is required when attributing evidence of deforestation and fire to the local presence of Polynesian settlers. Fire also has natural causes, and can be initiated by lightning strikes and hot lava, especially when conditions are very dry (Ogden *et al*. 1998). Elliot *et al*. (1998) record evidence of fire, erosion and some forest destruction at around 4000 yr BP at the Tauanui Volcanic Centre, and Newnham (1992) notes the high charcoal content of sediments dated between 21,480 - 7,820 yr BP in the Otakairangi Swamp. These significantly predate any recorded arrival of humans in New Zealand, and the fires were attributed to drier climatic conditions.

The size and shape of charcoal fragments can be used to help determine the site of origin. McGlone and Wilmshurst (1999) consider large (>50 µm) fragments are indicative of a fire of local origin. This is in agreement with a study on a burnt area following a heathland fire in the Yarner Wood and Trendlebere Down Nature Reserve, Devon, southwest England, in 1997 (Blackford 2000). Blackford collected samples from both the burned areas and the surrounding unburned areas. His findings demonstrated that large charcoal fragments were produced by local fires, while fine particles <20 µm in size were typically derived from unburnt areas. According to McFadgen (1994) the lowest sediment layer containing angular charcoal fragments suggests the arrival of human settlers.

Charcoal can travel great distances and very small fragments may indicate a distant origin. For example, tiny fragments can be transported to New Zealand by air currents from bush fires or dust storms in Australia (Butler 2008). These may arise from a recent fire or can be derived from the wind-erosion of older charcoal-containing sediments during dust storms. Charcoal-like particles can also be produced naturally in sub-surface peat without fire (Boyd 1982). According to McGlone and Wilmshurst (1999) short-lived minor deforestation only is not a reliable indicator of human impact. Instead the arrival of the first Polynesians is indicated by marked deforestation by fire, and then constant reburning as shown by the continued presence of short-lived seral vegetation. Sediments from areas ravaged by major fires of local origin will contain large (>50 µm), angular charcoal particles (Blackford 2000; McFadgen 1994; McGlone and Wilmshurst 1999).

Now an overview of the Whangarei geology and detailed descriptions of the study sites appear in Chapter Five.

CHAPTER FIVE

WHANGAREI STUDY SITES

5.1 Over-view of Whangarei Geology

Whangarei City lies in a NNW-trending half-graben which is about three kilometres wide. The area is underlain by several old fault lines, none of which are currently active. The Harbour Fault, possibly the most prominent, extends seawards to the south-east. The half-graben is bounded by tilted fault blocks consisting of Waipapa Terrane basement rocks. The land within the city is mostly low-lying, consisting of soft sedimentary rocks covered with lava flows or alluvial deposits (White and Perrin 2003). There is abundant evidence of previous volcanic activity around Whangarei City. Volcanic features include the Miocene andesitic remnants at the Whangarei Heads, the prominent dacite domes of Parihaka and Parakiore, while many small Quaternary basaltic volcanoes are scattered across the landscape (Edbrooke and Brook 2009; White and Perrin 2003).

Maungatapere and Rawhitiroa basaltic volcanic cones, the focus of this study, form part of two different volcanic clusters, both lying near the city's western boundary. They are now described in greater detail.

5.2 Description of Study Sites

5.2.1 Maungatapere

Geomorphology

Maunu, Maungatapere and Maungakaramea are three scoria cones lying to the west and south-west of the city. According to K-Ar dating they were formed about 300,000 years ago (Smith *et al.* 1993, in Sporli and Hayward (2002)). Maungatapere is the only one of the ten scoria cones in Whangarei to have reserve status (Sporli and Hayward 2002), and lies on the watershed between the east and west coasts. It is 344 metres in height (French 1980) and has a small crater containing a swamp (Ferrar *et al.* 1925). The crater is semi-oval in shape with a diameter of approximately 375 – 300 metres when measured across the 340 metre contour (see map in Figure 6.4). A small crescent-shaped area with an elevation exceeding 340 metres lies in the north-east of the crater. The soil type is classified as Papakauri clay loam (Gibbs *et al*. 1967).

Whatitiri, lying just west of Maungatapere, is a small shield volcano about 500,000 years old (Smith *et al.* 1993, in Sporli and Hayward (2002)). Some of the lava from Whatitiri flowed down the Wairua River, the outlet for the Otakairangi Swamp. The river now cascades over the edge of this lava flow forming the Wairua Falls (Sporli and Hayward 2002).

The Maunu-Maungatapere-Whatitiri basalt flows cover an area of about 60 km^2, the catchment forming an important groundwater resource. The basalt lies above somewhat impermeable Pliocene sediments (French and Hochstein 1980), which in turn are underlain by the Waipapa Group of Permian-Jurassic age (Edgebrooke and Brook 2009). There are numerous springs along the edges of the catchment (French and Hochstein 1980). The volcanic rocks weather to red and brown clay loams. These are characterized by high porosity and rapid infiltration of rainwater, so that surface runoff from volcanic areas is non-existent except in high-intensity rainfall events (French 1980). Sections of vesicular basalt are common, and many vesicles are partially or completely infilled with clay deposited from groundwater (French 1980).

In some areas around Maungatapere, lava flows have created topographic depressions often resulting in pockets of impeded drainage and the formation of swamps. The raupo swamp on Mangakahia Road is an example of this (Figure 1.1).

Photographs of the cone appear in Figures 5.1 and 5.2.

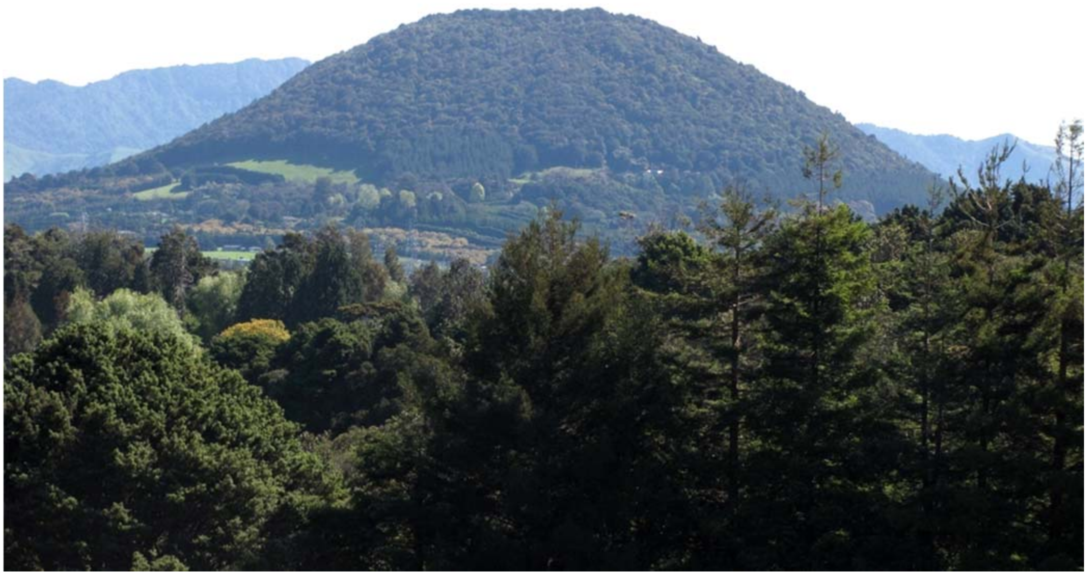

Figure 5.1: The Maungatapere volcanic cone viewed from the north.

Figure 5.2: The south-westerly view of the Maungatapere volcanic cone.
The patch of regenerating forest is the result of a forest fire.

Vegetation

The upper section of the Maungatapere cone is in native forest, while the surrounding countryside is in pasture with patches of native forest, or is used for horticulture. The forest on the cone consists almost exclusively of broadleaved species. Beever (1981) noted that broadleaved species are dominant on fertile soils such as occur at Maungatapere. However, patches of mixed conifer-broadleaved forest are scattered across the surrounding countryside. The swamp forest in the crater is dominated by *Syzygium maire* (swamp maire) and *Dacrycarpus dacrydioides* (kahikatea). Other species include *Laurelia novae-zelandiae (*pukatea), *Beilschmiedia tawa* (tawa), *Hedycarya arborea* (pigeonwood), and the tree fern *Dicksonia squarrosa. Freycinetia banksii* (kiekie), *Asplenium bulbiferum* (hen and chicken fern) and a cohort of young *Rhopalostylis sapida* (nikau) are abundant on the crater floor. *Ripogonum scandens* (supplejack) is also present.

A species list for Maungatapere appears in Appendix 4 with a photograph of the vegetation in Figure 5.3.

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Figure 5.3: A photograph of the vegetation growing in the Maungatapere crater. The crater contains a swamp forest dominated by *Syzygium maire* and *Dacrycarpus dacrydioides*. *Freycinetia banksii* and *Dicksonia squarrosa* are visible on the crater floor. Photographer; L. Forester 17-09-2011.

5.2.2 Rawhitiroa

Geomorphology

Rawhitiroa and Hurupaki form part of a cluster of four scoria cones formed by fire-fountaining eruptions in the Three Mile Bush area just west of Kamo. These cones plus three others further east are aligned, suggesting that the magma that fed them probably rose along a faultline as a single dyke (Sporli and Hayward 2002). The cones have been dated by K-Ar as about 300,000 years old (Smith *et al.* 1993, quoted in Sporli and Hayward 2002).

Rawhitiroa is described by Rollin (1991) as a steep-sided, slightly asymmetrical cone about 291 metres in height. The crater has not been breached suggesting that any lava flows were either non-existent or very small (Rollin (1991). The crater is roughly semi-oval in shape with a diameter of approximately 395 – 587 metres when measured across the 260 metre contour (see map in Figure 6.6). A small crescent-shaped area with an elevation exceeding 280 metres lies to the north of the crater. The swampy area which has formed in a circular depression is about 150 metres across (Rollin 1991). While obtaining a core for this study, the depth of the swamp was determined to be about 5 metres. However there is a central water hole which the farmer claims to be many metres deep (G. Hooker, *pers. com.*).

The variation in the height and thickness of the crater walls was attributed by Rollin (1991) to the effect of the dominant wind which was blowing during the short-lived eruptive phase of the volcano. Most of the scoria would be deposited downwind of the vent, and thus the higher and thicker north-northwestern wall could be explained by a south-southeasterly wind during the eruption. The soil is classified as Papakauri clay loam (Gibbs *et al*. 1967), possibly also with some Waiotu friable clay (NZMS 1981).

The presence of the wetland has been interpreted as being due to the presence of a pan of some sort beneath the swamp, possibly either a thin, relatively impermeable lava flow, or a clay pan formed through weathering of the scoria (Rollin 1991). The owner of the farm has built a house on the southern rim, and the surrounding lawn extends down to the periphery of the wetland.

Photographs of the volcanic cone appear in Figure 5.4.

Figure 5.4: Two views of the Rawhitiroa volcanic cone and wetland.

(A) This aerial view of Rawhitoria cone was downloaded from GeoEye Whangarei District Council, Map data @2011 Google MapData Sciences Pty Ltd, P. Whereis ® Sensis Pty Ltd.

(B) Rawhitiroa appears in the foreground and the Hurupaki cone and its associated scoria quarry appear in the centre background. A pa site is recorded on Hurupaki.

Vegetation

The vegetation growing in the wetland in the Rawhitiroa crater consists of a mixture of native and exotic species. The dominant species vary across the wetland, possibly determined by the relevant height of the underlying water table. The vegetation at the centre is dominated by a small patch of *Leptospermum scoparium* (manuka) which encircles a deep, water-filled hole. The hole contains dead manuka, probably killed by a rising water table. *Machaerina teretifolia* forms a dense patch adjacent to the manuka, and also appears as the dominant species in occasional patches across the wetland. *Sphagnum* forms a dense mat around the centre of the wetland and the sedges *Eleocharis acuta* and *Eleocharis sphacelata* are prominent. Other common species are *Machaerina rubiginosa, Juncus edgariae, Persicaria strigosa, Isolepis prolifer, and a Hydrocotyle* species. A rare clump of the Australian sedge, *Carex longebrachiata,* is growing on slightly higher ground. No sundews were noted.

The grass*, Holcus lanatus,* is a dominant component of the vegetation which surrounds the centre of the wetland. The exotic species, *Persicaria strigosa* and *Persicaria hydropiper* are common components, while the native species, *Persicaria decipiens* appears to be less abundant. *Eleocharis sphacelata* occurs throughout the wetland and has formed a dense patch near a small area of open water near the periphery. *Persicaria strigosa* is currently invading the same area of water. The wetland has a history of fluctuating water levels and was once in pasture (G. Hooker, *pers. com.*). (See photographs in Figures 5.5 to 5.7).

Although the wetland occupying the Rawhitiroa crater has been previously described as a swampy area (e.g. Rollin1991) or as a shallow lake (Edbrooke and Brook 2009) the current water level and vegetation suggests that it would be better described as a bog. Swamps are described as fertile wetlands which receive nutrients washed in by streams draining the surrounding countryside (Johnson and Gerbeaux 2004). *Sphagnum* moss is a low fertility species and the presence of the *Sphagnum* base at Rawhitiroa indicates a low fertility, acidic wetland or bog where the water is derived from rain or groundwater (L. Forester, *pers. com.*). Accordingly, the wetland occupying the Rawhitiroa crater will be described either as a bog or a wetland in the remainder of this report.

The rim of the Rawhitiroa crater and the surrounding countryside are now in pasture. There are also scattered patches of regenerating native forest plus a small *Pinus radiata* plantation.

Figure 5.5 **The wetland which has formed in the crater of Rawhitiroa.** *Leptospermum scoparium* (manuka) at the middle right of photograph surrounds a deep water-filled hole (see arrow), which contains dead manuka. The vegetation also includes *Sphagnum* moss, sedges, rushes and *Phormium* (flax). The crater rim is mainly in pasture.

Figure 5.6: Photographs of the vegetation growing in the Rawhitiroa crater (2011).

(A) *Eleocharis sphacelata* (bamboo spike sedge) and *Sphagnum* moss appear in the foreground, with *Leptospermum scoparium* (manuka) in the background. A patch of tall *Machaerina teretifolia* can be seen in front of the manuka.

(B) The small sedges scattered through the *Sphagnum* mat are *Eleocharis acuta.*

Photographer; R. Stewart 7-12-2011.

Figure 5.7: Photographs of the vegetation growing in the Rawhitiroa crater. (26-01-2012)

(A) *Persicaria strigosa*, an exotic plant, is invading this area of shallow water along the edge of the wetland. A patch of *Eleocharis sphacelata* can be seen in the background.

Figure 5.7; (continued).

(B) A group of ferns growing on slightly higher ground and surrounded by *Holcus lanatus. Eleocharis sphacelata* appears in the foreground of the photograph.

(C) A patch of *Machaerina teretifolia* and *Leptospermum scoparium* (manuka) near the centre of the wetland. *Machaerina teretifolia* is common in less fertile, more acidic conditions. (L. Forester, *pers. com.*).

Figure 5.7; (continued).

(D) Ground cover near the centre of the wetland. Species visible in the photograph include *Sphagnum* moss, *Eleocharis sphacelata*, *Eleocharis acuta,* and *Persicaria strigosa.*

(E) Vegetation growing along the periphery of the wetland. Plants visible include a tall *Machaerina* species probably *Machaerina rubiginosa,* the exotic rush *Juncus effusus,* and the grass *Holcus lanatus* or Yorkshire Fog. *Phormium tenax* (flax) appears at the top left of the photograph.

Figure 5.7; (continued).

(F) A small patch of native forest lies at the north-eastern edge of the wetland. The regenerating forest is dominated by *Podocarpus totara* (totara); other species appearing in the photograph include *Cordyline australis* and *Dacrycarpus dacryidioides.*

5.3 Soil Types and Drainage

Papakauri clay loam is the dominant soil type on the Maungatapere and Rawhitiroa scoria cones. It is both free draining and fertile.

The formation of red and brown loams is associated with basaltic rocks and the presence of a mull-forming broadleaved forest. Red loam is derived from scoriaceous rocks and brown loam from dense basalt flows (Gibbs *et al*. 1967). Red loams drain readily, but brown loams can vary as although they drain freely during heavy rainfall, the dense underlying basalt sheets can impede drainage. This can result in saturated soils and some surface water

(Gibbs *et al.* 1967). The topsoils are very friable and break down into fine aggregates, while subsoils are also friable and break down into fine structures. These fertile soils are characterised by low plasticity and are not sticky (Gibbs *et al.* 1967).

The red and brown loams are classified according to their degree of leaching. The Papakauri clay loam is a weakly leached red loam with excellent moisture, physical and chemical properties for plant growth. It is formed on the sides of the volcanic cones (Gibbs *et al.* 1967). The Kiripaka clay loam is a moderately leached clay loam derived from basaltic ash. It is less friable at depth than the Papakauri clay loam (Gibbs *et al.* 1967). These soils are often associated with a scattering of basaltic boulders across the surface. However most of the boulders have now been removed by the farmers and used to build stone walls (Gibbs *et al.* 1967).

5.4 Peat Cores

For the purposes of this study, peat cores were obtained from the wetlands of the Maungatapere and Rawhitiroa volcanic cones. Only a single core was collected at Rawhitiroa, but due to coring difficulties, three cores were required at Maungatapere. The cores were then transported to Massey University, Palmerston North, for processing in the palynology laboratory. Details of these techniques appear in Chapter Six.

CHAPTER SIX
FIELD AND LABORATORY METHODS

6.1 Field Methods

6.1.1 Equipment

Two different corers were used to collect samples from the crater wetlands. Photographs of these appear in Figure 6.1 (Livingstone corer) and Figure 6.2 (D-section corer), and are also displayed diagrammatically in Figure 6.3.

The Livingstone Corer

The Livingstone corer prior to assembly. It consists of a thin walled metal tube and a piston.

This photograph shows the location of the piston in relation to the metal tube at the commencement of coring. The piston is attached to a strong cord.

This photograph shows the location of the piston in relation to the metal tube once the core has been obtained.

Figure 6.1: Photographs of the Livingstone corer. Photographer; R. Stewart, 2011.

The Livingstone corer consists of a thin-walled metal tube containing a piston at the tip. The piston remains at ground level while the tube is pushed past it to the bottom of the borehole thus extracting a core. The cores obtained remain undisturbed provided sediments are soft (West 1977).

The D-section Corer

Figure 6.2: **D-section corer.** This is shown in the open position. Photographer; R. Stewart, 2011.

The D-section corer (Russian corer) consists of a half-cylinder or shuttle which is fixed to the sampler head, and is rotated half a turn to collect half a cylinder of peat against the stationary central anchor plate. The core is then bisected lengthwise by a fin-plate which lies at right angles to the anchor plate (West 1977). The fin-plate forces the core into the sampling chamber and cuts off the excess peat sealing a semicylindrical sample in the sampling chamber. The corer is then extracted from the sediments and the core is then carefully lifted out of the corer using a knife.

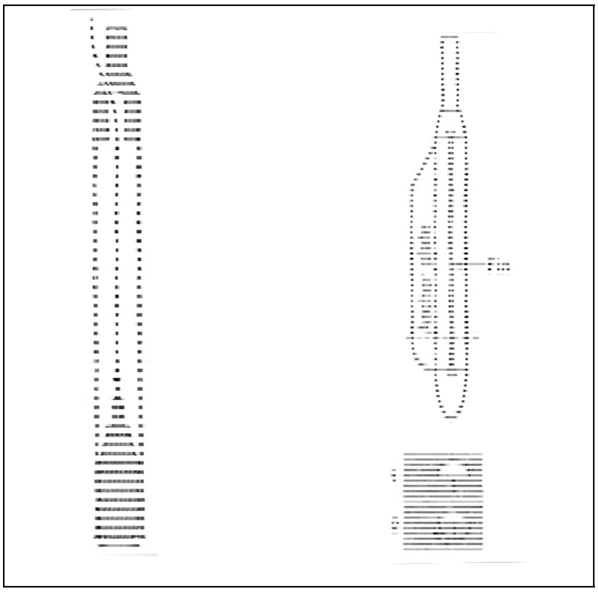

Figure 6.3: **A diagram of the corers used to collect samples from the crater swamps**. Left; the Livingstone corer.
Right; D-section or Russian corer.
(Reproduced from West 1977).

Table 6.1 summarizes the advantages and disadvantages of these hand-held corers.

Type	**Sample**	**Deformation of sediment**	**Compression of sediment**	**Suitability for sediments**	
	Length Width			**Good for**	**Bad for**
Livingstone	100 cm 4 cm	little	some	non-fibrous peat, mud	fibrous peat, loose organic sediment, inorganic sediment
D-section / Russian	50 cm 5 cm	none	none	peat, mud	loose organic sediment, inorganic sediment

Table 6.1: **A comparison of the corers used to collect samples from the crater swamps**. (Reproduced and modified from West 1977).

6.1.2 Collection of Core Samples

Maungatapere

As the crater of Maungatapere volcanic cone is fully forested, the crater floor is littered with fallen logs and tree roots. Several areas were probed to find suitable sites for coring, and three cores were attempted. The first core (labelled 1MT) was abandoned after 1 metre of core was obtained because the Livingstone corer encountered a dense object, probably a buried log. A second core (labelled 2MT) was attempted, but it too was abandoned for the same reason at a depth of 3.23 metres. The D-section corer was then used and 5 metres of core (labelled 3MT) were obtained, when further coring was again blocked by the presence of an impassable dense object. No further coring was attempted. The coring site is recorded on the contour map of the Maungatapere volcanic cone in Figure 6.4.

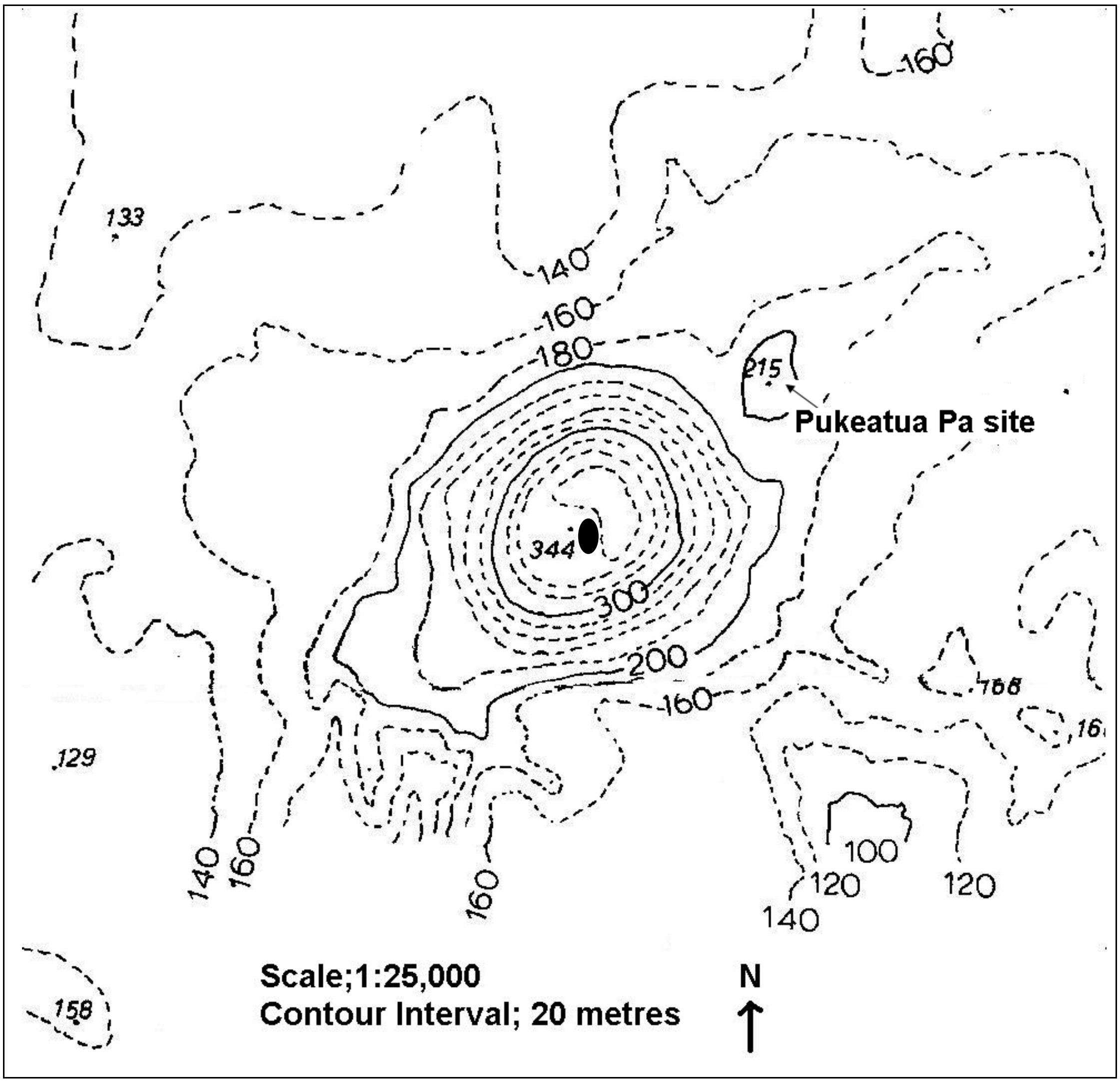

Figure 6.4: **A contour map of the Maungatapere volcanic cone.**
⬮ marks the approximate sampling site.
(S35°46.744 E174°11.336).
Map extracted from French (1980) Maunu Whatitiri Maungatapere Topographic Contour Map.
Produced for the Northland Catchment Commission.

The upper 3 cm of the core labelled 1MT consisted of firm black peat, beneath which was 16 cm of brown peat. The remainder of the 1 metre core consisted of moderately fibrous peat with the exception of a 2 cm layer of coarse fibrous peat between 25 and 27 cm.

The upper 1 metre from the core labelled 2MT consisted of fibrous peat while the 1 - 2 metre section was compressed to 57 cm in length. This mainly consisted of brown peat, but there was also a 2 cm layer of coarse fibrous material followed by 15 cm of soft black non-fibrous peat. The section between 2.00 and 3.18 metres consisted of non-fibrous peat, with a 2 cm layer of coarse fibrous peat between 3.18 and 3.20 metres, followed by 3 cm of non-fibrous material.

The upper 1 metre of the core labelled 3MT consisted of coarse fibrous peat, with fibrous peat containing small roots between 1.00 - 1.52 metres. Between 1.52 - 1.82 metres the core consisted of a decomposing log, while fibrous and non-fibrous peat formed alternating layers between 1.82 and 5.0 metres. Minor compression resulted in the total length of the 3MT core being 4.96 metres rather than a full 5.00 metres. Although another core was obtained at a depth of 5.00 - 5.50 metres it was considered suspect and likely contaminated and was therefore discarded.

Once the cores had been described and photographed, they were placed in sections of labelled plastic conduit which were wrapped in clear plastic and then sealed with plastic tape. The cores were then transported to Massey University for radiography, and storage at 4°C until required for further processing.

A photograph of the coring process appears in Figure 6.5.

Figure 6.5: **Obtaining a core from the Maungatapere crater swamp.**
Photographer; R. Stewart 08-12-2011.

Rawhitiroa

A single core was collected from the Rawhitiroa crater at a site adjacent to the deep hole towards the centre of the bog (see Figure 6.6). The Livingstone corer was used to obtain a core which extended to a depth of 4.8 metres. The 4.0 – 4.8 metre section was repeated to confirm that the core-hole extended to the base of the bog as was suggested by the basal section of brown-red clay.

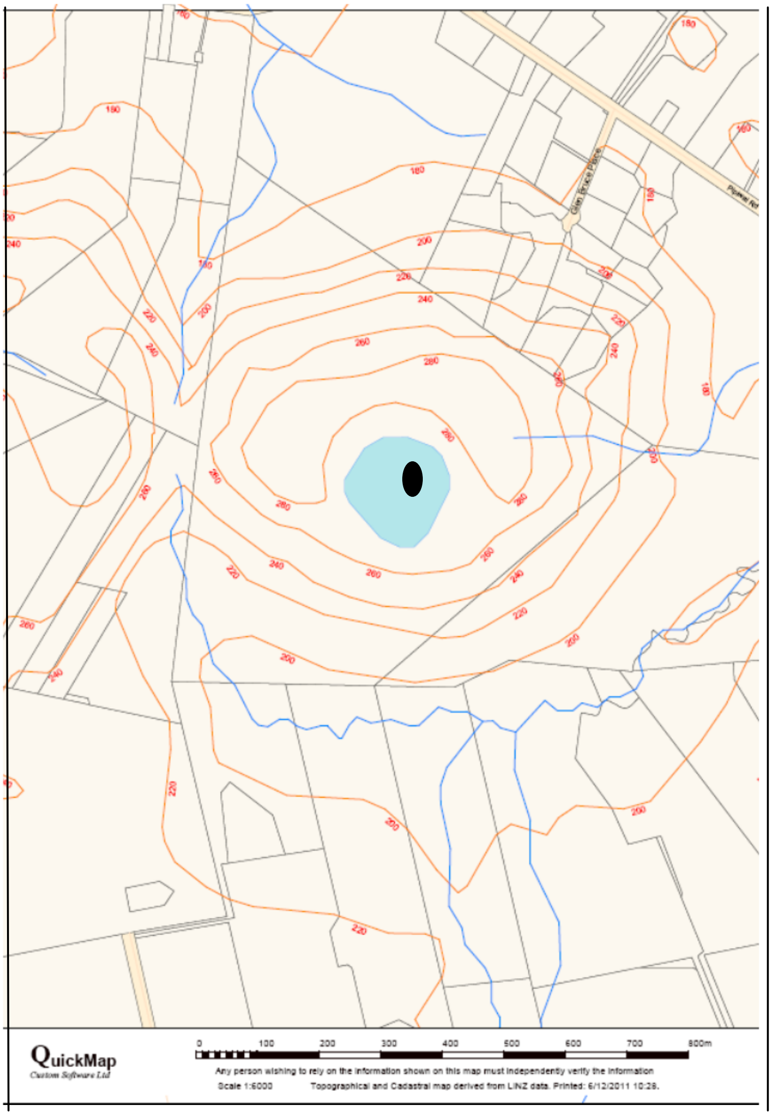

Figure 6.6: **A contour map of the Rawhitiroa volcanic cone.**
The area shaded blue indicates the crater bog & ⬮ represents the coring site.
(S35°40.822’ E174°16.131’).

The top metre section of core was compressed during collection (see Figure 7.1), but contained alternating layers of coarse plant material and organic mud, with fibrous peat between the 1.0 metre and 4.5 metre sections. Between 4.5 and about 4.8 metres the core consisted of clay varying from brown at the top to a reddish colour at the bottom. While the uncompressed, natural length of the core was 4.8 metres, when adjusted for compression it totalled 4.01 metres in length.

As with the Maungatapere samples once the core had been described and photographed, it was sealed in labelled plastic conduit then sent to Massey University for radiography and storage at 4°C until further analysis.

6.2 Laboratory Methods

6.2.1 Description of cores

The cores were measured and examined for any obvious tephra deposits or stratification, and the sediment described according to a modification of the Troels-Smith system (Kershaw 1997). Colour was defined by comparison with the Munsell colour chart. No tephra layers were apparent by visual examination of either core, although glass shards were noted in the upper Rawhitiroa core during pollen processing.

The Maungatapere peat did not vary greatly in colour, and was black to very dark grey in the lower sections of the core and very dark brown to greyish brown towards the top. A layer of crumbling rotting wood was yellow brown in colour. The peat was fibrous to slightly fibrous throughout, consisting entirely of a mixture of woody plant material and humus. There was no stratification and the peat was not elastic.

The Rawhitiroa peat was black throughout. It was not elastic and lacked stratification. The peat consisted mostly of humus, although herbs and mosses were important constituents of the upper peat. A 25 cm layer of clay lay beneath the peat. This varied in colour from yellowish red at the base to a dark greyish brown colour at the top of the clay. No plant detritus or coarse sediment was noted in the clay.

The summarised stratigraphic columns appear in Figures 6.7 and 6.8. Appendix 4 contains the detailed descriptions. A single sample of peat from Rawhitiroa and the 3MT core from Maungatapere were submitted for radiocarbon dating. These dates and the depth from which they were obtained, are recorded on the stratigraphic columns.

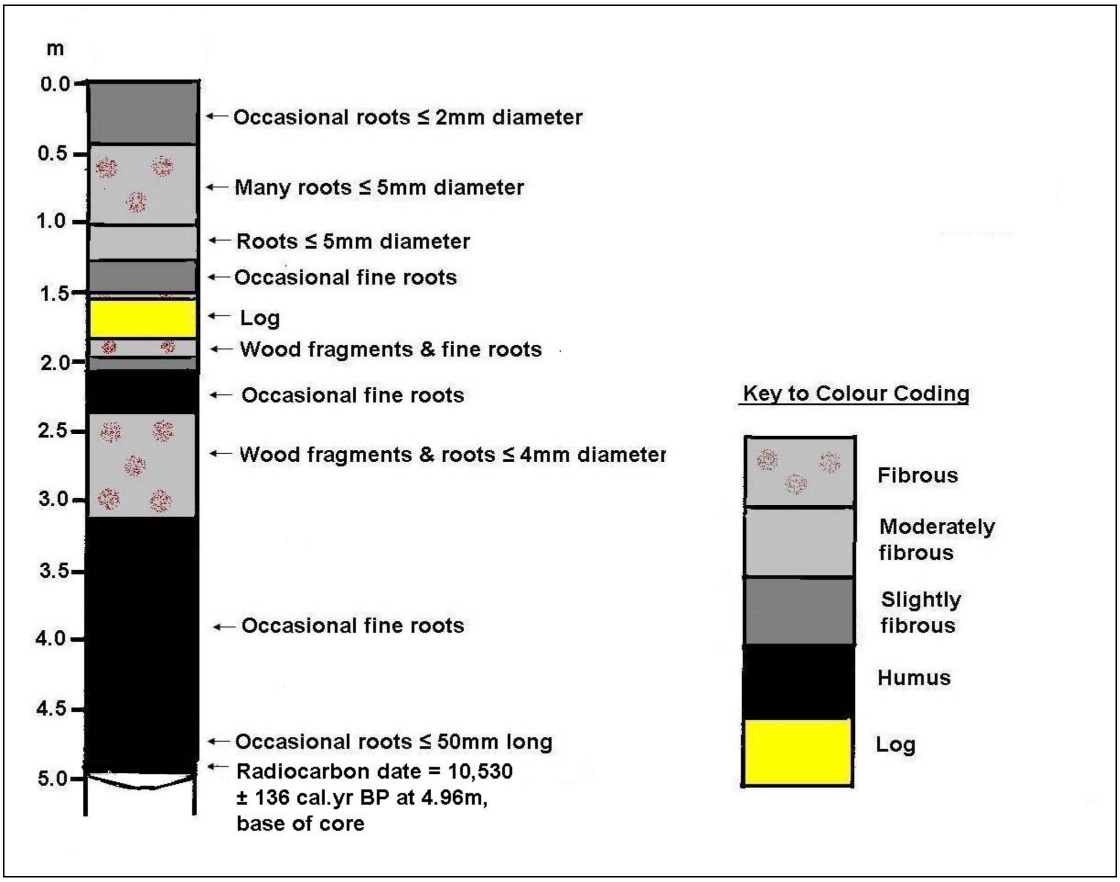

Figure 6.7: **Stratigraphic column for the 3MT Maungatapere core.**

Maungatapere; Q07/f0154.

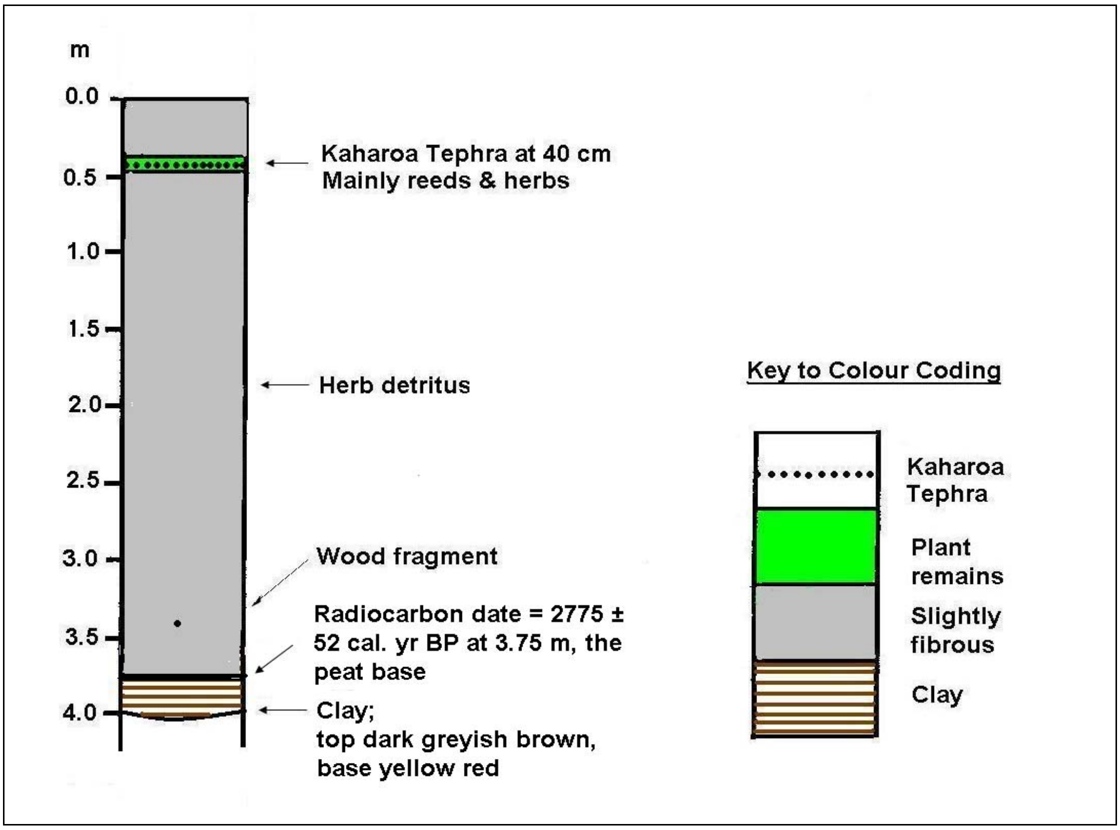

Figure 6.8: **Stratigraphic column for the Rawhitiroa core.**
Rawhitiroa; Q06/f0093

6.2.2 Pollen Processing

The cores were processed according to the following procedure; a summary diagram appears in Figure 6.9.

Step 1 Sampling

At 10 cm intervals, approximately 1 cm^3 of sediment required for pollen analysis was extracted from the centre of the core from Rawhitiroa and the longest core from Maungatapere (3MT). Ten additional samples at the intervening 5 cm intervals were taken from the upper metre of the Rawhitiroa core to provide more detailed information on the arrival and impact of humans in the area. An extra sample was also obtained from below the base of the Rawhitiroa peat at 390 cm.

Step 2 10% Hydrochloric Acid

Two *Lycopodium* tablets were added to each sample to enable the construction of absolute pollen diagrams, if required. 10% hydrochloric acid (HCl) was then added slowly to each tube and the sample stirred to remove carbonates. The process was repeated until all the CO_2 had been released. The tubes were then centrifuged, the supernatant discarded, and a distilled water wash performed.

Step 3 Potassium hydroxide/Sodium pyrophosphate

Potassium hydroxide is used to remove humic acid and to release palynomorphs from the matrix, while the sodium pyrophosphate deflocculates the clay. Each sample tube was filled with a 50:50 mixture of potassium hydroxide/sodium pyrophosphate ($KOH/Na_4P_2O_7$), stirred and heated at 100˚C for 5 – 15 minutes. Samples were then filtered through terylene gauze and the gauzes with the fibrous material placed in labelled plastic bags for microscopic study if required. The filtered samples were centrifuged, and washed with distilled water until the supernatant of each was clear.

Step 4 HF

Hydrofluoric acid is used to remove the silicates from the samples. Strict safety precautions were observed while handling the hydrofluoric acid (HF) and processing was performed in the Dynaflow cabinet. Hydrofluoric acid was added to each sample and heated at 100˚C for 15 minutes. The process was stopped with the addition of 10% hydrochloric acid, and the tubes were centrifuged followed by distilled water washes.

Step 5 Acetolysis

Acetolysis was used to remove cellulose, and processing performed in the Dynaflow cabinet. The samples were washed with acetic acid (CH_3COOH), then a fresh mixture of 9:2 acetic anhydride/sulphuric acid $(CH_3CO)_2O/H_2SO_4$ was added and the tubes heated to 100ºC for approximately 4 minutes. Processing was stopped with the addition of glacial acetic acid, and followed by 10% acetic acid and distilled water washes.

Step 6 6 µm Sieving

Each sample was sieved using a piece of 6 µm gauze and a vacuum flask attached to a venturi pump. Pressurised distilled water from a garden sprayer was used to force fine material <6 µm through the pores, while the pollen remained on the gauze. The pollen was then carefully washed from the gauze into an evaporating dish and poured back into the relevant sample tube.

Step 7 Dehydration

Dehydration is required to enable samples to be suspended in silicone oil for microscopic study. The dehydration process commenced with a 95% ethanol (C_2H_5OH) wash, followed by a wash in 100% ethanol. Samples were then washed with a 50:50 mixture of tertiary butanol ($C_4H_{10}O$) and absolute alcohol, followed by a wash in pure tertiary butanol. Each sample was then pipetted into a small vial, centrifuged and the supernatant discarded. Tertiary butanol and silicone oil were added to the contents of each vial, which were placed in a polystyrene tray in the 50°C oven overnight to allow the butanol to evaporate.

Step 8 Mounting

Warmed samples were well mixed and then mounted on microscope slides. At least two slides were made from each sample. Microscopic examination was then performed to identify and count the numbers of pollen grains and spores from the individual taxa in each sample.

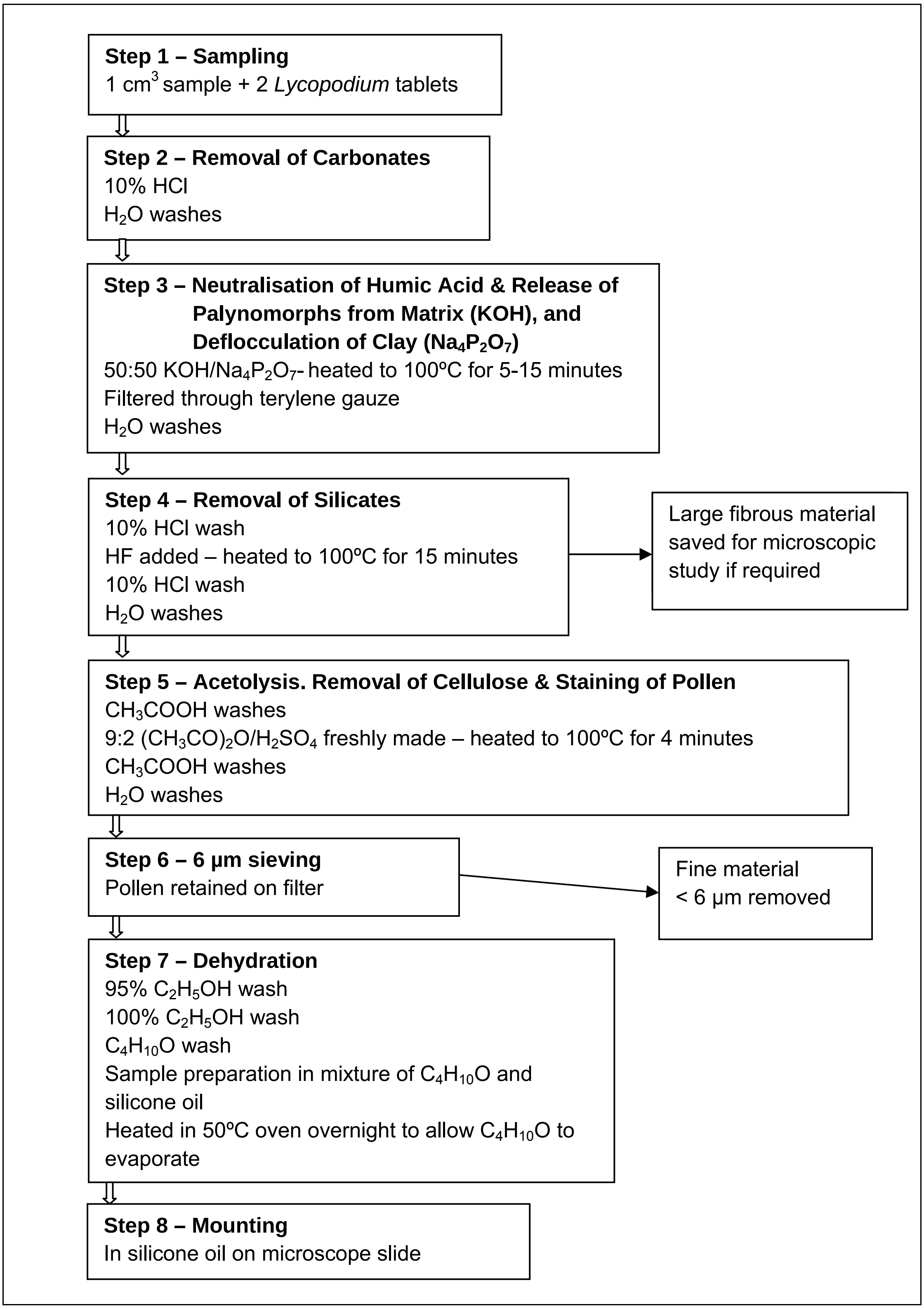

Figure 6.9: **Summary Diagram of Sample Preparation in the Laboratory.**

Microscopic Examination

The slides were examined by light microscopy using an Olympus CX21 microscope at 400 times magnification. The addition of *Lycopodium* tablets to enable the construction of an absolute pollen diagram, if required, is in accordance with the procedure of Faegri and Iverson (1989) and Moore *et al*. (1991).

At least 100 grains of pollen from dryland flora plus tree fern spores were identified and counted on each of the two slides from the 1 cm^3 samples. Dryland pollen includes the pollen of trees, shrubs, and herbs – i.e. species which do not typically grow in wetland environments. Where a total of 200 grains was not achieved extra slides were counted. The one exception was the 5 cm sample from Rawhitiroa where the total count was 186 grains.

Identification was performed using three reference books comprising Moar (1993) “Pollen Grains of New Zealand Dicotylendonous Plants”, Large and Braggins (1991) “Spore Atlas of New Zealand Ferns and Fern Allies,” and Macphail (undated) “Photographic Record of the Pollen Flora of New Zealand” as guides, and with the assistance of Dr. Kat. Holt. Charcoal fragments were also classified according to size and each group enumerated. Results were then entered onto the computer, and the Tilia Computer Programme (version 1.18) used to construct a relative pollen diagram for each core; these are displayed in Figures 7.2 and 7.3. The pollen spectra are represented as percentages of the total dryland tree and shrub pollen plus tree ferns. Pollen zones were identified through visual analysis.

The pollen diagrams also include the number of charcoal fragments. Problems associated with charcoal determination and identification are discussed by Patterson *et al*. (1987). While dense black, opaque and angular particles can be readily classified as charcoal and clear brown amorphous material as vegetable matter, other particles may not readily fit either category. Various attempts to improve accuracy have included boiling samples in nitric acid to remove opaque pyrite crystals and plant fragments, or by classifying only those particles which were uniformly opaque as charcoal.

During the examination of the slides for pollen identification from Maungatapere and Rawhitiroa only black, opaque and irregular particles were classified as charcoal fragments. These were divided into three sizes - <20, 20 – 50, and >50 μm in length. Semi-transparent, brownish particles which were either amorphous or clearly of cellular vegetable matter were not included.

Notes on Pollen Identification

The pollen of *Podocarpus* and *Prumnopitys* species were grouped together when the grains were too damaged to enable differentiation. Many species such as *Phyllocladus* were identified to genus level only, due to difficulties in distinguishing between the component species. With the exception of *Pteridium, Pyrrosia eleagnifolia* and *Phymatosorus,* monolete fern spores formed another such group. Some spores in the Rawhitiroa samples were too badly damaged to enable identification and were classified as damaged unidentified spores. These spores from Rawhitiroa were pale in colour with prominent spines. They were oval to circular in shape, and laesurae were not apparent.

6.2.3 Processing of Samples for Radiocarbon Dating

Sample Description

The cores were registered in the fossil record by the University of Auckland prior to radiocarbon dating. The New Zealand Fossil Record File site numbers are: for Maungatapere Q07/f0154, and for Rawhitiroa Q06/f0093.

Samples from the base of the peat from the Maungatapere 3MT and the Rawhitiroa cores were then sent to Waikato University for radiocarbon dating.

The corrected core depth from which a sample was taken for a radiocarbon dating was 4.96 cm for Maungatapere, and for Rawhitiroa was 3.75 cm.
The Rawhitiroa sample consisted of plant fossils picked by hand, washed in distilled water and then placed in an ultra-sonic bath. A bulk sample of peat was sent from the Maungatapere 3MT core.

At the University of Waikato visible contaminants were removed and the samples washed with hot HCl to remove carbonates. The samples were then rinsed and treated with multiple washes of hot NaOH to remove mobile organic acids such as humic and fulvic acids which may have washed down from upper, younger soil horizons. A final hot HCl wash was then used to neutralize the NaOH base and prevent the absorption of modern carbon dioxide from the air at a high pH. The samples were then filtered, washed and dried (A.G. Hogg, *pers. com*.).

Results obtained for the radiocarbon dating, pollen spectra, and tephra and clay analysis are fully described in Chapter Seven.

CHAPTER SEVEN

RESULTS

7.1 Radiocarbon Dating

The only radiocarbon dating performed in this study was for the basal peat in the cores from each wetland. These radiocarbon dates were used to calculate the average sedimentation rates and the approximate age of the pollen zones. However, a single date in calibrated years BP was also required in order to determine the approximate date of arrival of Maori and the Europeans. This was performed using the calib.qub.*ac.*uk/calib/calib.html website, and the radiocarbon dates provided by the University of Waikato. For each site the radiocarbon age and standard deviation were entered, and the Southern Hemisphere atmospheric curve and cumulative probability selected. The 0.5 level was used to obtain the calibrated ages.

The radiocarbon date obtained from the base of the Maungatapere 3MT core was 9367 ± *37* yr BP. There is a 63.8% probability of this being between 10,437 and 10,587 cal. yr BP, and 95.4% probability that it is between 10,401 and 10,673 cal. yr BP (Ref. Wk34573R) (Hogg 2012).

The radiocarbon date obtained for the base of the Rawhitiroa peat was 2707 ± 32 yr BP. For calibrated ages there is a 68.3% probability that this is between 2747 and 2837 cal. yr BP, and a 95.4% probability that it is between 2743 and 2848 cal. yr BP (Ref. Wk34572R) (Hogg 2012). (See Appendix for full reports).

Thus the calibrated age obtained for the base of the Maungatapere core was 10,530 ± 136 cal. yr BP, and for the base of the Rawhitiroa peat was 2775 ± 52 cal. yr BP. The 2 sigma error has been quoted.

The Radiocarbon Calibration Program available at the calib.qub.ac.uk/calib/calib.html website was used in conjunction with Stuiver and Reimer (1993) to determine a single calibrated age for the base of each core. The reference for the Southern Hemisphere calibration data sets is Reimer *et al.* (2013).

7.2 Tephra

No tephra layers were detected through the radiography of either core. However, during the pollen preparation process it was noted that some clear, glass-like fragments were present in all the Rawhitiroa pollen samples between the depths of 30 – 55 cm. The shard-maximum was at 40 cm and was found to contain a rare crystal of a black, shiny mineral identified as biotite. This is consistent with the identification of Kaharoa Tephra which has previously been identified at several sites in Northland. Examples include Lake Omapere (Newnham *et al.* 2004), Wharau Road Swamp, Bay of Islands (Elliot *et al.* 1997), and Rangihoua Bay, Bay of Islands (Horrocks *et al*. 2007).

The Kaharoa Tephra originated from the Okataina Volcanic Centre and was widely dispersed over much of the North Island including eastern Northland (Lowe *et al*. 2002).

7.3 Clay

Two samples of clay from the base of the Rawhitiroa core were examined by X-ray analysis. This indicated that the clay was principally kaolinite. There was a small quantity of quartz present, presumably from aerosolic or coarser wind blown origin–loess, and deposited before the swamp started to form. There was also a trace of chlorite, and possibly some acid leaching beneath the peat (R.B. Stewart, *pers. com.*).

The significance of the kaolinite–rich clay is discussed further under the Initiation of Wetland Formation, Section 8.3.1.

7.4 Sedimentation Rates

Maungatapere

As noted previously the pollen record for Maungatapere extends back to *c.* 10,530 ± 136 cal. yr BP. However it is likely the core did not extend to the base of the full peat sequence as coring was blocked by a large object, probably a buried log, lying at a depth of approximately 5 metres. 496 cm of sediment had accumulated over this period giving an average sedimentation rate of approximately 4.7 cm/100 years. This is only about half the usual accumulation rate of peat which is often assumed to be about 10 cm per 100 years in temperate environments (K.A. Holt, *pers. com.*).

No macroscopic Kaharoa Tephra was seen in the 3MT core. According to Elliot *et al.* (1997) tephra originating from distant sites often accumulates in isolated pockets (*i.e.* is discontinuous) in swamps so its absence is not unexpected. The 1MT and 2MT cores were not examined for glass shards.

Rawhitiroa

The pollen record for the Rawhitiroa peat extends to *c.* 2775 ± 52 cal. yr BP. Kaharoa Tephra, dated at AD 1314 ± 12, was identified in the 40 cm sample. The presence of some shards in all the samples between 30 and 55 cm is likely to be due to redistribution through water movement and bioturbation.

The accumulation of 375 cm of peat over a period of 2775 cal. years gives an average sedimentation rate of approximately 13.5 cm/100 years. However as calculated from the age of the Kaharoa Tephra, the upper 40 cm of sediment represents a period of *c.* 699 cal. years with an average sedimentation rate of 5.7 cm/100 cal. years. It is likely that this can be explained by the spongy nature of the upper sediment being compacted during sampling (see Figure 7.1). The depth of 40 cm for the Kaharoa Tephra accommodated this compaction.

Figure 7.1: **The 0 - 1 metre core from Rawhitiroa showing compaction of sediment.**

The average accumulation rate could not be used to date the clay base as it probably accumulated at a different rate from the peat.

Although there is a significant difference between the sedimentation rates of the Maungatapere and Rawhitiroa wetlands, many factors can affect the growth of peat. These will include the type of wetland species, which will vary in physical bulk, rate of growth, reproductive rates, and ecological preferences. Some species such as *Myriophyllum* only grow in shallow water, so are affected by changes in water depth, while other species such as *Haloragis* thrive in disturbed areas. The climate is also important with plant growth expected to accelerate during warm, moist conditions. Wetland fertility will change over time, but is enhanced by the input of fresh nutrients as may arise from the arrival of fresh sediment due to erosion of the surrounding landscape, or from ash derived from the burning of vegetation or volcanic activity.

7.5 Pollen Zones

A single radiocarbon dating was performed on the base of the core from Maungatapere, and on the base of the peat from Rawhitiroa. The average sedimentation rate for each wetland was calculated using the length of the peat core and the age of the peat base in calendar years. Accordingly in the absence of further radiocarbon dates or of dated tephra deposits other than Kaharoa Tephra, these calculated sedimentation rates were then used to determine the approximate age of the base of each zone in the pollen diagrams.

The calculated age for the base of *Zone 4* at Rawhitiroa was an exception. By taking the average sedimentation rate of 13.5 cm/100 cal. yrs and applying the 15 cm interval for the sample showing the first anthropogenic changes (between 55 and 40 cm) below the Kaharoa Tephra (dated at 1314 ±12 AD), an age difference of 111 years was determined. This calculation [(15/13.5) x 100] gives an age for the major environmental changes recorded in the 55 cm sample of 1203 AD or *c.* 750 cal. yr BP.

Limitations of this method will be discussed further in Chapter Nine.

7.6 Pollen Diagrams

The relative pollen diagrams, Figures 7.2 (Maungatapere) and 7.3 (Rawhitiroa), indicate the relative abundance of an individual taxon in each sample, collected from specified depths in the cores. The abundance of the various species is displayed as percentage data, whereby the pollen sum or total land pollen for each sample consists of the total count of pollen grains and spores from all dryland taxa including tree ferns. The number of pollen grains or spores from each taxon in this group is then converted into a percentage of the pollen sum, so that the abundance of one species is relative to that of all the others. Although wetland and fern taxa (excluding tree ferns) do not contribute to the pollen sum, their percentages are also calculated against it and may exceed 100%.

Pollen zones were identified through examining the pollen diagrams visually, and the contribution of pollen from the various taxa is described below.

7.6.1 Maungatapere

Zone 1: 4.90 - 3.12 m c. 10,530 – 6638 cal. yr BP.

In general in this zone, *Dacrydium cupressinum and Cyathea dealbata* dominate the dryland flora which includes the tree ferns. However at about a depth of 4.40 m and again between 3.70 - 4.00 m, there is a marked decline in gymnosperms, with a corresponding marked increase in small angiosperm trees and shrubs, especially *Coprosma. Ascarina, Prumnopitys, Podocarpus* and *Dacrycarpus dacrydioides* are all significant components of the pollen spectrum, while *Agathis australis* maintains a presence. An occasional grain of *Nothofagus* (*Fuscospora*) occurs throughout this zone but is never a significant component of the pollen spectrum.

There is a short-lived but marked increase in monolete fern spores at 4.30 m, followed by a temporary decline in the numbers of *Cyathea dealbata. Cyathea smithii* maintains a significant presence throughout, while *Phymatosorus* is present in low numbers.

The highest values for wetland species, especially *Haloragis and* Cyperaceae*,* occur in this zone, although their relative abundance fluctuates markedly with several discrete peaks. Restionaceae are a minor component, while *Myriophyllum* makes a rare appearance with a small peak towards the top. A rare grain of *Drosera* is present at the base.

A very occasional fragment of charcoal is present near the top of this zone.

Figure 7.3 Rawhitiroa Relative Pollen Diagram

Zone 2: 3.12 - 2.18 m c. 6638 – 4638 cal. yr BP.

The base of *Zone 2* is defined by an increase in small angiosperm trees and shrubs, and a change in the composition of the wetland flora. The wetland flora is now dominated by Cyperaceae which forms a major component of the pollen spectrum forming a peak near the base; however values decline with decreasing depth. Restionaceae maintain significant values, but only occasional grains of *Haloragis* and *Myriophyllum* are now present.

A peak in small angiosperm trees and shrubs at the base is largely due to a marked increase in *Coprosma* pollen. This coincides with a decrease in tree ferns, followed by a temporary decrease in the abundance of gymnosperms especially *Dacrydium cupressinum. Coprosma* values then decline markedly maintaining low levels throughout the remainder of this zone. Increased levels of *Ascarina* occur towards the base, but then also decline.

There is a slight but generalized increase in the values for gymnosperms and tree ferns as compared with *Zone 1*, with *Dacrydium cupressinum* and *Cyathea dealbata* remaining the dominant dryland species. *Dacrydium cupressinum* and monolete spores show a marked but short-lived peak at 2.20 m. *Cyathea smithii* is a significant component of the flora, and *Phymatosorus* maintains a presence*. Prumnopitys and Podocarpus* levels have increased, while values for *Dacrycarpus dacrydioides, Agathis australis* and *Nothofagus* (*Fuscospora*) are similar to the previous zone.

Large angular fragments of charcoal form three small peaks in the middle of the zone.

Zone 3: 2.18 - 1.32 m c. 4638 - 2808 cal. yr BP.

Most dryland species and ferns maintain similar values to the previous zone with *Dacrydium cupressinum* and *Cyathea dealbata* remaining dominant. *Coprosma* is an exception with low values throughout. A major change is the marked decline in wetland species. Cyperaceae decline markedly while *Haloragis* and *Myriophyllum* are present only in very low numbers.

No pollen data is available for the middle region, due to the presence of a log which lay between 1.80 – 1.50 m. The dates and accumulation rates were not adjusted for the large log. The log probably lay on the ground surface until it was buried by the accumulating peat. While the pollen data for this time period was not preserved in the core, it is likely that it did not significantly affect the dates and accumulation rates. A few large angular charcoal fragments are present in the samples closest to this log.

Zone 4:   1.32 - 0.32 m   c. 2808 – 680 cal. yr BP.

This zone is characterised by a generalized upwards and significant increase in the abundance of gymnosperms, especially *Prumnopitys, Podocarpus and Dacrydium cupressinum,* with a corresponding decrease in tree ferns. A peak in *Podocarpus* occurs near the base, accompanied by an increase in *Phyllocladus. Cyathea smithii* increases in abundance mid-zone, while *Phymatosorus* increases towards the top. The number of small angiosperm trees and shrubs remains stable, although *Ascarina* increases slightly in abundance. *Agathis australis* is always present, and pollen from *Dacrycarpus dacrydioides* and *Nothofagus* (*Fuscospora*) is present in most samples.

Wetland species are only a minor component of the vegetation. Exceptions are the small peaks in the values for Cyperaceae at 0.90 and 0.70 m; both are accompanied by a rare grain of *Drosera.* A few large angular charcoal fragments are present.

Zone 5:   0.32 - 0.0 m   c. 680 – 0 cal. yr BP.

There are major changes in the pollen spectra in this zone, with a marked decrease in *Dacrydium cupressinum* in the upper region and corresponding increases in tree ferns, small angiosperms trees, shrubs, and herbs. The pollen spectrum from the surface is again dominated by gymnosperms but the composition of the vegetation has changed.

Dacrydium cupressinum remains the dominant species at the base, then shows a marked decline and disappears at the top. *Agathis australis* also disappears. *Dacrycarpus dacrydioides* increases significantly and becomes the dominant species in the uppermost region accompanied by *Podocarpus* which also increases markedly. *Pinus* appears for the first time at the top becoming a major component of the pollen spectra.

Cyathea smithii declines in abundance while *Cyathea dealbata* also decreases with the exception of a short-lived marked increase at 0.10 m. *Dicksonia squarrosa* becomes important for the first time. There are marked increases in *Histiopteris and Phymatosorus* particularly at the base, and monolete ferns increase slightly while *Pteridium esculentum* becomes more significant in the middle region.

A peak in the abundance of small angiosperm trees and shrubs at 0.01 m is mainly due to an increase in *Coprosma* species. *Fuchsia* appears for the first time. *Hebe*, Asteraceae and *Knightia excelsa* are also present in small numbers while *Ascarina* disappears*. Poaceae* become more abundant towards the top, while there are rare grains of *Syzygium marie* pollen in the uppermost section.

Wetland species are an insignificant component of the floral spectrum, although there is a small increase in Cyperaceae at the top. A few large angular charcoal fragments are present throughout, particularly in the mid-zone.

7.6.2 Rawhitiroa

Zone 1: 3.90 - 3.77 m c. 2775 - ?cal. yr BP.

This clay zone which lies beneath the base of the peat, is dominated by *Cyathea dealbata* while *Cyathea smithii* is also abundant. *Phymatosorus* is abundant at the top where it achieves its highest level in the whole profile. *Dacrydium cupressinum, Podocarpus,* and *Ascarina* pollens are rare at the base but start to increase at the top of the zone. Large angular charcoal fragments are absent. No dates are available for the base of ths zone.

Figure 7.2. Maugatapere Relative Pollen Diagram

Zone 2: 3.77 - 3.05 m c. 2775 - 2259 cal. yr BP.

In this zone there is a marked change in the pollen spectrum. The dryland flora is now dominated by tall trees notably *Dacrydium cupressinum* and *Prumnopitys* species*, Podocarpus,* and the tree fern *Cyathea dealbata. Agathis australis, Dacrycarpus dacrydioides,* and *Phyllocladus* are regular components of the flora, and *Libocedrus* appears occasionally. *Cyathea smithii* values decline.

Dysoxylum spectabile is significant in the lower part of the zone, and then declines, while *Ascarina* is consistently present. Low numbers of *Coprosma* and monolete ferns are present mainly at the base, and while *Phymatosorus* is still significant at the base, numbers decline rapidly upwards.

Wetland species are an important part of the pollen spectrum. There is a marked increase in Cyperaceae near the bottom of the zone followed by a gradual decline, while there is a marked but short-lived increase in *Myriophyllum* between 3.20 – 3.30 m. It is likely that the damaged unidentified spores are those of Cyperaceae. Large angular charcoal fragments are rare in this zone.

Zone 3: 3.05 - 0.57 m c. 2259 – 750 cal. yr BP.

The pollen spectrum continues to be dominated by tall gymnosperms, especially *Dacrydium cupressinum, Prumnopitys* species, *Podocarpus,* and the tree fern, *Cyathea dealbata. Phyllocladus, Agathis australis, and Ascarina* all increase towards the top of the zone. *Metrosideros* has several abrupt peaks in the upper zone, where there is also a short-lived increase in *Libocedrus*. In Northland *Libocedrus* is often associated with *Agathis australis* and *Phyllocladus* suggesting that they all have similar ecological requirements (Newnham and Lowe 1991), while cohorts of *Libocedrus* may be found in areas where a major disturbance has occurred (NZPCN 2013). The marked variation in the abundance of *Metrosideros* and a temporary increase in *Libocedrus* at Rawhitiroa are interpreted as indicating disturbance.

Wetland species decline upwards from the boundary with *Zone 2* becoming insignificant at the top. The two main wetland species are Cyperaceae and *Haloragis.* Cyperaceae has a short-lived but marked increase at the base of the zone, while *Haloragis* peaks in the middle at about 1.80 m. Large angular charcoal fragments are rare.

Zone 4: 0.57 - 0.0 m c. 750 – 0 cal. yr BP.

This zone is characterized by significant changes in the pollen spectra. Tall trees especially *Dacrydium cupressinum,* and the tree fern *Cyathea dealbata,* continue to dominate the pollen spectrum at the base of the zone. However, *Dacrydium cupressinum and Prumnopitys taxifolia* then decline markedly, while *Agathis australis* and *Ascarina* disappear near the top. *Cyathea dealbata* declines upwards with the exception of a short-lived peak at 0.10 m. *Phyllocladus* and *Dysoxylum spectabile* are regularly present.

Metrosideros has a sharp, short-lived peak at 0.25 m, followed by *Coprosma,* while *Podocarpus* increases upwards throughout and *Dacrycarpus dacrydioides* becomes more abundant. Poaceae increase sharply in the upper zone, *Plantago* appears mid-zone and *Pinus* at the top. A peak in *Leptospermum* type pollen also occurs near the top. Unspecified species of *Lycopodium* are abundant in the upper zone, while monolete ferns are regularly present in small numbers.

The appearance of *Pteridium esculentum,* together with a marked increase in the number of large, angular charcoal fragments are significant features that occur at the base. *Pteridium esculentum* becomes abundant in the mid-zone, peaking at 0.15 m, and disappearing at 0.05 m. Large charcoal fragments peak at 0.15 m, and then slowly decrease in number.

Cyperaceae are important throughout while Restionaceae increase upwards. The aquatic species, *Myriophyllum,* becomes important in the upper zone, and dominates the pollen spectrum at the top.

An interpretation of the pollen data appears in Chapter Eight, when all results are discussed. The macroscopic plant remains recovered during the processing of the cores in the palynology laboratory were not identified, and absolute pollen diagrams on selected species not performed, as it was considered that neither would provide additional information on the palaeovegetation of the sites.

CHAPTER EIGHT

INTERPRETATION & DISCUSSION

8.1 Formation of Peat

The formation of peat is initiated by waterlogged conditions and anaerobic decay (Harris 1968). This depends on the dynamic inter-relationship between two factors; climate especially rainfall and temperature, and landscape which includes relief, drainage, altitude and substratum (Harris 1968). Both humification and anaerobic decay are involved in the decomposition of peat. Humification occurs in the upper layers and involves oxidation, while anaerobic decay mainly takes place below the permanent water table (Taylor and Pohlen 1979). Plant debris from mor-forming vegetation such as *Agathis australis* is readily converted to peat by creating a permanently saturated soil. The cessation of decay in the lower peat layers and an overlying layer of relatively impermeable material causes the peat deposit and water table to increase in height (Harris 1968).

Peats can be divided into two groups. These are the climatic or zonal peats, and the local or basin peats. Basin peats are subdivided further into convex peats the raised bog or high moor stage, and concave peats or low moor stage (Taylor and Pohlen 1979). These stages are illustrated in Figure 8.1

In the low moor stage the surface is concave, and nutrients and minerals supplied by the groundwater have a marked effect on the composition of the vegetation. As the peat accumulates the centre of the bog rises faster than the periphery where the continued supply of oxygen and bases from drainage water encourages decomposition. Finally a high moor stage or convex, raised bog is formed, where water is derived mainly from rainfall (Taylor and Pohlen 1979). *Dy* (see Figure 8.1) is a colloidal peat consisting mainly of humic substances and deposited from water (Taylor and Pohlen 1979).

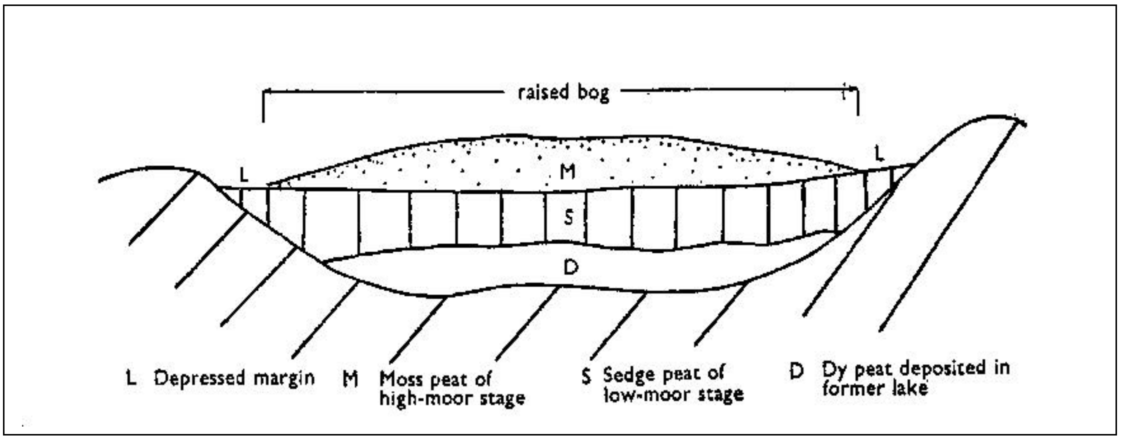

Figure 8.1: **Diagrammatic section through a basin peat**.
Reproduced from Taylor and Pohlen (1979).

Basin peats can be classified according to fertility, whereby eutrophic peats have abundant plant nutrients, oligotrophic peats are deficient in nutrients while mesotrophic peats are moderately fertile (Taylor and Pohlen 1979). The current Maungatapere and Rawhitiroa wetlands can be classified as containing basin peats in the concave or low moor stage. They are soligenous in nature as they are sustained by the local ground- or soil water (Taylor and Pohlen 1979).

8.2 Interpretation of the Palynology

Over time, there has been variation in the composition of the vegetation around the Maungatapere and Rawhitiroa volcanic cones. Reasons for change will now be explored.

8.2.1 Maungatapere

The formation of the wetland in the Maungatapere volcanic cone occurred sometime prior to 10,530 ± 136 cal. yr BP. The pollen data from *Zone 1* indicates the presence of a wetland which lacks significant areas of open water. This interpretation is largely based on the high values for *Haloragis* and Cyperaceae, and very low values for *Myriophyllum*. *Haloragis* grows on banks, disturbed areas, and on peat (Allan 1982), while many species of Cyperaceae are associated with swampy conditions (Moore and Edgar 1976). *Myriophyllum* is an aquatic genus which is associated with shallow open water (Elliot *et al.* 1997), so a small temporary increase in abundance in the upper zone is indicative of some open water, perhaps a small shallow lake. The presence of a rare grain of the insectivorous species *Drosera auriculata* at the base of the zone suggests boggy conditions (Allan 1982). The marked fluctuation in the abundance of *Haloragis* is suggestive of repeated disturbance, which together with a similar variation in the values for Cyperaceae, also indicates alternating expansion and contraction in the area of the swamp, possibly a reflection of climatic instability characterized by alternating wet and dry conditions.

In the mid-zone the temporary marked increase in monolete ferns followed by an increase in small angiosperm trees and shrubs, chiefly *Coprosma,* suggests more open, drier conditions. It is associated with a marked decline in wetland species and the decreased abundance *of Dacrydium cupressinum* and tree ferns. Together this suggests that the swamp has dried up, and that the wetland vegetation has been replaced by scrub and ground ferns. However, this situation is reversed in the upper zone where the pollen spectrum is again dominated by gymnosperms and tree ferns, with fluctuating abundance in *Haloragis* pollen.

Now kauri-podocarp-broadleaved forest surrounds the wetland. The dominant tree species is *Dacrydium cupressinum,* with *Cyathea dealbata* the dominant tree fern in damper areas. Large charcoal fragments are rare indicating that local fire is not a feature of this wetland.

At the base of Zone 2 and *c.* 6638 cal. yr BP, an increased abundance in *Ascarina* and *Coprosma* coinciding with a marked decline in wetland plants suggests drier conditions where the wetland vegetation is being replaced by shrubs. However, this situation is soon reversed and wetland plants again become a major component of the flora although the disappearance of *Haloragis* suggests less disturbance and greater environmental stability. The swamp vegetation is now dominated by Cyperaceae with some Restionaceae, while the rare grain of *Myriophyllum* indicates small areas of open water. Cyperaceaes decrease upwards through the zone indicating that the swamp is beginning to dry up, and a short-lived peak in monolete ferns at the top suggests that the wetland plants are being replaced by ground ferns.

The composition of the regional forest remains the same. *Dacrydium cupressinum* and *Podocarpus* increase slightly from the previous zone suggesting that they are starting to occupy some of the drier areas around the swamp. A few charcoal fragments suggest the occasional local fire and also may indicate drier conditions.

By *c.* 4638 cal. yr BP, the base of *Zone 3,* there is a major decline in wetland species indicating that the swamp has become significantly drier or smaller. With the exception of the mid-zone which will be discussed further under disturbance, dryland species show little change from the previous zone. The presence of a few charcoal fragments is consistent with drier conditions.

By *c.* 2808 cal. yr BP, *Zone 4,* the forest has expanded rapidly and now covers most of the crater floor. *Dacrydium cupressinum* remains the dominant tree. A small increase in *Phyllocladus, Podocarpus*, and *Ascarina* suggests disturbance. The decrease in tree ferns and occasional charcoal fragments are compatible with drier conditions, although there is a small infertile wetland near the middle of the zone, possibly about 1740 cal. yr BP.

Major environmental changes occur at *c.* 680 cal. yr BP, the base of *Zone 5.* The initial marked increase in shrubs and ground ferns such as *Phymatosorus* suggests re-growth after forest disturbance while the marked decline in forest trees especially *Dacrydium cupressinum* accompanied by an increase in tree ferns in the upper zone is consistent with widespread forest clearance. This is associated with the appearance of new species, such *Fuchsia,* an increased abundance of *Pteridium* and a marked increase in *Dicksonia squarrosa. Dicksonia squarrosa* prefers shelter from wind and frost, and is often found on swampy soil (Brownsey and Smith-Dodsworth 2000), while *Cyathea dealbata* prefers well drained soil (Brownsey and Smith-Dodsworth 2000). The increased abundance of *Dicksonia squarrosa* coincides with the expansion of *Dacrycarpus dacrydioides* which is consistent with damper conditions in the crater.

Tall trees again dominate the flora at the top of the zone, but the crater vegetation is different with an abrupt change in composition from a forest dominated by *Dacrydium cupressinum* and ferns to a swamp forest dominated by *Dacrycarpus dacrydioides* and *Syzygium maire:* a podocarp-broadleaved forest is growing on the surrounding countryside. Although charcoal fragments remain low, the small peak in *Pteridium* accompanied by an abrupt decrease in forest trees suggests forest clearance by Maori. However, as charcoal fragments are sparse it appears that repeated burning to encourage the spread of *Pteridium* was not important at this site, suggesting instead that forest clearance took place to enable the establishment of gardens. This is in accordance with the presence of ancient kumura pits around the crater rim. The appearance of new species such as *Fuchsia* around the forest margins would have been welcomed by Maori. For example Maori ate the *Fuchsia* berries or made them into a drink (Foster 2008), while the berries would probably also have attracted the native birds, another food source.

The peak in Poaceae in the upper zone is probably a reflection of forest clearance and the spread of unspecified species of tussock (NZAA 1982) while its subsequent decline is likely due to the establishment of a new wetland and the formation of a swamp forest in the crater. The appearance of *Pinus* at the top marks the presence of Europeans and the establishment of pine plantations nearby for forestry.

To summarize, and prior to the arrival of humans, the pollen diagram for Maungatapere indicates the consistent presence of a kauri-podocarp-broadleaved forest which expanded during the Holocene and invaded the crater floor. There is a cyclic pattern in the composition of the flora, whereby a short-lived decline in gymnosperms, especially *Dacrydium cupressinum,* coincides with the increased abundance of either small angiosperm trees and shrubs, or ferns. This will be discussed further under disturbance. The crater probably contained a large swamp during the early-to-mid Holocene but has decreased in size over time as conditions became drier. This could be the result of a fall in the annual rainfall in the later Holocene, the increased uptake of water by an encroaching forest, or to a combination of both. A further possibility is that the peat continued to accumulate above the water table to form a raised bog, but later the water table dropped. The most significant change occurred after the arrival of humans when deforestation resulted in the formation of a swamp forest dominated by *Dacrycarpus dacrydioides* and *Syzygium maire.*

8.2.2 Rawhitiroa

The pollen record for Rawhitiroa extends back to >*c. 2775 cal. yr BP* (*Zone 1)* and prior to the formation of the peat. The abundance of tree ferns and of

Phymatosorus, together with low but increasing values for *Dacrydium cupressinum, Podocapus* and *Ascarina* is consistent with colonization by wind-dispersed spores and seeds.

The base of *Zone 2* dated at 2775 cal*.* yr BP marks a change from a colonizing vegetation dominated by tree ferns to a kauri-podocarp-broadleaved forest with an understorey of ferns in damper areas; this is consistent with plant succession. *Phymatosorus* is still significant at the base. The *Phymatosorus* species which 1are currently found in Northland grow on bare ground, rocks or as epiphytes in trees (Brownsey and Smith-Dodsworth 2000; Crowe 1994; Foster 2008). *Microsorum pustulatum* formerly *Phymatosorus pustulatus or Phymatosorus diversifolius,* is the most common species and found in montane forest, scrub, and open ground. It prefers slightly drier conditions and can be epiphytic but often creeps along the ground and over rocks and logs (Brownsey and Smith-Dodsworth 2000). The relative abundance of *Phymatosorus* at around 2775 cal*.* yr BP suggests the presence of some open ground or scrub. However, it then declines rapidly in abundance which coincides with a marked increase in Cyperaceae; this suggests that the amount of dry open ground is decreasing and that a swamp has formed. As indicated by a marked peak in the aquatic species, *Myriophyllum*, conditions in the swamp then become progressively wetter, culminating in the formation of a small shallow lake.

At *c.* 2259 cal. yr BP, *Zone 3,* conditions in the crater have become drier and the lake has largely disappeared to be replaced by a swamp dominated by Cyperaceae and *Haloragis*. Swampy conditions and some shallow water persist throughout this zone, with the temporary appearance of small lakes. The increased abundance of *Haloragis* in the middle of the zone suggests increased disturbance (Allan 1982); however large charcoal fragments are rare indicating that the disturbances are not the result of local fires.

Major environmental changes commencing at *c.* 750 cal .yr BP, *Zone 4*, indicate the arrival of Maori. The marked decline in forest trees and increased numbers of *Pteridium esculentum* spores, together with an abrupt increase of large angular charcoal fragments suggests forest destruction by burning. It is likely that one of the aims was to encourage the growth of *Pteridium esculentum,* an important source of carbohydrate (McGlone and Wilmshurst 1999). Large, angular charcoal fragments are indicative of local fires (Blackford 2000; McFadgen 1994; McGlone and Wilmshurst 1999).

The burning possibly destroyed some of the peat as indicated by the disappearance of *Haloragis* (Allan 1982); if so this would also have resulted in a loss of some of the pollen record. However, the fires created a new wetland dominated by Cyperaceae, Restionaceae, and some species of *Lycopodium. Dacrycarpus dacrydioides* grows in some of the drier areas of the swamp, while regenerating dryland forest is dominated by *Podocarpus.* A short-lived abundance in *Metrosideros* is probably due to a more open canopy. An extensive period of burning has followed. This has opened up the vegetation and not only enhanced the growth of *Pteridium esculentum* but caused a proliferation of shrubs, ferns and allied plants. *Agathis australis* is very susceptible to burning (Kershaw and Strickland 1988; Newnham 1992) and has disappeared. The loss of trees has made conditions wetter causing water levels to rise and the swamp to expand, which as indicated by the marked increase in *Myriophyllum,* culminated in the formation of a shallow lake. *Leptospermum* tends to spread after fire and probably is growing around the edges of the lake or as currently pertains to the site, invaded the swamp itself.

An increase in Poaceae and the appearance of *Plantago* and *Pinus* pollen near the top of the zone denote the arrival of the European and the development of agriculture and forestry.

To summarize, tree ferns dominated the original vegetation at Rawhitiroa. This was replaced by a kauri-podocarp-broadleaved forest and a Cyperaceae swamp. *Haloragis was* also abundant over most of the period, with the occasional formation of small shallow lakes or ponds. A marked change occurred after the arrival of humans with an abrupt decline in *Dacrydium cupressinum,* accompanied by the appearance of abundant *Pteridium* spores, charcoal fragments, and exotic species. A bog with areas of open water now occupies the crater floor, and the land surrounding the cone is now mostly in pasture with a few patches of native forest.

Summaries of the palynology and inferred regional vegetation at Maungatapere and Rawhitiroa appear in Tables 8.1 and 8.2.

Pollen zone	Cal. yr BP	Key dryland / tree fern taxa	Key wetland vegetation	Inferred regional vegetation
5	*c.* 680	*Pinus* *D. dacrydioides* *Dicksonia squarrosa* *Podocarpus* *Prumnopitys* *Phymatosorus* *Coprosma, & Cyathea* mid-zone only *Pteridium esculentum* appears	Sparse	Pasture with pine plantations Kauri-podocarp-broadleaved native forest
4	*c.* 2808	*Dacrydium cupressinum* *Cyathea* species *Podocarpus & Ascarina* increase	*Haloragis* mid-zone only	Kauri-podocarp-broadleaved forest
3	*c.* 4638	*Dacrydium cupressinum* *Cyathea* species *Podocarpus* important	Sparse	Kauri-podocarp-broadleaved forest
2	*c.* 6638	*Dacrydium cupressinum* *Cyathea* species *Podocarpus* increases *Ascarina* & *Coprosma* important at base, monolete ferns at top	Cyperaceae	Kauri-podocarp-broadleaved forest
1	*c.* 10,530	*Dacrydium cupressinum* *Cyathea species* *Ascarina & Podocarpus* significant Monolete ferns (briefly) then *Coprosma* prominent in mid-zone	*Haloragis* Cyperaceae	Kauri-podocarp-broadleaved forest

Table 8.1: Summary of palynology and inferred regional vegetation since *c.* 10,530 ± 136 cal. yr BP at Maungatapere.

Pollen zone	Cal. yr BP	Key dryland / tree fern taxa	Key wetland vegetation	Regional vegetation
4	*c.* 750	*Pinus* Poaceae & *Plantago* *Podocarpus* *D. dacrydioides* *Pteridium esculentum* + charcoal *Dacrydium cupressinum, Prumnopitys taxifolia* & *Cyathea* decrease upwards *Metrosideros* & *Coprosma* peak mid-zone, *Leptospermum* at top	*Myriophyllum* at top Cyperaceae Restionaceae *Lycopodium* species	Pasture & pine plantations Fernbrake Kauri-podocarp-broadleaved native forest
3	*c.* 2259	*Dacrydium cupressinum* *Podocarpus* & *Prumnopitys* *Metrosideros* *Cyathea* species *Phyllocladus, Agathis australis*, & *Ascarina* increase	*Haloragis* Cyperaceae	Kauri-podocarp-broadleaved forest
2	*c.* 2775	*Dacrydium cupressinum* *Cyathea* species *Podocarpus* & *Prumnopitys* *Ascarina* important *Phymatosorus* peak at base	Cyperaceae *Myriophyllum* at top	Kauri-podocarp-broadleaved forest
1	> *c.* 2775	*Cyathea* species *Phymatosorus*	Sparse	Kauri-podocarp-broadleaved forest

Table 8.2: Summary of palynology and inferred regional vegetation at Rawhitiroa.

8.3 Significance of Charcoal

Fire has had a significant influence on the composition of vegetation in New Zealand in the past. This includes both natural fires perhaps due to volcanic activity or to lightning, as well as those initiated by humans.

Patterson *et al*. (1987) reviewed a number of studies covering the production and distribution of charcoal following forest fires, and the use of fossil charcoal as evidence when interpreting the palynological history of an area. They state that there are a number of factors which influence the production and dispersal of charcoal including the type of fuel, size and intensity of fire, method of dispersal, and the proximity of the fire-ravaged area to the collection site.

Although there is an increase in the abundance of charcoal fragments in the upper sections of the pollen diagrams for Rawhitiroa, this is minimal for Maungatapere and appears to be considerably less than for other Northland sites of a similar age. Suggested reasons for this will now be explored.

Production

The amount and type of charcoal produced depends on the fuel source (Patterson *et al*. 1987). The amount of charcoal produced by the burning of different trees, varies considerably as determined by the "hardness, and compactness" of the wood (Ure 1824, in Patterson *et al*. 1987). For example Ure (1824) noted that when burning the same volume of wood under controlled conditions, the amount of charcoal produced was 25.5% for the dense Mahogany wood but only 16.5% for the Scots Pine when compared with the original. Patterson *et al*. (1987) suggests much greater differences would occur between wood and less compact herbaceous vegetation such as grass. In turn this suggests that considerably less charcoal would be produced by the burning of shrubby and herbaceous wetland vegetation, as for example at Rawhitiroa, than by burning the surrounding podocarp-broadleaved forest.

Dispersal

As noted above, the intensity and size of a fire depends largely on the fuel source. It is likely that a large amount of dead woody litter would accumulate on the forest floor after a severe storm. Butler (2008) suggests that in times of severe drought it is possible that this could be ignited by lightning, while Maori used fire to clear the land for a variety of reasons. Evergreen forest could be burnt during dry periods, but if necessary small trees and shrubs could be felled to provide dry matter for burning (McGlone and Wilmhurst 1999). It is likely that such fires would not have the same amount of energy as the Australian bushfires, which can produce powerful updrafts and smoke columns several kilometers high (Butler 2008). Microscopic charcoal fragments entrained in the updrafts could then be dispersed over a wide area, and as stated by Butler (2008) very small fragments from Australian bushfires and dust storms are often transported to New Zealand.

Wind and water are the main mechanisms of charcoal transport (Patterson *et al*. 1987). Dispersal by wind is not only affected by convective currents created by fire, but by the direction and intensity of wind. Fragments may also be deposited by raindrops. Usually the larger fragments are deposited closest to the source of the fire (Patterson *et al*. 1987). In a study after a fire in a heathland in Devon, southwest England in 1997, Blackford (2000) not only noted that very small charcoal fragments (< 20 μm) were typically found in the areas not burnt, but that some adjacent areas contained no fragments at all.

Patterson *et al*. (1987) suggest that often more charcoal may be transported by water than by air, with the possible exceptions of lakes that receive little surface runoff. The burning of forest often results in accelerated erosion whereby charcoal-rich sediment is washed away, or accumulates in a depositional basin. Both Maungatapere and Rawhitiroa have small catchments consisting only of the volcanic craters. There are no inlet streams into the craters, and their elevated location means that the only source of sediment arising from accelerated erosion would be the crater walls. This indicates that the source of charcoal in these wetlands could only have arisen from a fire within the craters or have been transported there by wind from a source outside.

In the event of accelerated erosion arising from fire within the craters, the cores could be expected to contain sedimentary layers with particles of different sizes (McGlone and Wilmshurst 1999) and perhaps colour. However particulate sedimentary layers are not present in the Maungatapere and Rawhitiroa cores. This suggests that accelerated erosion was not prominent at these sites.

Charcoal Source

The source of charcoal deposited in a wetland will vary according to the size of the site (Patterson *et al*. 1987). Charcoal found in a very small site such as a pond would mostly reflect a local source, while the charcoal influx in a large lake would be mostly derived from regional fires (Patterson *et al*. 1987). Fossil charcoal found in small lakes and wetlands can be used as an indicator of extra-local fires (Patterson *et al*. 1987): it is suggested that the Maungatapere and Rawhitiroa wetlands fit this latest category.

Location of Wetland and Demographics of Catchment

It is suggested that both the elevation of a wetland and the demographics of the catchment have roles to play in determining the abundance of fossil charcoal in a wetland. Table 8.3 contains a summary of the elevation and characteristics of the various Holocene wetlands in Northland.

As can be seen from Table 8.3, both Maungatapere and Rawhitiroa have very small, discrete catchments. Their elevated location means that they are also isolated from the surrounding countryside. The wetlands of several of the other Northland sites lie below the surrounding countryside, as for example, Tauanui Lake, Lake Omapere, Whangape Harbour, and Otakairangi Swamp. Charcoal arising from forest fires on the surrounding hillsides would be readily transported by wind and water to the wetlands below. It is likely that this would apply to low-lying or dune wetlands such as Lake Taumatawhana and McEwan’s Bog as well. However it is argued that a different scenario may apply to Maungatapere and Rawhitiroa. The elevated, isolated location of these wetlands means that only some of the windblown charcoal from fires burning on the surrounding countryside would be deposited in the crater, depending on factors such as the intensity of the fire and wind direction.

Very little charcoal was noted in the Maungatapere core, indicating that it was not repeatedly burned. This is consistent with archaeological evidence. It was once a major horticultural site, but was later abandoned by Maori, and as currently is the case, has probably been forested throughout most of its history. The early Maori settlers would have used fire to cook their food, but as may be seen from the contour map of Maungatapere, (Figure 6.4), the Pukeatua Pa site lies about 130 m below the crater. It is likely that the fires were low in intensity and the difference in height between the crater and the pa suggests that very little charcoal would have reached the crater wetland. The photograph of the south-westerly view of the Maungatapere cone, (Figure 5.2), shows a patch of forest that is regenerating after a forest fire. Again there is little, if any, evidence of this in the sedimentary record. However, the wind direction at the time of the fire would have been an important factor in determining the distribution of the charcoal, and the date could determine whether or not any charcoal lay at an appropriate level for detection during the processing of the core.

Wetland	Description
Tauanui Volcanic Centre Elliot *et al.* 1998.	Tauanui Lake has a surface area of 10 ha. and is about 230 m a.s.l. It was formed as a result of runoff from the Mangakahia Range being trapped in two conjoint explosion craters forming part of the Tauanui Volcanic Centre. There are no inlet or outlet streams. The Tauanui cone is *c.* 340 m a.s.l.
Lake Omapere Newnham *et al*. 2004.	Lake has a surface area of 11.6 km^2 and is 238 m a.s.l. It has a small catchment of 1700 ha. It was formed through the ponding of stream waters by lava flows from Te Ahuahu volcano.
Rangihoua Bay Horrocks *et al*. 2007.	It has a small catchment of *c.* 95 ha. There are two swamps, 1.8 - 2.3 m a.s.l. The large swamp has a surface area of about 20 ha and the small swamp about 0.5 ha. The swamps are drained by a stream.
Whangape Harbour – intertidal flats Horrocks *et al.* 2001.	The Whangape Harbour is a Y shaped estuary formed at the confluence of the Awaroa and Rotokakahi Rivers. These rivers have a combined catchment of 300 km^2 or 30000 ha.
Wharau Rd Swamp Elliot *et al.* 1997.	This peat swamp covers approximately 17.5 ha, and is enclosed in a valley basin partially dammed by a basaltic lava flow. Surrounding hills are nowhere above 100 m.a.s.l.
Lake Taumatawhana Elliot *et al.* 1995.	<1 ha dune lake. The lake drains by seepage into a larger adjacent peat swamp. It is about 30 m a.s.l.
McEwan's Bog Kershaw and Strickland 1988.	The bog lies in an interdune depression about 100 metres in diameter giving a surface area of about 0.79 ha. It is a few m a.s.l.
Otakairangi Swamp Newnham 1992.	The swamp fills a 77 ha flat tectonic depression bounded by small hills to the north, south, and west. The surrounding hills are up to 250 m a.s. l. Drainage is to the southwest via the Wairua River which has cut through lava flows from Whatitiri volcano.
Rawhitiroa	The Rawhitiroa crater and catchment covers about 18.8 ha. The cone is 280 m a.s.l. The bog has a surface area of 1.8 ha.
Maungatapere	The Maungatapere crater and catchment covers about 8.9 ha. The cone is 344 m a.s.l.

Table 8.3: A summary of the elevation and catchment characteristics of the Holocene wetlands in Northland.

To summarize it is suggested that the paucity of charcoal in the Maungatapere core in particular is due to several factors;

- Low-intensity forest and wetland fires
- An elevated and isolated catchment
- Minimal fluvial transport within the crater
- Land probably cleared by fire but then used for horticulture
- The conservative identification of charcoal fragments as detailed under Pollen Processing in Section 6.2.2.

8.4 Sources of Pollen

While pollen usually only travels about 10 – 1000 m from its source, sometimes it is carried over great distances. Once airborne, the pollen from different sources is mixed by the wind. Consequently it can be difficult to determine whether a few pollen grains in a sediment originated from a few plants growing nearby or from a large stand growing at a distance (Seppa 2007). This is a particular problem with plants that produce pollen which is readily transported over long distances by wind.

The type of pollen found in any wetland is determined by its source, and according to Jacobson and Bradshaw (1981) the pollen source area depends on two main factors;

- The mechanisms by which the pollen is transported to a site. This varies depending on the size and type of site, and the pollen can be separated into local, extra-local, and regional pollen depending on the source.
- The dispersal properties of pollen from individual taxa, especially the difference between wind-pollinated and animal-pollinated species (Jacobson and Bradshaw 1981).

Jacobson and Bradshaw (1981) define *local pollen* as that derived from plants growing within 20 m of the edge of the sampling site, *extra-local* pollen from plants growing between 20 m and several hundred metres from the site, while *regional* pollen represents long-distance pollen. In the transport model presented in Jacobson and Bradshaw (1981) pollen can be transported by streams and surface runoff (C_w), through the trunk space (C_t), above the canopy (C_c), and by rainfall (C_r). A gravity component (C_g) is defined as the vertical dry deposition of pollen, anthers, and catkins from plants growing along the edge or hanging over the sampling site. The proportion of these components varies according to the size of the sampling site, as displayed in Figure 8.2.

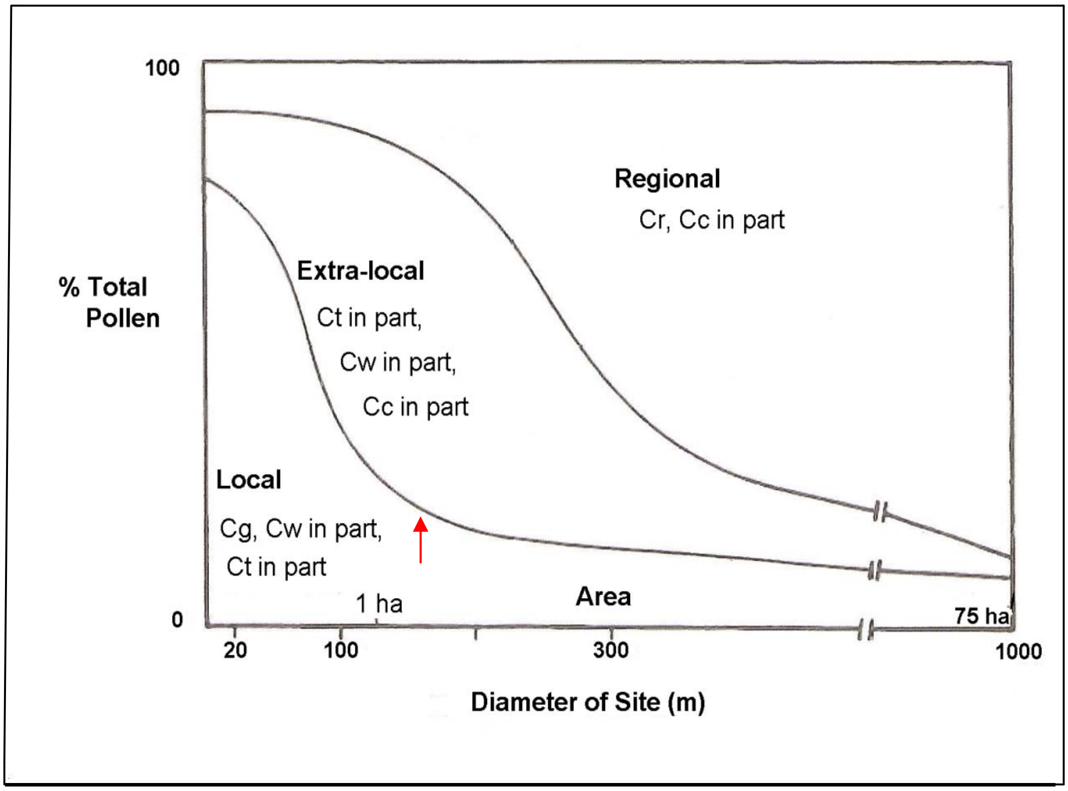

Figure 8.2: **Pollen source areas**

Relationship between the size of a site that has no inflowing stream and the relative proportions of pollen originating from different areas around the site. The arrow indicates the likely whereabouts of the Rawhitiroa wetland within this diagram. Adapted from Jacobson and Bradshaw (1981). (Text redrawn).

Key;

From surface runoff	C_w
Through trunk space	C_t
Above the canopy	C_c
By rainfall	C_r
Gravity component	C_g
Rawhitiroa	↑

The Rawhitiroa wetland is about 150 m in diameter. Figure 8.2 showing the relationship between the size of a site and relative proportions of pollen originating from different areas, suggests that at Rawhitiroa about 20 % of the pollen is local in origin, about 64 % extra-local, while the remaining 16% is regional. Both the extra-local and regional pollen have a significant canopy component. The Maungatapere crater is smaller than the Rawhitiroa crater; if the wetland is also smaller it will probably contain a higher percentage of local pollen and less regional pollen than at Rawhitiroa.

The location of a peat deposit and the size of the area lacking a tree canopy also affect the relative proportions of pollen originating from different areas according to Jacobson and Bradshaw (1981). They quote studies by Andersen (1970) and Bradshaw (1981) which demonstrated that within a closed forest, most pollen remains within 20 – 30 m of its source. However as sites increase in size and the tree canopy opens up, extra-local and regional pollen becomes increasingly important.

Large trees were sparse prior to the formation of the wetland at Rawhitiroa, resulting in a wide open canopy. According to the diagram in Figure 8.2, this would have increased the proportion of regional pollen with a corresponding decrease in extra-local pollen. A reversal occurred when the area of open canopy decreased as forest invaded the crater. Rawhitiroa is now again an open wetland surrounded by pasture with only patches of native forest and pines nearby. This indicates that extra-local and regional dryland pollen will have increased in volume with a corresponding decrease in local pollen.

A different situation applies to Maungatapere. Wetland plants have decreased over time while woody trees, shrubs and tree ferns have become more abundant and now form a closed forest canopy within the crater. Local pollen will now form a large part of the pollen spectrum, with a reduction from regional sources. *Pinus* pollen is a significant component of the pollen spectrum in the surface sample of the core, even though the closest pine plantation lies at least 130 m below the crater. This is an example of the high dispersal properties of the pollen from wind pollinated plants such as *Pinus.*

Another model, the 'Prentice-Sugita model', was later developed in order to quantify the amount of pollen arising from vegetation growing around a sampling site, either to the whole surface area of the site, or to the centre (Seppa 2007). According to this model "the input depends on the pollen productivity of the plant species, the mean plant abundance at a given distance from the centre of the basin, and a pollen deposition function" (Seppa 2007). A central concept, the 'relevant source area of pollen' (RSAP) refers to the size of an area around a study site, that determines the individualistic features of the pollen assemblage in relation to the background regional pollen (Seppa 2007). Simulation outputs from this model indicate that the RSAP of small to medium sized lakes with a radius ranging from 50 to 250 metres will be 300 – 800 m from the edge of the lake.

Again this suggests that most of the pollen preserved in the peat at Maungatapere and Rawhitiroa would have originated from local and extra-local sources. However unlike many peat deposits, lakes have an open canopy.

8.5 Volcanism and Wetland Development

8.5.1 Initiation of Wetland Formation

Maungatapere

Unfortunately the Maungatapere core did not extend to the base of the peat, so the nature of the soil immediately beneath the peat could not be examined. However it is suggested that after the formation of the volcanic cone colluvial deposition of fines would have sealed the crater floor causing a wetland to form.

Rawhitiroa

Four different scenarios are presented in an attempt to explain the formation of the wetland in the Rawhitiroa crater.

Tephra Deposits

Rawhitiroa is one of seven small volcanoes which appear to be aligned along a fault-line (Sporli and Hayward 2002). It is possible that a tephra eruption from one of the near-by vents could have blocked the drainage from the crater and initiated the formation of a wetland. However, this does not explain the high kaolinite content of the clay base.

Hydrothermal Activity

Another possibility is that Rawhitiroa was part of an old hydrothermal system, and the materials in the clay pan were hydrothermally altered to kaolinite in the vent. In hydrothermal areas it appears that kaolinite is formed from sulphuric acid solutions possibly associated with a zone of secondary enrichment. The presence of sulphuric acid is due to the oxidation of pyrite or hydrogen sulphide from oxygen dissolved in percolating meteoric waters (Steiner 1977).

Acid Leaching

Some acid leaching appears to be present beneath the peat, and it is suggested that humic acid solutions filtering down from the peat may have converted other clays to kaolinite. As described below this process is observed to occur beneath coal seams elsewhere (Staub and Cohen 1978).

The formation of kaolin rattles in rattling iron concretions found in the Waikato Coal Measures is described by Childs *et al*. (1974). It is thought that the formation of these concretions was initiated by the mobilisation of iron under reducing conditions created by decomposing organic matter. This resulted in the precipitation of iron as siderite. Later oxidation resulted in the formation of ‘boxes” or concretions with ferric oxide shells. Some of these had an interior void containing a kaolin rattle formed from the weathering of the host sediment. The presence of kaolinite-rich clays lying beneath certain Palaeozoic coals has also been noted overseas (Staub and Cohen 1978). However, as the Waikato Coal Measures are Eocene in age (Stevens 1980) and the Paleozoic coals are much older it suggests that the initiation of kaolinite formation through acid leaching is a very slow process. It is probably unlikely that there was sufficient time for this to occur at Rawhitiroa since radiocarbon dating indicates it is only of Holocene age.

Although not implicated in the formation of kaolinite, the presence of acid leaching at Rawhitiroa may be due to the presence of mor-forming species in the crater. Pollen grains from conifers including *Agathis australis, Dacrydium cupressinum* and *Phyllocladus* plus some broad-leaved trees and shrubs were present at the base of the peat, and above the fern-rich clay layer. The formation of acid litter, especially from the kauri trees would presumably result in the release of relatively large amounts of humic acid. However against this scenario is the pollen evidence that at Rawhitiroa, ferns and then wetland species were important in the lower core, so forest trees probably only grew on the crater walls surrounding the wetland. Possibly though, the humic acid would percolate downwards and contribute to acid leaching noted in the clay base.

Contamination of the Cone by Old Soil

As can be seen from the map in Figure 8.3, both Kiripaka and Waiotu soils lie close to the Rawhitiroa cone, which is covered by young Papakauri clay loam. Waiotu friable clay is rich in both gibbsite and kaolinite. It is suggested that Rawhitiroa erupted through the Waiotu soil-covered landscape forming a scoria cone, but with some Waiotu friable clay lining the inner rim. Later erosion washed the Waiotu friable clay onto the crater floor thus providing the kaolinite for the clay pan and the formation of peat. It is suggested that this is the most likely reason for the formation of the wetland.

The fact that Waiotu and Papakauri soils are currently exposed side by side on the landscape negates the hypothesis that ash from near-by vents sealed the Rawhitiroa crater and initiated the formation of peat.

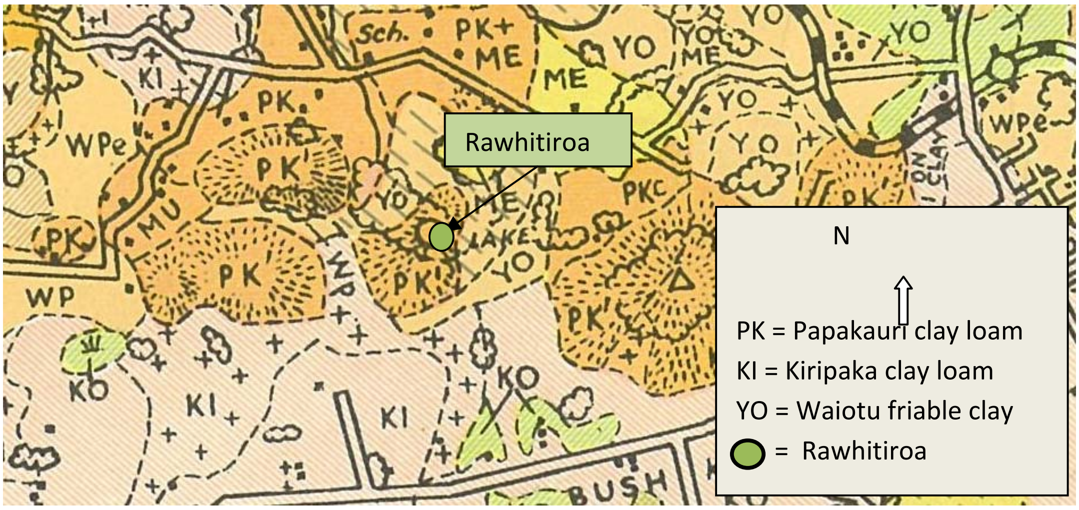

Figure 8.3: **Map showing soils surrounding the Rawhitiroa volcanic cone.**

Extract from a one mile to one inch map by Taylor *et al*. 1948

8.5.2 Colonization of Fresh Substrates

Colonization of a new surface is influenced by the rate nitrogen is incorporated into the biomass (Burrows 1990). Basalt contains more plant nutrients than either rhyolite or andesite, so is a better medium to encourage the establishment of plants. Previous studies, as for example on Krakatau Island, indicate that the earliest colonists on a fresh substrate include bacteria and the lower plants such as lichens and mosses which have tiny spores and are readily transported by wind. Fern spores are also readily dispersed by wind. Once a biomass has formed, an area is ready for colonization by angiosperms and conifers, whose seeds may be dispersed by animals and birds, or by wind (Burrows1990) and streams.

Burrows (1990) shows how quickly the colonization of a bare substrate proceeds, and provides an example of the rapid vegetation trends recorded for the eastern side of Mount Tarawera above an altitude of 600 m following the devastating 1886 eruption. He notes that *Coriaria arborea*, capable of fixing nitrogen, was an early and vigorous pioneer species on Mount Tarawera, speeding up the development of tall scrub by 15 – 20 years. Within 100 years of the eruption the mountain side was covered in a broad-leaved angiosperm forest up to 22 metres in height. It is predicted that 200 years post eruption a tall broad-leaved forest with emergent podocarps will be present (Burrows 1990).

The size of an area devastated by a volcanic event will vary according to the style of the eruption, the volume, and type of erupted material. While the young basaltic volcanoes in the Whangarei Field are associated with both scoria cones and lava flows, each volcano is small so the area of devastation would likely be localized.

There was an inorganic substrate at Rawhitiroa prior to the accumulation of peat. With the exception of the clay layer at the base of the core, the underlying material is unknown. Just before the peat began to accumulate the vegetation consisted mainly of tree ferns with a scattering of podocarps probably sourced from nearby forest. A seral change to a kauri-podocarp-broadleaved forest with an understorey of ferns is detected in the first pollen zone at the base of the peat. No *Coriaria* pollen was recorded.

The absence of *Coriaria* pollen in the Rawhitiroa clay base and initial abundance of tree fern spores needs further consideration. It is possible that the tree fern spores in the clay below the base of the peat may have been concentrated by fluvial transport, and therefore over-represented in the pollen spectra. However, the Rawhitiroa crater is small and there are no inlet streams.

Coriaria pollen is not recorded in the pollen diagram for Lake Waiatarua which was formed after drainage was blocked by the Mount Wellington eruption (Newnham and Lowe 1991). Newnham and Lowe (1991) suggest that *Metrosideros* species may have been the early migrants onto fresh lava surfaces resulting from the Mount Wellington eruptions as has currently occurred on Rangitoto Island.

The pollen data from the peat examined in this study suggests that the development of the vegetation at Rawhitiroa was similar to that recorded by Elliot (1998) for Lake Tauanui. The earliest flora consisted mainly of *Cyathea* tree ferns, but was followed by the formation of a mixed conifer-broadleaved forest dominated by *Dacrydium cupressinum.* Elliot (1998) describes this as a volcanosere since it was initiated by volcanic events. Similar volcanoseres have been described for Krakatau (Flenley and Richards 1982) and Mount Tarawera after the 1886 eruption (Burrows 1990). The pollen diagram for

Tauanui suggests that *Coriaria* was not significant until after the arrival of humans and following deforestation by burning (Elliot 1998).

8.5.3 Vegetation

Many of the trees and shrubs which grow in Northland have a distinct preference of site. For example *Dacrydium cupressinum, Prumnopitys ferruginea, Ascarina lucida* and tree ferns favour moist areas lacking severe frosts, while *Libocedrus, Knightia excelsa, Phyllocladus* and *Agathis australis* favour areas with frequent vegetation disturbance. It appears that *Prumnopitys taxifolia* and *Podocarpus* prefer drier areas, (McGlone *et al*. 1993), and are described by Elliot *et al.* (1998) as hardy podocarps. Several tall trees will grow in saturated ground and tolerate long periods of flooding including *Dacrydium cupressinum, Dacrycarpus dacrydioides* and *Syzygium maire*. Small trees and shrubs which tolerate wet conditions include *Leptospermum scoparium,* some *Coprosma* species and *Gaultheria depressa (*McGlone 2009).

During the Holocene and prior to the arrival of humans there was a regional podocarp-broadleaved forest in Northland. *Dacrydium cupressinum* was a dominant taxon, while *Agathis australis* was commonly present as for example at Lake Taumatawhana (Elliot *et al*. 1995), Lake Tauanui (Elliot *et al.*1998), McEwan's Bog (Kershaw and Strickland 1988), Rangihoua Bay (Horrocks *et al*. 2007), Whangape Harbour (Horrocks *et al.* 2001), and Wharau Road Swamp (Elliot *et al*. 1997). *Dacrydium cupressinum* is the dominant dryland taxon in the pollen samples from both the Maungatapere and Rawhitiroa peats. However, it is often over-represented in the pollen record because its pollen is produced in abundance and it is readily dispersed (Elliot *et al*. 1998; Mildenhall 1976).

According to Newnham (1992) *A. australis* was an important forest component around the Otakairangi Swamp over the last 30,000 yrs with the possible exception of the Last Glacial Maximum. At McEwan's Bog (Kershaw and Strickland 1988) *A. australis* was most abundant about 3500 - 3000 years ago, and the later, sharp decline coincided with an increase in charcoal fragments. At Wharau Road Swamp a peak in abundance occurred at *c.* 3700 yr BP and *c.* 1088 yr BP. (Elliot *et al.* 1997).There are no similar peaks in abundance at Maungatapere, while the age of the basal peat at Rawhitiroa does not extend back 3000 years. *A. australis* is often under-estimated in the floral spectrum (Elliot *et al.* 1997), but was consistently present in both the study sites prior to the arrival of humans. This is in agreement with studies performed on other Northland wetlands.

Nothofagus (*Fuscospora*) prefers cool conditions and is not usually a significant component of Northland forests of Holocene age, e.g. Lake Taumatawhana (Elliot *et al.* 1995), Whangape Harbour (Horrocks *et al*. 2001), and Wharau Road Swamp (Elliot *et al.* 1997). An exception is McEwan's Bog (Kershaw and Strickland 1988) where *Nothofagus* (*Fuscospora*) was relatively abundant suggesting an isolated beech stand was growing nearby. *Nothofagus* (*Fuscospora*) was quite common in Northland during the Last Glacial and the relative abundance of *Nothofagus* versus *Agathis australis* has been used to infer climatic oscillations between cool and warm intervals (Newnham *et al*. 2004). This is in agreement with pollen data from one of the boreholes obtained from the Kaitaia Bog (Elliot 1998) which indicated that *Nothofagus* (*Fuscospora*) was abundant between *c.* 22,500 - 10,500 yr BP, but declined rapidly in the early Holocene especially after *c.* 9500 yr BP. *Nothofagus* (*Fuscospora*) maintained a presence in the Maungatapere and Rawhitiroa samples, but as the pollen grains were low in numbers they probably originated from distant hill country in Northland.

In keeping with other wetlands in Northland of Holocene age *Podocarpus* and *Prumnopitys* were important constituents of the forest around Maungatapere and Rawhitiroa. *Podocarpus* shows a marked increase in the uppermost zone at Rawhitiroa where it is accompanied by a decrease in *Dacrydium cupressinum.* Although initially this may suggest drier conditions (McGlone *et al*. 1993) or perhaps some forest clearance, regeneration on a cleared landscape is the most likely explanation for the significant increase in *Podocarpus* in the surface samples from both Maungatapere and Rawhitiroa. *Phyllocladus* appeared to be less common at Maungatapere and Rawhitiroa than at some other sites as for example at McEwan's Bog (Kershaw and Strickland 1988), and Wharau Road Swamp (Elliot *et al.* 1997), while both *Libocedrus* and *Phyllocladus* were much more abundant at Lake Taumatawhana (Elliot *et al.* 1995). *Metrosideros* was abundant or common at Lake Tauanui (Elliot *et al.* 1998), Lake Taumatawhana (Elliot *et al.* 1995). McEwan's Bog (Kershaw and Strickland 1988), Otakairangi (Newnham 1992), Whangape Harbour (Horrocks *et al.* 2001), and Wharau Road Swamp (Elliot *et al*. 1997), but was only common in the upper Rawhitiroa core where abundance fluctuated.

At Maungatapere the abundance of *Ascarina* showed a steady decline during the Holocene, and finally disappeared from the pollen spectra. This is in agreement with findings elsewhere. *Ascarina lucida* is described by Elliot *et al*. (1998) as a small, frost and drought sensitive tree. The greater abundance of *Ascarina lucida* in the early Holocene is attributed to a milder, moist climate, but populations declined as the climate became more seasonal, and perhaps drier (McGlone and Moar 1977; Newnham and Lowe 1991). At Rawhitiroa, *Ascarina* became slightly more abundant in the very late Holocene but then also vanished from the pollen spectra. Elliot *et al.* (1998) noted that *Ascarina lucida* became more abundant at Tauanui *c.* 3400 yrs BP, and suggest that fluctuations in the abundance in other species in the mid-Holocene were due to seral trends and forest disturbance.

Cyathea species, mostly *C. dealbata,* were the dominant tree ferns at Maungatapere and Rawhitiroa; this is consistent with other Northland sites. *Gleichenia* was never significant. Unlike some other sites, Cyperaceae was more abundant than Restionaceae at Maungatapere and Rawhitiroa. Another difference was in the abundance of *Haloragis.* This was abundant in the lower Maungatapere core, and also at Rawhitiroa, and although recorded in other Northland peats it was never common. *Haloragis* thrives where there is soil disturbance or after fires (Allan 1982), but the paucity of charcoal fragments at both the study sites prior to the arrival of humans, suggests its abundance was not due to fire. Soil disturbance could also arise from sediment input during accelerated erosion during storms. However unlike some of the other Northland wetlands, neither Maungatapere nor Rawhitiroa has an inlet stream and no particulate sedimentary layers were noted. Another possible explanation is that the water content of the soil and the abundance of other wetland vegetation were such that heavy rainfall was able to disturb the soil and enable *Haloragis* to spread.

While Burrows (1990) notes that *Coriaria arborea* was an early and vigorous pioneer species on Mount Tarawera after the 1886 eruption, according to Wardle (1991) this occurs more commonly during secondary succession. There was only the occasional grain of *Coriaria* at Rawhitiroa which occurred after the commencement of anthropogenic fires. *Coriaria* was also present at Lake Taumatawhana (Elliot *et al.* 1995), Lake Taunaui (Elliot *et al.* 1998) and at Wharau Road Swamp (Elliot *et al.* 1997) but again only appeared, or was more abundant, after the arrival of the Maori and therefore associated with secondary succession.

At Maungatapere, the base of *Zone 5* is marked by an abrupt rise in the abundance of *Phymatosorus* and in small angiosperm trees and shrubs, suggesting forest clearance and an increase in open ground and scrub. This is accompanied by the appearance of new species which are often associated with forest margins such as *Fuchsia,* followed by a change in the composition of the vegetation, and is interpreted as indicating a nearby Maori presence. Only a few *Pteridium* spores and charcoal fragments were noted. *Dicksonia squarrosa* and *Dacrycarpus dacrydioides* increase upwards through the zone indicating a change to damp conditions, while a marked decline in *Dacrydium cupressinum* follows later.

At Rawhitiroa, the abrupt and marked increase in the abundance of *Cyperaceae, Pteridium esculentum,* and large charcoal fragments which occurs at the base of *Zone 4* is interpreted as indicating Maori deforestation. This is in accordance with other Northland sites of a similar age. An increase in shrubs, ground ferns, and wetland species accompanied by a decrease in the abundance of tall trees, occurs in the upper part of the zone. As elsewhere, the appearance of exotic species such as *Pinus* indicates the arrival of European farmers. This was associated with a period of increased burning as also occurred at Lake Tauanui (Elliot *et al.* 1998) and Wharau Road Swamp (Elliot *et al.* 1997). However, there was no accelerated erosion due to human activities at either of the study sites, although this did occur in other areas such as at Lake Taumatawhana (Elliot *et al.* 1995), Whangape Harbour (Horrocks *et al.* 2001), and Wharau Road Swamp (Elliot *et al.* 1997).

8.5.4 Disturbance

Ogden (1985) considers disturbance is a major factor influencing the structure of New Zealand forests. He quotes from numerous sources giving examples of the many different causes of forest disturbance: these consist of storms, drought, fire, volcanism, earthquakes, avalanches, snow and insect infestation.

According to Newnham (1999) environmental conditions in Northland were fairly stable during the Holocene prior to the arrival of humans. However the frequency of disturbance may have increased during the mid - late Holocene (McGlone and Neall 1994) and conditions may have become slightly cooler and drier (Newnham 1999). Between *c.* 2000 and *c.* 1400 yr BP there may have been a period when the climate was moister and milder as suggested by increases in *Ascarina lucida, Cyathea, and Dacrydium cupressinum* (Elliot *et al.* 1997). According to McGlone *et al*. (1993) precipitation patterns in New Zealand changed after *c.* 7000 yr BP. Rainfall has tended to become more seasonal in the northern parts of New Zealand with drier summers and wetter winters forming a regular pattern (McGlone *et al*. 1993). This would increase the likelihood of storm, drought and fire damage and thus forest disturbance.

According to Elliot *et al.* (1998) an increase in the abundance of shrubs such as *Coprosma,* ferns and other understorey plants accompanying a decrease in tall forest is suggestive of disturbance. If human impact can be eliminated, the most likely causes are storm activity or droughts and fire (Elliot *et al*. 1998; Newnham 1999).

The impact of cyclonic activity on vegetation has been emphasized by Elliot *et al*. (1995), and Newnham *et al*. (1989). Elliot *et al.* (1995) suggest that windthrow during severe storm activity in the past may have been responsible for the felling of *Agathis australis* trees in the dry sand-dune country around Lake Taumatawhana. Windthrow has also been implicated in the destruction of tall conifers in the Waikato lowlands. Newnham *et al*. (1989) suggest that cyclic fluctuations in the abundance of *Dacrydium cupressinum* may have been due to windthrow which felled the mature emergent trees that once dominated the canopy. This opened up the canopy allowing the proliferation of understorey species and competitors for canopy space (Newnham *et al*. 1989).

Windthrow may be implicated in the cyclic variation in the abundance of *Dacrydium cupressinum* at both Maungatapere and Rawhitiroa as shown by the pollen diagrams. For example a decrease in the abundance of *Dacrydium cupressinum* at Maungatapere is associated with a marked increase in *Coprosma* in the early Holocene, and in *Phyllocladus* in the late Holocene. The pollen spectra for the 150 cm and 180 cm samples from Maungatapere provide another likely example of disturbance. A log lies in between these samples. The abundance of *Dacrydium cupressinum* in the 150 cm sample is significantly less than at 180 cm, while *Cyathea dealbata* shows the reverse trend. Sparse, large charcoal fragments are present in both samples. Together this suggests a major storm where emergent trees have been toppled by windthrow, and possibly burned during a dry period. The decrease in tall forest trees such as *Dacrydium cupressinum* encouraged the expansion of *Cyathea dealbata.* At Rawhitiroa the decreased abundance of *Dacrydium cupressinum* in the pre-human upper core is associated with increases in *Ascarina* and often with short-lived but marked peaks in *Metrosideros* pollen*.*

Most New Zealand wetlands make a good recovery after fire (McGlone 2009), and some wetland species seem to be especially adapted to survive. Examples include *Coprosma* species and *Empodisma minus* which can resprout from burnt bases or buried rhizomes respectively, and *Leptospermum scoparium* with regeneration from buried seed *(*McGlone 2009). It is likely that these features enabled the rapid increase of *Coprosma, Leptospermum scoparium* and Restionaceae at Rawhitiroa after anthropogenic burning.

Changes attributed to the impact of humans and projected dates of arrival will now be discussed further.

8.6 The Human Impact

The association between deforestation, fire, and a marked increase in the abundance of *Pteridium esculentum* spores with the arrival of Polynesian settlers is now well known (McGlone 1983, 1989). The association has been noted at several sites in Northland with some variation in the approximate date of arrival. (See Section 4.3 Human Impact).

Maungatapere

The major environmental changes which took place at the base of *Zone 5* of the pollen diagram indicate the arrival of Maori. Based on an average sedimentation rate of 4.7 cm/100 cal. yrs for Maungatapere this indicates Maori arrived here *c.* 680 cal. yr BP, or at about 1333 AD, which is in keeping with the widely accepted age of ~1280 AD (Wilmshurst *et al.* 2008), allowing for variation in sedimentation rates.

As previously noted in Section 4.3 Human Impact, the pa which they built at Maungatapere had been very important. The volcanic cone would have been a marked advantage during warfare, providing a good view over the surrounding countryside. The fertile volcanic soil is ideal for cultivation and had been developed extensively. Water is abundant as there are a number of fresh water springs in the area; these would have provided a home for eels. The thick surrounding forest would have been a source of food and medicine for Maori and was the natural habitat for native birds, yet another food source.

Yet when the European farmers arrived at about 1840 AD (NZAA 1982) this ideal pa site had been deserted. The reason for this remains elusive, although defeat in warfare must be a possibility. Most of the Maungatapere cone remains covered in thick native forest, and is now part of a scenic reserve.

Rawhitiroa

As described more fully under Section 7.5 Pollen Zones, by taking the average sedimentation rate of 13.5 cm/100 cal. yrs, and applying the 15 cm interval for the sample showing the first anthropogenic changes (between 55 and 40 cm) below the Kaharoa Tephra an age difference of 111 years was determined. This gives a calculated age of *c*. 1203 AD for the 55 cm sample, suggesting that Maori arrived at Rawhitiroa at *c.* 750 cal. yr BP. While consistent with the findings of McGlone and Wilmshurst (1999) who consider Maori deforestation began between 1200 and 1400 AD, it is inconsistent with the now widely accepted age of ~1280 AD (Wilmshurst *et al.* 2008). A plausible explanation is that the location of the greatest density of the Kaharoa Tephra does not represent the base, i.e time of eruption, of this tephra. The true base may lie closer to a depth of 55 cm, rather than 40 cm. This would give a date more consistent with the findings of Wilmshurst *et al.* (2008). Variation in the sedimentation rates is another possible source of error in the dating.

Although there are both native and exotic species of *Plantago* and Poaceae*,* a marked increase in these species in the 10 cm sample is interpreted as indicating the presence of European farmers. Assuming a sedimentation rate of 5.7 cm/100 yrs, as suggested for the upper 40 cm of peat, this indicates that Europeans arrived about 175 years ago or around 1840 AD. This is consistent with the dates of European settlement near Maungatapere.

8.7 A Minimum Age for the Volcanic Cones

8.7.1 Radiocarbon Dating

The dates for the basal peats in each core as recorded under Radiocarbon Dating suggest minimum ages for the volcanoes. These indicate that Maungatapere erupted over 9367 ± 37 radiocarbon years or over 10,530 ± 136 calendar years ago, while Rawhitiroa is at least 2707 ± 32 radiocarbon years or 2775 ± 52 calendar years in age. Unfortunately the Maungatapere core did not extend to the base of the peat so that a more accurate date for the minimum age is not available. The pollen diagram for Rawhitiroa indicates an abrupt change in the composition of the vegetation just prior to the formation of peat. It is here argued that the true age of Rawhitiroa may be close to 2775 cal. yr BP based on evidence provided in Burrows (1990) regarding the speed of plant colonization on fresh volcanic surfaces, and discussed above under Volcanism and Wetland Development (Section 8.5).

8.7.2 Erosional Stages of Cones

Kear (1957) used the erosional stages of volcanic cones to provide a physical estimate of age, and thus provide a relative dating method when radiometric and paleontological techniques were unavailable. A diagram showing these four erosional stages is reproduced in Figure 8.4. The Volcano Stage (Figure 8.4a) refers to cones which are similar to those of active volcanoes, while in the Planeze Stage (Figure 8.4b) planezes remain on ridges between eroded valleys. In the Residual Mountain Stage (Figure 8.4c) although the mountain still looks like a volcanic remnant, the original cone surface has gone. Finally in the Skelton Stage (Figure 8.4d) only the most resistant internal structure remains.

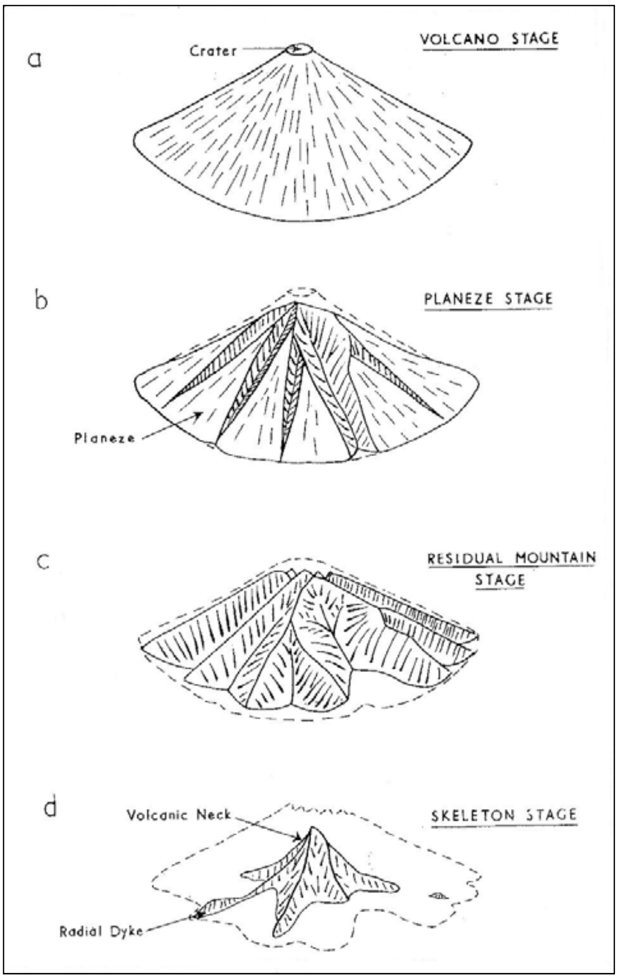

Figure 8.4: Erosional stages of volcanic cones.
Reproduced from Kear 1957.

Maungatapere and Rawhitiroa volcanic cones both have craters indicating that they are in the Volcano Stage of erosion. As may be seen in the photographs in Figures 5.1 and 5.2, Maungatapere has retained its youthful appearance. It is covered in thick native forest, and except for a period after Maori arrived, has probably been forested throughout most of its existence. No planezes are visible, although any early signs would be masked by the thick forest. Rawhitiroa however is mostly in pasture with some native forest and a *Pinus* plantation on part of the outer cone. The upper photograph in Figure 5.4 indicates a slight irregularity in the periphery of the upper rim, but rather than suggesting that planezes may be starting to form this feature is probably related to radial irregularities in the accumulation of scoria.

As suggested by Kear (1957) very permeable rocks are relatively resistant to erosion from surface water. The volcanic rocks at Maungatapere are of known high porosity with surface runoff only during high intensity rainfall events (French 1980). This would contribute to the youthful appearance of the cone. Rawhitiroa however, now appears to be quite susceptible to storm damage as was illustrated during the major 2007 Northland floods when torrential rain resulted in erosion and the loss of some pine trees growing on the steep outer walls (G. Hooker, *pers. com.*). (See Figure 8.5).

Figure 8.5: **A slip on the north face of Rotomate Road, which partially encircles the Rawhitiroa cone.** The slip shows a distinct slip plane at about 500 mm depth, which is probably due to differences in soil permeability.
Photograph supplied by B. Cathcart, Northland Regional Council.

According to Kear (1957) the basalt cones in Auckland are in the Volcano to Planeze Stage. This provides an estimated age of Holocene to Haweran age (Upper Pleistocene), and is consistent with the dating of 9150 ± 50 yr BP for a young basalt flow at Penrose. The physical appearance of the Maungatapere and Rawhitiroa cones suggests that they are similar in age to the Penrose basalts, providing supporting evidence for the radiocarbon dates.

8.7.3 Soil Types

Papakauri clay loam is the predominant soil type on the Maungatapere and Rawhitiroa cones. The specific ages of the Papakauri soils are not known, but they are presumed to be the youngest basalt soils in Northland (V.E. Neall, *pers. com.*).

8.7.4 Palynology

During the Last Glacial Maximum *Nothofagus* (*Fuscospora*) was the dominant taxon of the regional forest in Northland. Pollen data from the Kaitaia Bog indicated that *Nothofagus* decreased rapidly in abundance between 14,000 and 10,000 yrs BP, while *Dacrydium cupressinum* expanded (Elliot 1998). Podocarp-broadleaved forest became dominant during the early Holocene (Newnham 1999). *Nothofagus* is now scarce in Northland. Podocarp-beech-broadleaved forest occurs in small patches in the Omahuta Forest, south of Kaitaiia, with a few scattered trees near Whangarei and in the Waipoua Forest (Elliot 1998). *Nothofagus* (*Fuscospora*) only formed a minor component of the pollen spectra at Maungatapere and Rawhitiroa. This is consistent with other Northland forests of a Holocene age.

To summarize, all the evidence presented in this study indicates a late Pleistocene to Holocene age for the cover beds on the Maungatapere and

Rawhitiroa cones. This is consistent with a radiocarbon dating of 35,500 - 36,000 years BP for carbonized wood lying beneath a Whangarei lava flow (Cox 1973). However, it is at variance with the older K-Ar dates recorded previously for volcanoes in the Puhipuhi-Whangarei Field (Hayward and Smith 2002; Rollin 1991; Smith *et al.* 1993, in Sporli and Hayward 2002).

8.8 Why the Difference between the Whangarei Wetlands?

The type of wetland that forms in a depression is largely determined by the fertility of the water (Burrows 1990). The fertility changes over time causing the composition of the vegetation to change also. As noted previously, swamps are fertile wetlands where fresh nutrients are derived from drainage of the surrounding land, while bogs are infertile with nutrients supplied by rain or groundwater only.

A luxuriant forest dominated by tall trees has now invaded the Maungatapere wetland. The formation of the swamp forest has been enabled by eutrophic conditions where there is an abundance of plant nutrients and a favourable environment. As stated by Harris (1968), mesotrophic or even oligotrophic wetlands can occur in areas with fertile soils. The fertile Papakauri clay loam is the dominant soil type on the Rawhitiroa scoria cone, but currently the crater contains a natural wetland dominated by moss, rushes and sedges. The presence of short, low-fertility-demanding species such as *Sphagnum* moss and *Machaerina teretifolia* indicates that the wetland is low in plant nutrients and that oligotrophic conditions currently prevail.

Although the Maungatapere wetland is currently fertile, the presence of rare grains of *Drosera* in some of the samples, suggest that infertile conditions occurred there occasionally in the past. Carnivorous plants such as *Drosera* often live in acidic bogs, where they capture and digest small animals to increase their supply of nutrients (Burrows 1990). *Drosera* was not identified in any of the Rawhitiroa samples, but the current infertile conditions are confirmed by the presence of a wetland dominated by *Sphagnum* and other low-fertility-demanding species.

So Maungatapere, a swamp forest, and Rawhitiroa, a bog dominated by *Sphagnum* and sedges represent the two extremes of the fertility spectrum. Yet the wetlands are relatively similar in age and the volcanic cones in which they lie, both consist of basaltic scoria. Reasons for this dissimilarity are explored further below.

The pollen diagram for Rawhitiroa indicates repeated episodes of burning since the arrival of humans about 800 years ago. The burning of forests induces wetter conditions (McGlone 2009), but provides a brief supply of fresh nutrients (Burrows1990) which encourages the growth of herbaceous vegetation and the formation of new wetlands (Burrows1990) if drainage is impaired. However, as the peat continues to build-up it limits the availability of nutrients to plants growing in the wetland, and together with the loss of nutrients through drainage, the wetland becomes more acidic and infertile forming a “raised bog” (Burrows 1990). It appears that this is what has happened at Rawhitiroa. Waterlogging was enhanced by the loss of tall forest trees through fire while fresh nutrients and higher water levels stimulated the growth of wetland plants contributing to the build-up of peat and ensuing infertile conditions.

Swamp forests, such as the one growing in the Maungatapere crater, are not normally associated with deep peat (McGlone and Neall 1994). However, the presence of sandy peat and abundant volcanic lapilli in Eltham Swamp, Taranaki, may have enabled the establishment of a swamp forest there by providing nutrients and drainage (McGlone and Neall 1994). Similarly the presence of nutrient-rich, porous scoria forming the volcanic cone is a likely factor in enabling the establishment of a swamp forest at Maungatapere. Newnham (1992) noted a transition from an infertile poorly drained swamp, through a period dominated by *Dacrydium cupressinum* to a swamp forest dominated by *Dacrycarpus dacrydioides* at Otakairangi; this probably followed changes in drainage. He notes that this is a similar pattern to what has occurred in modern vegetation in the south-west of New Zealand. This may have also occurred at Maungatapere. Although the core did not reach the base of the peat, the pollen diagram indicates that the swamp was much wetter in the early Holocene than it is currently. As suggested previously, it may have become drier over time due to a decrease in rainfall or to the increased uptake of water by an encroaching forest. Another possibility is that the build up of sediments has enabled better drainage through the more porous rocks in the higher levels of the cone where fines were washed away into the central floor of the crater and thus below the base of the core.

Dacrydium cupressinum has increased in abundance during the Holocene and probably grew on the swamp prior to the arrival of humans. The paucity of charcoal fragments suggests that the site was not repeatedly burned by Maori, thus maintaining fertility and drainage and enabling the establishment of a swamp forest. It is suggested that at Maungatapere, Maori cleared the outer flanks of the cone for horticulture rather than using fire to stimulate the growth of *Pteridium esculentum* as is likely at Rawhitiroa. Thus when the site was finally deserted by the local Maori population a new fertile wetland developed rather than a peat bog.

Concluding remarks on the findings of this thesis and suggestions for future research are the focus of Chapter Nine.

CHAPTER NINE

CONCLUSIONS AND SUGGESTIONS FOR FUTURE RESEARCH

9.1 Conclusions

This thesis had five aims. Each will now be considered and the results analysed.

- ***To collect cores of sediment to enable the identification of fossil pollen and sediment trapped in the crater swamps of Maungatapere and Rawhitiroa volcanic cones.***

  A single core of sediment for processing was obtained from the Rawhitiroa crater wetland, and while three were collected from Maungatapere, only the longest one was processed. Fossil pollen was identified in the Rawhitiroa and the longest Maungatapere core, and radiocarbon dating was performed on samples from the bases of the peat successions.

- ***To use information derived from the pollen profiles and radiocarbon dating to provide a minimum age for the volcanoes.***

  The radiocarbon dating indicated a minimum age of 10,530 ± 136 cal. yr BP for the Maungatapere cone and 2775 ± 52 cal. yr BP for Rawhitiroa. The erosional stages of the cones and the fossil pollen data are consistent with a Holocene or late Pleistocene age. There is no evidence of a change in the composition of the vegetation from the Maungatapere wetland to suggest cold conditions, as for example from the Last Glacial, when high levels of *Nothofagus* (*Fuscospora*) pollen could be expected. The radiocarbon dating of the cover beds is at variance with the previous K/Ar dating.

It is perhaps a little surprising that *Nothofagus* (*Fuscospora*) was not more abundant near the base of the Maungatapere core at *c.* 10,530 ± 136 cal. yr BP. Elliot (1998) noted that *Nothofagus* cf. *truncata* declined sharply after 9.5 ka, only becoming a minor part of the vegetation at the Kaitaia Bog by *c.* 8 ka. The pollen record from two Holocene swamp deposits in the Dargaville region also indicated that *Nothofagus* (*Fuscospora*) was most abundant prior to *c.* 6850 cal. yrs BP (D'Costa *et al.* 2009). Conversely the pollen record from the Paranoa Swamp in far northern New Zealand, extending back to *c.* 17,000 yr BP, indicated *Nothofagus* was never an important part of the vegetation there. Unfortunately a lack of dating, or of chronological problems preclude comparison with some other Northland sites of a similar age, as for example the Otakairangi Swamp (Newnham 1992), Trig Road (Newnham *et al.* 1993), and Ranghoua Bay (Horrocks *et al*. 2007).

Due to the absence of plant macrofossils, the radiocarbon dating at the base of the Maungatapere core was performed on a bulk sample of peat, which by its very nature has a mixed composition. Given a low average sedimentation rate of approximately 4.7 cm/100 cal. years, and the paucity of *Nothofagus* (*Fuscospora*) in the older pollen samples, combined with the youthful geomorphology of the volcano and the fact that that the core did not extent to the peat base, it is surprising that the radiocarbon date of the basal peat in the core was as old as 10,530 ± 136 cal. yr BP.

However, a possible explanation for the paucity of *Nothofagus* pollen in the base of the Maungatapere core may lie with the input of regional pollen. Although there is currently a closed forest canopy at Maungatapere, the higher proportion of wetland species in the deeper portions of the 3MT core, suggest that an open canopy once existed. The size of the opening would help to determine the amount of pollen received from the different pollen source areas, in particular the proportion of regional pollen. If the opening was small the input of regional pollen would be reduced, limiting the input of *Nothofagus* pollen from distant sites.

- ***To reconstruct the vegetation history and palaeoecology of the area, and identify changes in climate over the time represented.***

The Maungatapere volcano erupted some time prior to 10,530 ± 136 cal. yr BP. Fines derived from the crater walls must have been washed inwards to seal the crater floor, creating a wetland dominated by *Haloragis* and Cyperaceae. Over time conditions changed and the swamp largely dried up. A kauri-podocarp-broadleaved forest dominated by *Dacrydium cupressinum* advanced over the crater floor, but showed cyclic disturbance probably as a result of windthrow during storm activity. Tree ferns dominated by *Cyathea dealbata* flourished in damper areas. A major change occurred in the late Holocene when an abrupt decline in *Dacrydium cupressinum* coincided with a marked increase of *Podocarpus and Dacrycarpus dacrydioides,* and the formation of a swamp forest. Finally the exotic species, *Pinus,* made an appearance. The paucity of charcoal fragments indicated that fire was never a characteristic of this wetland.

The volcanic cone at Rawhitiroa was formed some time prior to 2775 ± 52 cal. yr BP. The small volcanic eruption provided a fresh substrate for the rapid colonization by ferns sourced from nearby areas. Kaolinite-rich Waiotu friable clay which remained exposed in the crater walls after the eruption, was later washed down, and sealed the crater floor creating a wetland. A kauri-podocarp-broadleaved forest quickly invaded the crater and a Cyperaceae-dominated swamp was formed.

Short-lived shallow lakes or ponds appeared indicating periods of increased water-logging. Changes in the vegetation began to occur about AD 1200. Wetland species, especially Cyperaceae and *Pteridium esculentum,* increased in abundance accompanied by a marked rise in charcoal fragments. This was followed by a generalised decrease in tall trees especially *Dacrydium cupressinum. Podocarpus* was an exception becoming more abundant. Exotic species, *Pinus, Plantago,* and Poaceae, became common. Finally a marked increase in *Myriophyllum* pollen and the presence of abundant *Sphagnum* moss indicated that the wetland had transformed into an infertile bog with areas of open water.

The vegetation history of the Maungatapere and Rawhitiroa wetlands provides no firm evidence of major climate change, and the floral assemblages are typical of those of a Holocene age. The Maungatapere crater was initially much wetter than it is currently. While this could be attributed to a lower rainfall during the later Holocene, drier conditions may also be due to increased water uptake by an encroaching forest or to better drainage following the build-up of sediment.

- ***To seek evidence of human impact.***

Changes which occurred in the composition of the vegetation at Maungatapere and Rawhitiroa during the late Holocene can be attributed to human activity. The arrival of humans at Maungatapere was not marked by abundant charcoal fragments and spores of *Pteridium esculentum.* However deforestation is inferred from the appearance of new species such as *Fuchsia, Hebe, and Dicksonia squarrosia,* a marked increase in *Coprosma* and *Phymatosorus,* followed by the abrupt decline of *Dacrydium cupressinum.* Later changes included the formation of a swamp forest and the appearance of exotic *Pinus* pollen. It is suggested that Maori arrived here at *c.* 653 cal. yr BP or at about 1360 AD. Although the archaeological report records the presence of extensive Maori cultivations around Maungatapere, there is no indication of when this occurred. However changes in the composition of the pollen from local and extra-local sources, has enabled the estimation of an approximate date. The arrival of European farmers at 1840 AD is recorded in archeological records.

A significant rise in the numbers of large charcoal fragments and spores of *Pteridium esculentum* marks the arrival of the Maori at Rawhitiroa. This occurred shortly before the deposition of the Kaharoa Tephra, possibly around 1200 AD. A later marked decline in *Dacrydium cupressinum* and the appearance of exotic species indicates the arrival of Europeans probably at around 1840 AD.

- ***To compare the projected vegetation history of the Maungatapere and Rawhitiroa volcanic cones with each other and with other study sites of a similar age in Northland*.**

The presence of a *Dacrydium*-dominated kauri-podocarp-broadleaved forest at Maungatapere and Rawhitiroa is consistent with other Holocene sites in Northland. *Nothofagus* (*Fuscospora*) is never abundant which is also consistent with most other sites, but unlike other wetlands *Haloragis* is often a common taxon at Maungatapere and Rawhitiroa.

The arrival of humans is associated with deforestation and compositional changes in the vegetation, but not with accelerated erosion as sometimes occurred elsewhere such as at Lake Taumatawhana (Elliot *et al.* 1995). There is a cyclic element in the abundance of *Dacrydium cupressinum* at Maungatapere in particular. This is attributed to storm damage which has been recorded in other areas such as in the Waikato lowlands (Newnham *et al*. 1989). Although Maori burned the forest around Maungatapere, there are very few charcoal fragments in the Maungatapere core. This is inconsistent with other Northland sites and is probably due mainly to the discrete, isolated and elevated location of the wetland.

The difference in the fertility and thus vegetation of the Maungatapere and Rawhitiroa wetlands can be partially attributed to the activities of humans. Repeated burning of the forest at Rawhitiroa increased waterlogging in the crater and released an influx of fresh nutrients. This stimulated the growth of herbaceous wetland vegetation, and the rapid build-up of peat, creating infertile conditions. The forest at Maungatapere was not repeatedly burned and the wetland became drier over time, maintaining its fertility.

9.2 Limitations

The conclusiveness of some findings in this thesis is limited by several factors. This includes;

- An incomplete core of the peat infill at Maungatapere crater. This not only precluded a radiocarbon date for the beginning of peat accumulation but also a more accurate minimum age for the volcano, and a complete vegetation history of the area.

- Minimal age control on the peat deposits. Only one radiocarbon date was performed on each core, and while the Kaharoa Tephra was recorded at Rawhitiroa, no tephras were noted at Maungatapere.

- The use of the *average* sedimentation rate for the peat accumulation rate at each site to provide the approximate ages of the different pollen zones and the arrival of humans. These interpreted dates are only accurate if the growth rate of the peat remained constant. Peat accumulation rates can vary considerably over time depending on environmental factors, and mass can be lost through compaction, bacterial activity, or fire (McGlone and Wilmshurst 1999).

9.3 Future Research

The collection of a core that reached the base of the peat at Maungatapere would enable a more complete understanding of the palaeoecology of the area. Of particular interest would be any evidence of a change in the vegetation suggestive of the Last Glacial period. More extensive radiocarbon dating would demonstrate any variations in the accumulation rate of the peat and may provide supporting evidence for the dates provided in this study. The identification of any further tephra deposits could also be used to confirm the radiocarbon dates.

It is hoped that this study may stimulate greater interest in the Whangarei Volcanic Field. It appears that the volcanoes are of a similar age to those at Penrose, in the Auckland Volcanic Field, and much younger than the dates provided by K-Ar dating. The devastating 2010 and 2011 Christchurch earthquakes and the 2013 earthquakes currently affecting Wellington and Seddon are a reminder of how vulnerable New Zealand is to tectonic activity and how this impacts on human populations. Although there is a low earthquake risk in Northland, the presence of young monogenetic volcanic cones indicates that like Auckland, Whangarei could experience volcanic activity in the future, such as occurred at Paricutin in Mexico in 1943 (Segerstrom 1962). This current study suggests that the time period between any potential volcanic events in the Whangarei Field may be considerably less than previously thought.

To conclude, this was a very interesting study for me, which it is hoped has provided a better understanding of the geological history and palaeoecology of the Whangarei area.

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APPENDICIES

APPENDIX 1

Northland pollen sites with anthropogenic-induced environmental changes;

Lake Taumatawhana

Whangape Harbour

Rangihoua Bay.

Lake Omapere

Wharau Road Swamp

Tauanui Volcanic Centre

McEwan's Bog

Otakairangi (Hikurangi) Swamp

Author	Site	Dating of Anthropogenic-induced Environmental Changes	Tephra Record
Elliot *et al*. 1995.	Lake Taumatawhana - formed in an extensive dune system. Located on the Aupouri Peninsula between Houhora and Te Kao.	There was evidence of human-induced environmental changes at *c.* 900 yr BP (800 cal. yr BP). Evidence consisted of a sharp decline in forest, a sharp rise in abundance of *P. esculentum* spores and charcoal fragments accompanied by sedimentological changes. Radiocarbon dating was performed. The two uppermost sediments of the sequence appeared to have been contaminated by older carbon caused by the agricultural activities of European farmers.	Nil
Horrocks *et al.* 2001.	Whangape Harbour - 2 sites sampled. Sites were located on intertidal flats and approximately 2.5 km. apart.	Results are derived from a series of "snapshots" discontinuous over time. Anthropogenic-induced, widespread deforestation by burning and increased erosion rates occurred either between or after 700 - 430 cal. yr BP. The age was based on the radiocarbon dating of an articulated cockle from Core B. An older date obtained from a similar deposit from Core A was considered unreliable as possibly derived from transported wood or may have had a built-in age.	Nil
Horrocks *et al.* 2007.	Rangihoua Bay, Bay of Islands. Back dune swamps.	High magnitude human impact noted; included deforestation of the catchment and drainage of the wetlands for Polynesian agriculture. Sediments were potentially reworked from surrounding slopes. Accurate dating of human impact was impossible due to errors in the radiocarbon and tephra chronologies. A suggested solution to the dating problem was	Yes, but chronological errors

		to isolate and date the microfossils of any introduced cultivated plants.	
Newnham *et al.* 2004.	Lake Omapere, near Kaikohe. Bay of Islands.	The modern lake was formed about 600 - 700 years ago as indicated by the presence of the Kaharoa Tephra near the top of the core. The formation of the lake may have resulted from damming of an outlet due to accelerated erosion following Polynesian deforestation. This is in accordance with Maori oral tradition.	Two of the fourteen tephra layers were suitable for correlation with records from other NZ sequences. This included the Kaharoa Tephra (AD 1314).
Elliot *et al.* 1997.	Wharau Road Swamp. Bay of Islands	Polynesian deforestation accompanied by soil erosion occurred about 600 yr BP.	Nil
Elliot *et al.* 1998.	Tauanui Volcanic Centre. Bay of Islands.	Anthropogenic forest disturbance was radiocarbon dated to *c.* 1000 yr BP. Evidence included a major decline in tree and shrub pollen accompanied by an increase in pteridophytes particularly *P. esculentum,* and charcoal fragments. The arrival of the Europeans was accompanied by major deforestation and a marked increase in the abundance and diversity of herbs.	Nil
Kershaw & Strickland 1988.	McEwan's Bog, near Whangarei Harbour.	*Agathis* was at maximum abundance between about 3500 and 3000 BP, followed by a sharp decline sometime after 3000 BP. This was accompanied by evidence of burning, but the upper sediment sequence was too condensed or incomplete to determine whether or not this was the result of human activities.	Nil
Newnham 1992.	Otakairangi (Hikurangi) Swamp.	The palynological record predates the arrival of humans to this area. The record for the last 2000 years has been lost, probably as a result of European burning and drainage of the swamp. Radiocarbon dating was	Nil

		problematical as the swamp sediments were potentially prone to “hard water” error” and the swamp may have been subjected to water table movement and flooding. Of interest is the high charcoal content of sediments dated between 21,480 and 7,820 yrs BP. It is suggested that fires may have become more abundant during this period as a result of drier climatic conditions.	

APPENDIX 2

Summary of vegetation and climate changes for the three wetland sites from mid-Northland;

Tauanui Volcanic Centre
McEwan's Bog
Otakairangi (Hikurangi) Swamp

Summary of Three Previous Pollen Studies in Mid-Northland

Site / Author	Dating yr BP	Significant terrestrial palynoflora	Classification	Environmental changes at site	Regional climate
Tauanui Volcanic Centre. Elliot *et al.* 1998.	1000 - present	European influence – major vegation clearance. Herbs increase markedly in diversity & abundance. Polynesian influence – decline in forest trees & shrubs. Increase in pteridophytes & charcoal.	Mixed conifer-broadleaved forest.		
	1600	Increasing forest disturbance.			?Increasing no. of summer droughts, & increasing frequency of cyclonic winds
	3500	Forest disturbance – fluctuation in abundance of many forest species e.g. *A. lucida, A. australis, & D. cupressinum.*			
	4000			Fire at site →erosion of surrounding slopes & some forest destruction.	Climate cooler & drier.
	5,500	*D .cupressinum* dominant. *A. australis* always present.		Formation of lake followed volcanic events at Tauanui Volcanic Centre. Volcanosere initiated.	

<table>
<tr><th>Site / Author</th><th>Dating yr BP</th><th>Significant terrestrial palynoflora</th><th>Classification</th><th>Environmental changes at site</th><th>Regional climate</th></tr>
<tr><td rowspan="5">McEwan's Bog, near Whangarei Harbour.

Kershaw & Strickland 1988.</td><td>After 3000</td><td>The marked decline in A. australis sometime after 3000 yrs BP & increased evidence of burning suggests that kauri trees were destroyed by fire or possibly felled for timber. A. australis is very sensitive to fire.</td><td rowspan="5">Mixed conifer-broadleaved forest until clearance by European settlers.

A substantial A. australis component.

An inverse relationship between % of Dacrydium & Phyllocladus may indicate a successional or competitive link.</td><td></td><td>Wetter and cooler</td></tr>
<tr><td>3000</td><td>A. australis maximum abundance.</td><td></td><td></td></tr>
<tr><td>3500</td><td>A. australis maximum abundance.</td><td></td><td>Drier & cooler around 3600 BP. Effective precipitation rose about 3400 BP, possibly partially due to further reduction in temperature.</td></tr>
<tr><td>4000</td><td>D. cupressinum still dominant, but decreasing in abundance relative to Podocarpus and Nothofagus fusca type.</td><td></td><td></td></tr>
<tr><td>6500</td><td>D. cupressinum dominant.
A. australis was always present at this site.</td><td>Bog formed in a small interdune depression.</td><td>Wetter & warmer before 4000 BP.</td></tr>
</table>

Site / Author	Dating yr BP	Significant terrestrial palynoflora	Classification	Environmental changes at site	Regional climate
Otakairangi (Hikurangi) Swamp. Newnham 1992.	2,200 - 2,400 Ot; 7.	*Empodisma* pollen virtually absent, & *Gleichenia* at lowest level since Zone Ot. 2. Cyperaceae & *Coprosma* pollen common, & *Leptospermum* abundant. Tall podocarp taxa increased & *Dacrydium* was dominant. *Agathis* pollen was consistently present, while *N. fusca* type pollen levels remained relatively low throughout.		Charcoal levels generally low. The expansion of the *Leptospermum/Coprosma/*Cyperaceae swamp communities suggests continued lowering of the swamp water table (? due to higher net evaporation). A drier overall climate is also suggested by changes in dryland taxa, esp. expansion of the more drought-resistant *Agathis australis*, & *Phyllocladus trichomanoides* & the loss of *Ascarina lucida.*	A drier overall climate.
	2,400 – 7,820 Ot; 6.	*Leptospermum* & Cyperaceae increase steadily. Pollen peaks from *Metrosideros* & *Dacrycarpus. Dacrydium* peaks initially, declines with *Metrosideros &* *Dacrycarpus* peaks, & then increases again.	Vegetation reversal – conifer-angiosperm forest now prominent but with some important differences from Ot; 4.	Charcoal falls to low levels. A brief increase in *Dacrydium* pollen early in this zone followed a period of high *Empodisma* & *Gleichenia* levels, & preceded a peak in *Dacrycarpus* pollen. This may reflect vegetation changes in parts of the swamp or swamp margin where drainage was improving. Lateral transitions from infertile, poorly drained restiad peat swamp, through a *Dacrydium cupressinum* belt to better drained *Dacrycarpus dacrydioides*	Milder, moister, less frosty climate than Zone Ot; 5 is suggested by the expansion of *Metrosideros* vines, *Ascarina lucida, &* tree ferns, & the loss of *Lagarostrobos colensoi*.

Otakairangi (Hikurangi) Swamp. Newnham 1992. Cont'd.				swamp forest in modern vegetation has been described in southwestern N.Z.	
	7,820 - 13,600 Ot; 5.	*Empodisma* and *Gleichenia* pollen at highest sustained level, and Poaceae highest in entire sequence. *Leptospermum* pollen low. Tree pollen initially high, then falls. Conversely *Nothofagus fusca* type and *Halocarpus* rise to their highest levels. Only *Lagarostrobos* failed to recover in subsequent zones.	Conifer-angiosperm forest gave way to forest & grassland communities where *Nothofagus, Halocarpus, &* Poaceae & diverse shrub flora important.	Charcoal at highest sustained level. Cyperaceae & *Leptospermum/Kunzea* low moor vegetation was succeeded by restiad peat bog communities; this change may have been facilitated by fire.	
	13,600 - 21,480 Ot ;4.	*Leptospermum* predominant wetland pollen; *Empodisma* and *Gleichenia* still common but decreasing. Tree pollen shows minor changes only from previous.	*Agathis, Phyllocladus,* & *Prumnopitys taxifolia* all expanded; these are deep-rooted trees preferring drier climates, while *Ascarina lucida* and tree ferns which are	Charcoal conspicuous except in middle section. Fire may have promoted expansion of *Leptospermum/Kunzea* populations around swamp margins or on its surface, as these plants are common on swamps following fires. Change in predominant local pollen from *Empodisma* to *Leptospermum* suggests lowering of swamp water table.	Changes in regional dry-land vegetation suggest an overall drier climate.

			more drought-susceptible declined.		
	21,480 – 29,300 Ot; 3.	*Dacrydium* predominant. *Ascarina* and *N. fusca* type appear. Increase in *Empodisma* (characteristic of rain-fed peat swamp) and decrease in *Leptospermum* and Cyperaceae suggestive of fluctuating but rising water tables.	Regional vegetation more diverse.	Swamp develops over much of basin. Low charcoal.	Moister climate.
	>30,000 Ot; 2.	Tree pollen; *Dacrydium* and *Libocedrus* predominant. *Asteraceae* declines rapidly; shrub flora increase.	As previous.	Lake shallowing. Increase in *Dacrydium* and *Libocedrus* may suggest that these trees were expanding onto swampy lake margins.	
Otakairangi (Hikurangi) Swamp. Newnham 1992. Cont'd.	>30,000 Ot;1.	Some tree pollen incl. *Agathis, Dacrydium, Dacrycarpus.* Poaceae and *Nothofagus* infrequent.	Lowland podocarp forest.	Low charcoal. Lake fringed with sedges and wetland shrubs including *Asteraceae.*	Warm temperate.
	N.B. The identification of *N. fusca* pollen tentatively as *N. truncata pollen* was based on aperture counts, ecological and biogeographical considerations. Newnham (1992) reviews dating (e.g. "hard water error" phenomenon) and other anomalies under discussion. Newnham (1992) favours the interpretation that *Nothofagus* forest and shrub-grassland communities were the dominant vegetation in Northland during the Last Glacial Maximum. This is more consistent with pollen evidence for this period from higher latitudes in N.Z. However, a more conclusive judgement awaits further work in the Northland region.				

APPENDIX 3

Species lists for Maungatapere and Rawhitiroa;

- Maungatapere volcanic cone
- Rawhitiroa crater wetland

Species list for Maungatapere Volcanic Cone

Maungatapere Mountain

Map Ref. NZMS 260 Q07/180020

Checklist of Vascular Plants

Compiled by Nigel Clunie & Lisa Forester & Auckland Botanical Society (17/09/11)

* = introduced

+ = added by Auckland Botanical Society

Lycophytes

Huperzia varia ....tassel fern

Ferns & Fern Allies

+*Adiantum diaphanum* ....small maidenhair

Adiantum fulvum... maidenhair fern

+*Adiantum hispidulum* .... rosy maidenhair

Adiantum viridescens .... maidenhair fern

Arthropteris tenella

Asplenium bulbiferum .... hen & chickens fern

Asplenium flaccidum .... hanging spleenwort

Asplenium flaccidum ×A. lamprophyllum

+*Asplenium gracillimum*

Asplenium lamprophyllum

Asplenium oblongifolium ....shiny spleenwort

Asplenium polyodon

Blechnum chambersii

Blechnum discolor ....crown fern

Blechnum filiforme ....thread fern

Blechnum fraseri

Blechnum membranaceum

Blechnum novae-zelandiae ....kiokio

Cardiomanes reniforme.......... kidney fern

Cyathea cunninghamii

Cyathea dealbata .... ponga, silver fern

Cyathea medullaris.......... mamaku

+*Deparia petersenii* subsp. *congrua*

Dicksonia squarrosa .... wheki

+*Diplazium australe*

+*Doodia australis* .... rasp fern

Histiopteris incisa .... matata, water fern

Hymenophyllum demissum .... filmy fern

+*Hymenophyllum dilatatum*.......... filmy fern

Hymenophyllum flabellatum .... filmy fern

+*Hymenophyllum flexuosum*.......... frilly knickers

Hymenophyllum rarum .... filmy fern

Hymenophyllum revolutum.......... filmy fern

Hymenophyllum sanguinolentum .... filmy fern

Hymenophyllum scabrum .... hairy filmy fern

Lastreopsis glabella

Lastreopsis hispida .... old hairy legs

Loxogramme dictyopteris

Lygodium articulatum .... mangemange

Microsorum pustulatum.......... hound's tongue fern

Microsorum scandens .... fragrant fern

Pneumatopteris pennigera.......... gully fern

Pteridium esculentum .... bracken

Pteris macilenta

Pteris tremula .... shaking brake

Pyrrosia eleagnifolia .... leather fern

Rumohra adiantiformis

Tmesipteris elongata .... chain fern

Tmesipteris lanceolata .... chain fern

+*Tmesipteris sigmatifolia* .... chain fern

+*Tmesipteris tannensis* .... chain fern

Trichomanes elongatum .... bristle fern

Trichomanes venosum

Gymnosperms

Dacrycarpus dacrydioides .... kahikatea

Dacrydium cupressinum .... rimu

+*Phyllocladus trichomanoides* .... tanekaha

Podocarpus hallii .... Hall’s totara

Podocarpus totara .... totara

Prumnopitys ferruginea .... miro

Dicotyledons

Ackama rosifolia .... makamaka

*Ageratina adenophora** .... Mexican devil

Alectryon excelsus .... titoki

Alseuosmia macrophylla

Aristotelia serrata .... wineberry

Beilschmiedia tarairi .... taraire

Beilschmiedia tawa .... tawa

Brachyglottis repanda .... rangiora

Centella uniflora

+*Cestrum nocturnum** .... queen-of-the-night

*Cirsium vulgare** .... Scotch thistle

Clematis cunninghamii .... yellow-flowered clematis

+*Clematis paniculata* .... clematis

*Conyza sumatrensis** .... broad-leaved fleabane

Coprosma arborea .... mamangi

+*Coprosma areolata*

Coprosma grandifolia .... kanono

+*Coprosma lucida* .... shiny karamu

Coprosma propinqua × *C. robusta*

Coprosma rhamnoides

Coprosma robusta .... karamu

Coprosma spathulata

Coprosma tenuicaulis .... swamp coprosma

Corynocarpus laevigatus .... karaka

+*Cyphomandra betacea** .... tamarillo

+*Dichondra repens* .... Mercury Bay weed

Dysoxylum spectabile .... kohekohe

Elaeocarpus dentatus .... hinau

Fuchsia excorticata .... kotukutuku

Geniostoma ligustrifolium .... hangehange

+*Geranium homeanum*?

*Geranium molle**

Griselinia lucida

Haloragis erecta

Hedycarya arborea .... pigeonwood

Hoheria populnea .... lacebark

*Hypochoeris radicata** ....catsear

Knightia excelsa... rewarewa

Laurelia novae-zelandiae .... pukatea

Leptospermum scoparium.. manuka

Leucopogon fasciculatus .... mingimingi

*Leycesteria formosa** .... Himalayan honeysuckle

Litsea calicaris .... mangeao

Lobelia anceps

Lophomyrtus bullata ....ramarama

*Lotus pedunculatus**

Macropiper excelsum .... kawakawa

Melicytus macrophyllus.. large-leaved mahoe

Melicytus ramiflorus.. mahoe

Metrosideros carminea ....carmine rata

+*Metrosideros diffusa* .... white rata vine

Metrosideros fulgens...red rata vine

Metrosideros perforata .... white rata vine

Myrsine australis .... mapou

Nertera dichondrifolia

Olearia rani.. heketara

+*Pittosporum cornifolium*

*Plantago lanceolata** ....narrow-leaved plantain

*Prunella vulgaris** ....selfheal

+*Prunus campanulata** ....Taiwan cherry

+*Pseudopanax arboreus*... five finger

Pseudopanax crassifolius ....lancewood

*Ranunculus repens** .... buttercup

Raukaua edgerleyi .... raukawa

Rubus cissoides .... bush lawyer

Rubus fruticosus agg. * .... blackberry

Schefflera digitata .... pate

*Senecio bipinnatisectus** .... Australian fireweed

Senecio hispidulus .... fireweed

+*Senecio petasitis** .... velvet groundsel

Solanum aviculare .... poroporo

Streblus heterophyllus .... small-leaved milk tree

Syzygium maire .... maire tawake

*Veronica arvensis** .... field speedwell

*Vicia sativa** .... vetch

Vitex lucens .... puriri

Wahlenbergia violacea .... NZ harebell

Weinmannia silvicola .... towai

Monocotyledons

Acianthus sinclairii .... pixie cap orchid

*Anthoxanthum odoratum** .... sweet vernal

*Asparagus scandens** .... climbing asparagus

Astelia solandri

Bromus sp.*

*Bromus wildenowii** .... prairie grass

Collospermum hastatum

Cordyline australis .... cabbage tree

Cordyline banksii .... bush cabbage tree

*Cortaderia selloana** .... pampas grass

Corybas cheesemanii..helmet orchid

Dianella nigra

+*Drymoanthus adversus*.. a perching orchid

Earina autumnalis .... Easter orchid

Earina mucronata.. spring orchid

Freycinetia banksii.. kiekie

Gahnia lacera .... cutty grass

*Holcus lanatus** .... Yorkshire fog

Ichthyostomum pygmaeum .... pygmy orchid

Juncus sp. .... rush

Microlaena avenacea .... bush rice grass

+*Microlaena stipoides* .... meadow rice grass

Microtis unifolia .... onion orchid

Nematoceras trilobum .... spider orchid

Oplismenus hirtellus subsp*. imbecillis*... panic grass

Pterostylis banksii1

.... tutukiwi, greenhood orchid

Rhopalostylis sapida..nikau

Ripogonum scandens .... supplejack

*Schedonorus phoenix** .... tall fescue

Singularybas oblongus .... spider orchid

+*Tradescantia fluminensis**.. wandering Jew

Uncinia uncinata .... hook grass

+*Winika cunninghamii*...bamboo orchid

This Maungatapere species list is from “Whangarei Weekend, 17-18 September 2011”, in the *Auckland Botanical Society Journal Vol. 66(2).* Permission to include it in this thesis was granted by Maureen Young.

Species List for Rawhitiroa

Wetland in Rawhitiroa Crater

Growth Form	Taxon Name	Common name	Native	Exotic	Family
Moss					
	Sphagnum perichaetiale	Moss	Y		Sphagnaceae
Ferns					
	Histiopteris incisa	Water fern	Y		Dennstaedtiaceae
	Blechnum novae-zelandiae	Kiokio, palm leaf fern	Y		Blechnaceae
	Dicksonia squarrosa	Wheki Rough tree fern	Y		Dicksoniaceae
Dicotyledonous shrubs					
	Leptospermum scoparium	Manuka	Y		Myrtaceae
Herbs					
	Hydrocotyle ? *pterocarpa .*		Y		Araliaceae
	Phormium tenax	Flax	Y		Xanthorrhoeaceae
	Myriophyllum propinquum	Common water milfoil	Y		Haloragaceae
	Ranunculus flammula	Spearwort		Y	Ranunculaceae
	Ludwigia palustris	Water purslane		Y	Onagraceae
	Lotus pedunculatus	Lotus		Y	Fabaceae
	Hypochaeris radicata	Catsear		Y	Asteraceae
	Bidens frondosa	Beggars ticks		Y	Asteraceae
	Persicaria strigosa			Y	Polygonaceae
	Persicaria hydropiper	Water pepper		Y	Polygonaceae
	Persicaria decipiens		Y		Polygonaceae
Rushes					
	Juncus edgariae	Wiwi	Y		Juncaceae
	Juncus articulatus	Jointed rush		Y	Juncaceae
	Juncus effusus	Soft rush		Y	Juncaceae
Sedges					
	Eleocharis sphacelata	Bamboo spike sedge	Y		Cyperaceae
	Eleocharis acuta	Sharp spike sedge	Y		Cyperaceae
	Machaerina teretifolia	Common twig rush	Y		Cyperaceae
	Isolepis prolifer		Y		Cyperaceae
	Carex longibrachiata	Australian sedge		Y	Cyperaceae
	Machaerina rubiginosa	Baumea	Y		Cyperaceae

Grasses				
	Holcus lanatus	Yorkshire fog	Y	Poaceae

Tall trees and Shrubs on Crater Wall

Growth Form	Taxon Name	Common name	Native	Exotic	Family
Gymnosperm trees					
	Dacrycarpus dacrydioides	Kahikatea	Y		Podocarpaceae
	Podocarpus totara	Totara	Y		Podocarpaceae
	Dacrydium cupressinum	Rimu	Y		Podocarpaceae
	Agathis australis	Kauri	Y		Araucariaceae (in garden)
	Pinus radiata	Radiata pine		Y	Pinaceae (plantation)
Dicotyledonous trees					
	Beilschmiedia tarari	Taraire	Y		Lauraceae
	Sophora sp.	Kowhai	Y		Fabaceae
	Corynocarpus laevigatus	Karaka	Y		Corynocarpaceae
Monocotyledonous shrubs					
	Cordyline sp.	Cabbage tree	Y		Laxmanniaceae

The crater walls have been developed for agriculture and are in pasture. There are also a number of exotic species present which are not listed above; these form shelter belts or are growing around the owner's house which is situated on the crater rim.

The identification of plants which appear in the species list for Rawhitiroa was performed by Mrs. L. Forester, Biodiversity Specialist, Northland Regional Council.

APPENDIX 4

Detailed descriptions of the Maungatapere (3MT) and Rawhitiroa cores;

Maungatapere (3MT

Rawhitiroa

Maungatapere 3MT Core																								
		Physical features							Components (Total=4)															Comments
Upper boundary (cm)	Lower boundary (cm)	0-4				Colour Maunsell	Structure	Upper boundary	Mosses	Woody Plants	Herbs	Herb Detritus	Fine Detritus	Charcoal	Organic Lake Mud	Humus	Organosilicates	Carbonates	Iron Oxides	Clay	Silt	Sand	Gravel	
		Darkness	Stratification	Elasticity	Dryness																			
0	40	3	0	3	2	10YR 2/2 Very dark brown	Slightly fibrous	NA		1						3								Mainly decompos-ed. Occ. roots ≤ 5 mm diameter.
40	107	3	0	4	2	10YR 2/2 Very dark brown	Fibrous	1		2						1								Many roots ≤ 5 mm diameter. Not very decompos-ed.

107	127	3	0	4	2	10YR 2/1 Black	Less fibrous	1		2						2								Roots ≤ 5 mm diameter.
127	150	3	0	4	2	10YR 2/2 Very dark brown	Slightly fibrous	1		1						3								A few fine roots. Mostly decompos-ed.
150	154	3	0	4	2	10YR 3/1 Very dark grey	Fibrous	1		2						2								Fine roots.
154	158	2	0	4	3	10YR 3/2 Very dark greyish brown	Slightly fibrous	2		3						1								Mixture of crumbly rotting wood and peat.
158	179	2	0	0	3	10YR 4/4 Dark yellow brown	Fibrous			4														Rotting wood.
179	195	2/3	0	0/4	3	10 YR 3/2 Very dark greyish brown + 10YR3/2 Dark yellow brown	Fibrous	1		3						1								Mixed – lumps of rotting wood (≤ 15 x 5 mm) & peat containing fine roots.

195	210	3	0	4	2	10YR 2/2 Very dark brown	Slightly fibrous	1		2						2								Fairly decompos-ed. A few fine roots.
210	235	3	0	4	2	10YR 2/2 Very dark brown	Very slightly fibrous	2		1						3								Very decompos-ed. *Occ.* fine roots.
235	314	4	0	4	2	10YR 2/1 Black	Fibrous	2		2						2								Fine roots & woody fragments. Largest root 4 mm in diameter.
314	485	4	0	4	2	10YR 2/1 Black	Slightly fibrous	1		1						3								Fine roots. Very decompos-ed.

485	4096	4	0	4	2	10YR 3/1 Very dark grey	Fibrous	2		2						2								Many roots – fragments ≤ 7mm long. Specimen from base taken for radiocar-bon dating.

Rawhitiroa Core																								
		Physical features							Components (Total=4)															Comments
Upper boundary (cm)	Lower boundary (cm)	0-4				Colour Maunsell	Structure	Upper boundary	Mosses	Woody Plants	Herbs	Herb Detritus	Fine Detritus	Charcoal	Organic Lake Mud	Humus	Organosilicates	Carbonates	Iron Oxides	Clay	Silt	Sand	Gravel	
		Darkness	Stratification	Elasticity	Dryness																			
0	37	3	0	4	2	10YR 2/1 Black	Slightly fibrous	NA	1			+				3								A few glass shards at 30 cm.
37	44	3	0	4	2	10YR 2/1 Black	All plant remains	3			3					1								Mostly reeds & other herbs. Glass shards prominent at 40 cm.

44	345	3	0	4	2	10YR 2/1 Black	Slightly fibrous	3				1				3								Some glass shards at 50 cm.
345	366	3	0	4	2	10YR 2/1 Black	Slightly fibrous	1				+				3				1				Wood at 341 cm. Specimen from peat base taken for radiocar-bon dating.
366	373	2	0	0	2	10YR 4/2 Dark greyish brown	Clay	3				+								4				Gradual colour change.
373	381	2	0	0	2	5YR 4/3 Reddish brown	Clay	1												4				Gradual colour change.
381	401	2	0	0	2	5YR 4/6 Yellowish red	Clay	1												4				

APPENDIX 5

Radiocarbon dating reports;

- Maungapatere 3MT Core
  - Radiocarbon dates
  - Calibrated dates
- Rawhitiroa Core
  - Radiocarbon dates
  - Calibrated dates

Maungatapere 3MT Core

The University of Waikato
Radiocarbon Dating Laboratory

Private Bag 3105
Hamilton,
New Zealand.
Fax +64 7 838 4192
Ph +64 7 838 4278
email c14@waikato.ac.nz
Head: Dr Alan Hogg

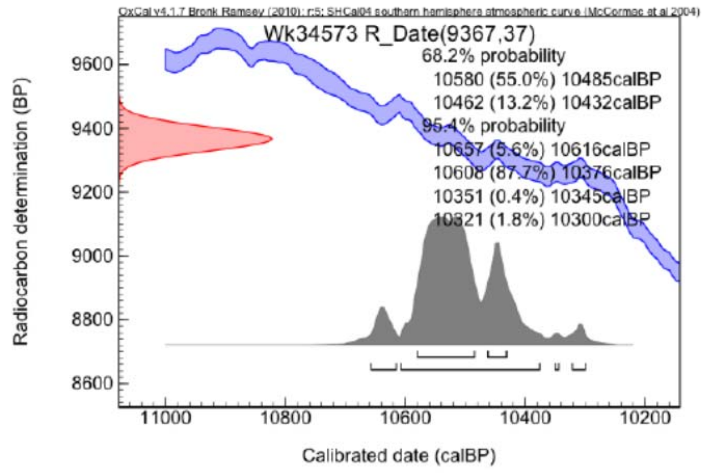
Report on Radiocarbon Age Determination for Wk- 34573

Submitter	V. E. Neall
Submitter's Code	Q07/f0154
Site & Location	Maungatapere Crater, Northland, New Zealand
Sample Material	Peat Dried
Physical Pretreatment	Visible contaminants removed.
Chemical Pretreatment	Sample washed in hot HCl, rinsed and treated with multiple hot NaOH washes. The NaOH insoluble fraction was treated with hot HCl, filtered, rinsed and dried.

$\delta^{13}C$	-28.0 ±	0.2 ‰
$D^{14}C$	-688.4 ±	1.4 ‰
$F^{14}C\%$	31.2 ±	0.1 %
Result	**9367 ± 37 BP**	

(AMS measurement)

Comments



11/09/12

- Result is *Conventional Age or Percent Modern Carbon (pMC)* following Stuiver and Polach, 1977, Radiocarbon 19, 355-363. This is based on the Libby half-life of 5568 yr with correction for isotopic fractionation applied. This age is normally quoted in publications and must include the appropriate error term and Wk number.
- Quoted errors are 1 standard deviation due to counting statistics multiplied by an experimentally determined Laboratory Error Multiplier.
- The isotopic fractionation, $\delta^{13}C$, is expressed as ‰ wrt PDB.
- $F^{14}C\%$ is also known as *Percent Modern Carbon (pMC)*.

Radiocarbon Dating Report for the Base of the Maungatapere Core (3MT)

Radiocarbon Calibration Dating Report for the Base of the Core from Maungatapere (3MT)

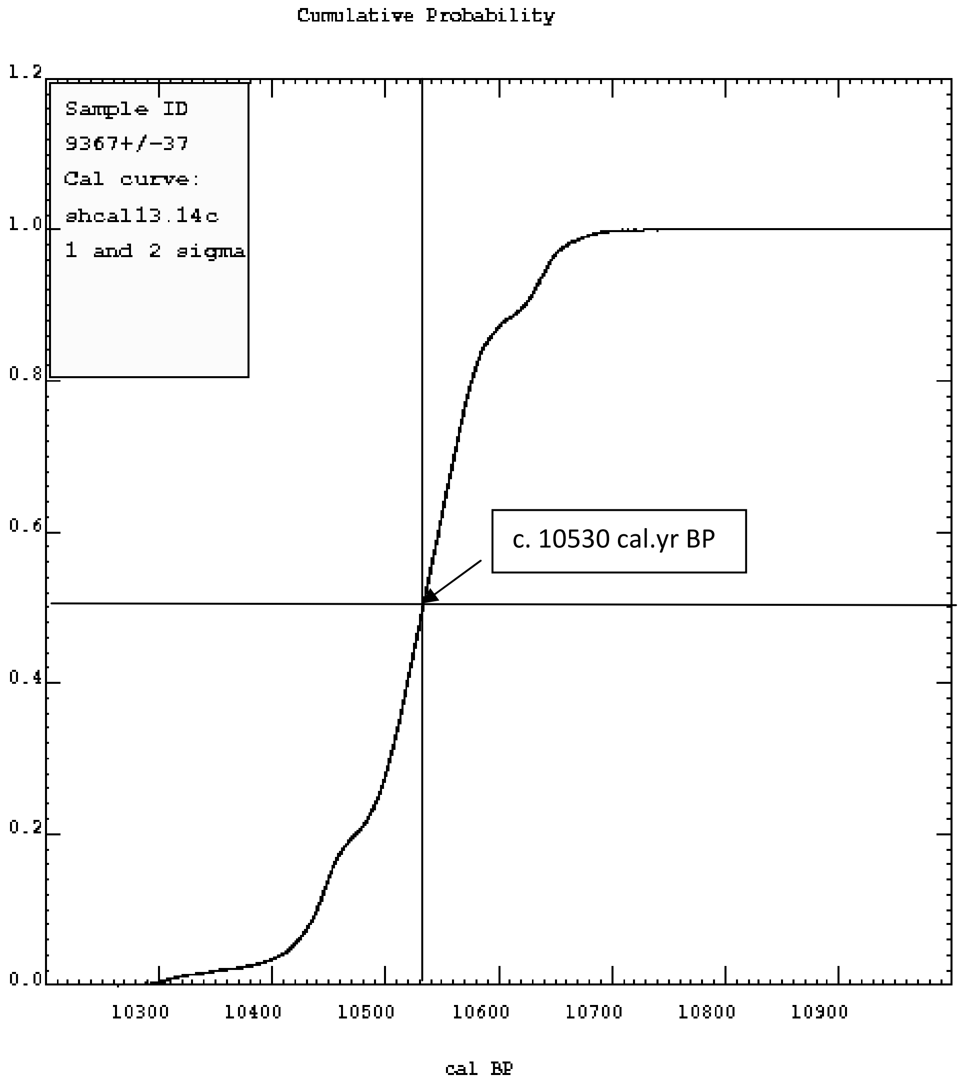
```
       RADIOCARBON CALIBRATION PROGRAM*
                                CALIB REV7.0.0
                  Copyright 1986-2013 M Stuiver and PJ Reimer
          *To be used in conjunction with:
          Stuiver, M., and Reimer, P.J., 1993, Radiocarbon, 35, 215-
230.
                    Annotated results (text) - -
                    Export file - c14res.csv
```

```
 Sample ID
 Lab Code
 Sample Description (80 chars max)
 Radiocarbon Age BP   9367 +/-   37
 Calibration data set: shcal13.14c                 # Hogg et al. 2013
   % area enclosed       cal BP age ranges             relative area
under
                                                   probability
distribution
   68.3 (1 sigma)     cal BP 10437 - 10457                 0.105
                             10489 - 10587                 0.895
   95.4 (2 sigma)     cal BP 10401 - 10673                 1.000
```

```
  References for calibration datasets:
 Alan G Hogg, Quan Hua, Paul G Blackwell, Caitlin E Buck, Thomas P
Guilderson
 Timothy J  Heaton, Mu Niu, Jonathan G Palmer, Paula J Reimer, Ron W
Reimer,
 Christian S M Turney, Susan R H Zimmerman
 Radiocarbon 55(4). DOI: 10.2458/azu_js_rc.55.16783
```

```
 Comments:
 * This standard deviation (error) includes a lab error multiplier.
 ** 1 sigma = square root of (sample std. dev.^2 + curve std. dev.^2)
 ** 2 sigma = 2 x square root of (sample std. dev.^2 + curve std.
dev.^2)
 where ^2 = quantity squared.
 [ ] = calibrated range impinges on end of calibration data set
 0* = cannot calibrate due to nuclear testing C-14.
 1955* or 1960* denote influence of nuclear testing C-14
```

```
 NOTE:  Cal ages and ranges are rounded to the nearest year which
        may be too precise in many instances.  Users are advised to
        round results to the nearest 10 yr for samples with standard
        deviation in the radiocarbon age greater than 50 yr.
```



Radiocarbon Calibrated Dates for the Base of the Maungatapere Core (3MT)

Rawhitiroa Core

The University of Waikato
Radiocarbon Dating Laboratory

Private Bag 3105
Hamilton,
New Zealand.
Fax +64 7 838 4192
Ph +64 7 838 4278
email c14@waikato.ac.nz
Head: Dr Alan Hogg

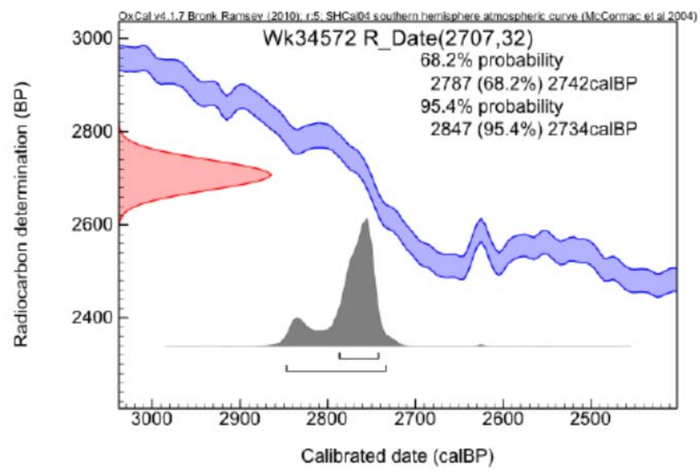
Report on Radiocarbon Age Determination for Wk- 34572

Submitter	V. E. Neall
Submitter's Code	Q06/f0093
Site & Location	Rawhitiroa Crater, Northland, New Zealand
Sample Material	Peat Plant macrofossils
Physical Pretreatment	Visible contaminants removed.
Chemical Pretreatment	Sample washed in hot HCl, rinsed and treated with multiple hot NaOH washes. The NaOH insoluble fraction was treated with hot HCl, filtered, rinsed and dried.

$\delta^{13}C$	-26.7 ±	0.2 ‰
$D^{14}C$	-286.1 ±	2.8 ‰
$F^{14}C\%$	71.4 ±	0.3 %
Result	**2707 ± 32 BP**	

(AMS measurement)

Comments



11/09/12

- Result is *Conventional Age or Percent Modern Carbon (pMC)* following Stuiver and Polach, 1977, Radiocarbon 19, 355-363. This is based on the Libby half-life of 5568 yr with correction for isotopic fractionation applied. This age is normally quoted in publications and must include the appropriate error term and Wk number.
- Quoted errors are 1 standard deviation due to counting statistics multiplied by an experimentally determined Laboratory Error Multiplier.
- The isotopic fractionation, $\delta^{13}C$, is expressed as ‰ wrt PDB.
- $F^{14}C\%$ is also known as *Percent Modern Carbon (pMC)*

Radiocarbon Dating Report for the Base of the Rawhitiroa Peat

Radiocarbon Dating Calibration Report for the Base of the Peat at Rawhitiroa

```
RADIOCARBON CALIBRATION PROGRAM*
                                 CALIB REV7.0.0
                  Copyright 1986-2013 M Stuiver and PJ Reimer
          *To be used in conjunction with:
          Stuiver, M., and Reimer, P.J., 1993, Radiocarbon, 35, 215-
230.
                    Annotated results (text) - -
                    Export file - c14res.csv
```

```
 Sample ID
 Lab Code
 Sample Description (80 chars max)
 Radiocarbon Age BP   2707 +/-   32
 Calibration data set: shcal13.14c                # Hogg et al. 2013
   % area enclosed       cal BP age ranges            relative area
under
                                                  probability
distribution
   68.3 (1 sigma)     cal BP 2747 - 2792                  0.950
                             2832 - 2837                  0.050
   95.4 (2 sigma)     cal BP 2743 - 2848                  1.000
```

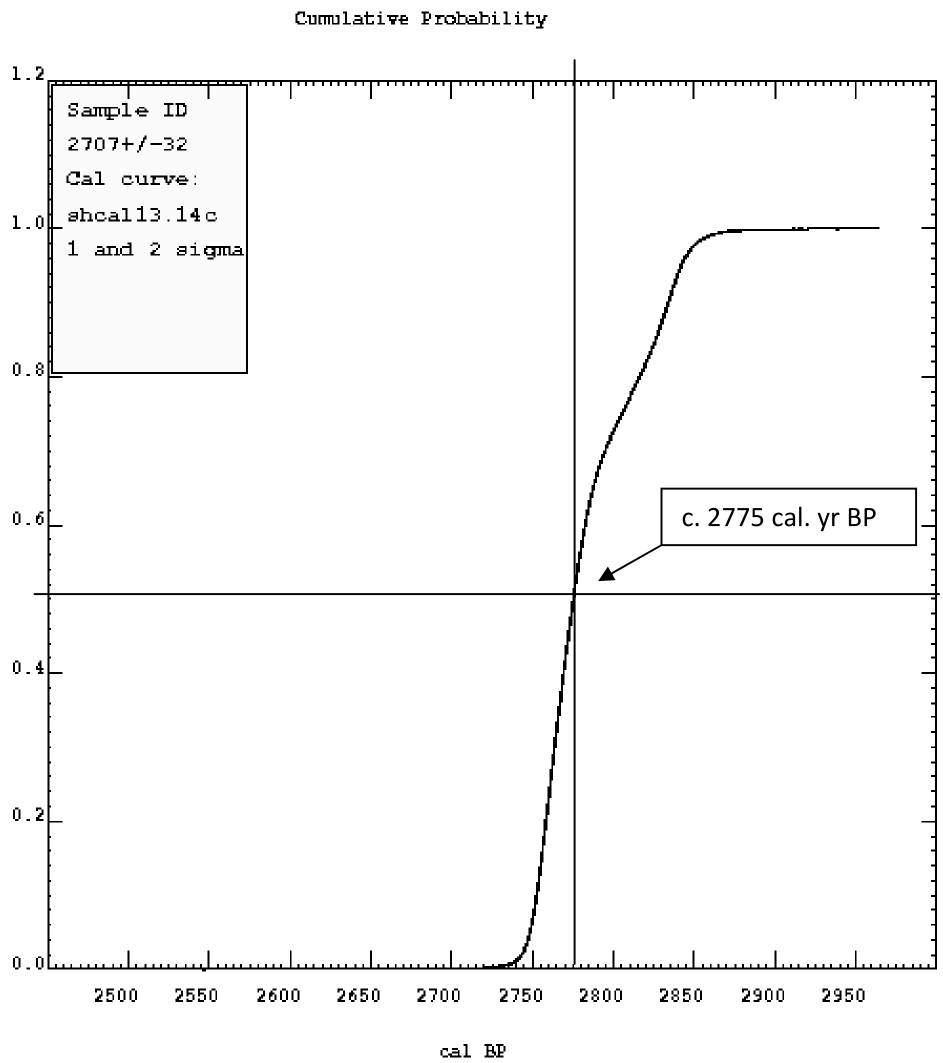
```
 Sample ID
 Lab Code
 Sample Description (80 chars max)
 Radiocarbon Age BP   2707 +/-   32
 Calibration data set: shcal13.14c                # Hogg et al. 2013
   % area enclosed       cal BP age ranges            relative area
under
                                                  probability
distribution
   68.3 (1 sigma)     cal BP 2747 - 2792                  0.950
                             2832 - 2837                  0.050
   95.4 (2 sigma)     cal BP 2743 - 2848                  1.000
```

References for calibration datasets:
Alan G Hogg, Quan Hua, Paul G Blackwell, Caitlin E Buck, Thomas P Guilderson
Timothy J Heaton, Mu Niu, Jonathan G Palmer, Paula J Reimer, Ron W Reimer,
Christian S M Turney, Susan R H Zimmerman
Radiocarbon 55(4). DOI: 10.2458/azu_js_rc.55.16783

Comments:
* This standard deviation (error) includes a lab error multiplier.
** 1 sigma = square root of (sample std. dev.^2 + curve std. dev.^2)

** 2 sigma = 2 x square root of (sample std. dev.^2 + curve std. dev.^2)
where ^2 = quantity squared.
[ ] = calibrated range impinges on end of calibration data set
0* = cannot calibrate due to nuclear testing C-14.
1955* or 1960* denote influence of nuclear testing C-14

NOTE: Cal ages and ranges are rounded to the nearest year which may be too precise in many instances. Users are advised to round results to the nearest 10 yr for samples with standard deviation in the radiocarbon age greater than 50 yr.



Radiocarbon Calibrated Dates for the Base of the Rawhitiroa Peat

APPENDIX 6

Original-counts data for the species, reference *Lycopodium* and charcoal fragments from Maungatapere and Rawhitiroa wetlands

Maungapatere 3MT core

Rawhitiroa core

Original-counts data for the numbers of pollen grains, spores, and charcoal fragments from the wetland in the Maungatapere crater

Depth	0	10	20	30	40	50	60	70	80
Nothofagus fusca type	0	0	1	0	1	1	2	0	1
Agathis australis	0	0	3	3	1	2	1	3	6
Dacrycarpus dacrydioides	57	11	19	3	0	0	3	0	2
Dacrydium cupressinum	0	5	135	156	116	129	124	97	140
Libocedrus	0	0	0	0	0	0	0	0	0
Halocarpus	0	0	0	0	0	0	0	0	0
Halocarpus biformis	0	0	0	0	0	0	0	0	0
Phyllocladus	0	1	2	1	0	0	3	2	2
Pinus	40	0	0	0	0	0	0	0	0
Podocarpus type	40	14	13	10	15	11	15	16	36
Prumnopitys ferruginea	5	9	1	0	0	1	0	1	1
Prumnopitys taxifolia	0	2	8	0	1	2	0	7	5
Prumnopitys/Podocarpus g	17	7	3	2	4	4	6	8	3
Total conifers	159	49	185	175	138	150	154	134	196
Alectryon excelcus	0	0	0	0	0	0	0	0	0
Dysoxylum spectabile	0	0	1	1	0	0	2	0	0
Griselinia	0	0	0	0	0	0	0	0	0
Knightia excelsa	0	8	1	1	1	0	1	0	0
Laurelia novae-zelandiae	0	0	0	0	0	0	0	0	0
Metrosideros	2	2	1	3	0	1	0	0	1
Syzygium marie	2	0	0	0	0	0	0	0	0
Weinmannia	0	0	1	0	0	0	0	0	0
Total angiosperm trees	4	10	4	5	1	1	3	0	1
Alepis flavida	0	0	0	0	0	1	0	0	0
Araliaceae	0	0	0	0	0	0	0	0	0
Ascarina	0	0	0	0	4	4	7	3	6
Asteraceae	6	1	5	1	0	1	0	0	0

Depth	0	10	20	30	40	50	60	70	80
Comprosma	3	37	14	7	0	2	6	1	0
Dodonaea viscosa	0	0	1	1	0	0	0	0	0
Epacridaceae	1	2	0	2	0	0	0	0	0
Ericaceae	0	0	0	0	0	0	0	1	0
Fushia	0	12	2	0	0	0	0	0	0
Gentianaceae	0	0	0	0	0	0	0	0	0
Hebe	0	5	4	4	1	1	1	0	0
Leptospermum type	0	0	0	0	1	0	1	0	1
Liliaceae	0	0	0	0	0	0	0	0	0
Malvaceae gp	3	2	3	1	0	0	2	0	0
Muehlenbeckia	0	0	3	0	0	0	0	0	0
Palm	1	3	2	0	0	0	0	0	1
Pseudopanax	1	1	3	3	3	6	3	0	1
Pseudowintera	0	0	0	1	1	0	1	0	1
Scrophulariaceae	0	0	2	0	0	0	0	0	0
Total shrubs	15	73	59	50	50	65	81	75	271
Unknown	0	8	0	0	0	0	0	0	0
Chenopodiaceae	0	4	0	0	0	0	2	0	0
Plantago	0	0	0	0	0	0	0	0	0
Phormium	0	1	0	0	0	0	0	0	0
Poaceae	3	16	1	0	0	0	1	0	0
Total herbs	3	21	1	0	0	0	3	0	0
Cyathea dealbata	7	90	7	28	46	47	32	72	137
Cyathea smithii	1	6	0	6	10	10	13	28	9
Dicksonia squarrosa	22	87	26	4	1	0	1	2	1
Gleichenia	0	0	0	0	0	0	0	0	0
Histiopteris	0	6	17	13	0	0	0	0	0
Lycopodium unspecified	0	1	0	1	0	0	0	0	0

	Depth								
	0	10	20	30	40	50	60	70	80
L:ycopodium varium	0	0	3	1	0	0	1	0	0
Monolete spores	4	37	65	32	21	21	9	8	30
Phymatosorus	15	14	27	128	6	20	4	1	1
Pteridium esculentum	0	1	13	1	0	3	1	1	2
Trilete unspec	1	6	8	7	3	3	6	4	2
Ferns & fern allies	50	248	166	221	87	104	67	116	182
Cyperaceae	9	1	2	2	2	1	3	18	5
Drosera auriculata	0	0	0	0	0	0	0	5	0
Haloragis	0	0	0	0	0	0	0	0	1
Myriophyllum	0	2	1	0	0	2	0	0	0
Restionaceae	0	0	1	1	0	0	2	0	1
Wetland species	9	3	4	3	2	3	5	23	7
Spores unidentified	0	0	0	0	0	0	0	0	1
Lycopodium marker	29	58	55	63	38	64	53	34	51
Charcoal									
<20	0	1	0	0	1	0	0	1	0
20-50	0	2	0	0	3	1	1	1	0
>50	3	8	8	2	5	0	4	0	0

								Log	Interval	
Depth	90	100	110	120	130	140	150	160	170	180
Nothofagus fusca type	1	2	1	1	4	3	2			0
Agathis australis	3	1	3	2	7	3	2			2
Dacrycarpus dacrydioides	1	3	2	3	2	1	0			1
Dacrydium cupressinum	112	88	90	79	120	84	58			97
Libocedrus	0	0	3	0	0	0	0			0
Halocarpus	0	0	0	0	0	0	0			0
Halocarpus biformis	0	0	0	0	0	0	0			0
Phyllocladus	3	1	10	2	6	5	0			1
Pinus	0	0	0	0	0	0	0			0
Podocarpus type	28	14	14	41	50	8	15			15
Prumnopitys ferruginea	5	0	1	0	1	1	0			1
Prumnopitys taxifolia	3	2	6	8	4	0	6			1
Prumnopitys/Podocarpus g	6	1	4	8	4	5	4			2
Total conifers	162	112	134	144	198	110	87			120
Alectryon excelcus	0	0	0	0	0	0	0			0
Dysoxylum spectabile	1	0	0	5	2	2	3			0
Griselinia	0	0	0	0	0	0	0			0
Knightia excelsa	0	0	0	0	0	1	0			1
Laurelia novae-zelandiae	0	0	0	0	0	0	0			0
Metrosideros	0	1	1	0	1	1	0			0
Syzygium marie	0	0	0	0	0	0	0			0
Weinmannia	0	0	0	0	0	0	0			0
Total angiosperm trees	1	1	1	5	3	4	3			1
Alepis flavida	0	0	0	0	0	0	0			0
Araliaceae	0	0	0	0	0	0	0			0
Ascarina	9	0	8	9	4	7	7			0
Asteraceae	0	0	0	0	1	1	0			0

											184
									Log	Interval	
	Depth	90	100	110	120	130	140	150	160	170	180
Comprosma		0	4	2	0	1	5	2			1
Dodonaea viscosa		0	0	0	0	0	0	1			0
Epacridaceae		0	0	0	0	0	0	0			0
Ericaceae		0	0	0	0	0	0	0			0
Fushia		0	0	0	0	0	0	0			0
Gentianaceae		0	0	0	0	0	0	0			0
Hebe		0	0	0	0	0	0	0			0
Leptospermum type		0	0	0	0	0	0	0			0
Liliaceae		0	0	0	0	0	0	0			0
Malvaceae gp		0	0	0	0	0	0	1			0
Muehlenbeckia		0	0	0	0	0	0	0			0
Palm		0	0	1	0	0	0	0			0
Pseudopanax		2	1	2	3	2	1	0			1
Pseudowintera		2	3	1	0	1	0	0			1
Scrophulariaceae		0	0	0	0	0	0	0			0
Total shrubs		103	108	124	132	139	154	161			367
Unknown		0	0	0	0	0	0	0			0
Chenopodiaceae		0	0	0	0	0	0	0			0
Plantago		0	0	0	0	0	0	0			0
Phormium		0	0	0	0	0	0	0			0
Poaceae		0	0	0	0	0	0	0			0
Total herbs		0	0	0	0	0	0	0			0
Cyathea dealbata		52	77	74	51	60	78	94			81
Cyathea smithii		12	2	4	4	2	8	8			6
Dicksonia squarrosa		0	0	0	0	0	0	0			3
Gleichenia		0	0	0	0	0	0	0			0
Histiopteris		0	0	3	0	0	0	0			0
Lycopodium unspecified		0	0	0	0	0	0	0			0

										185
								Log	Interval	
Depth	90	100	110	120	130	140	150	160	170	180
L:ycopodium varium	0	0	0	0	0	0	0			1
Monolete spores	12	24	26	14	6	9	42			58
Phymatosorus	2	1	3	1	2	2	2			8
Pteridium esculentum	1	0	0	0	0	0	0			0
Trilete unspec	1	2	0	0	4	3	2			3
Ferns & fern allies	80	106	110	70	74	100	148			160
Cyperaceae	29	2	3	4	4	3	6			2
Drosera auriculata	1	0	0	0	0	0	0			0
Haloragis	0	0	0	0	0	0	14			1
Myriophyllum	0	0	0	0	0	0	3			3
Restionaceae	4	0	2	0	1	1	1			1
Wetland species	34	2	5	4	5	4	24			7
Spores unidentified	0	1	1	0	0	0	4			0
Lycopodium marker	71	61	163	55	93	70	384			31
Charcoal										
<20	0	0	0	0	0	0	1			0
20-50	0	1	0	0	0	0	0			0
>50	1	6	2	0	0	0	4			5

Depth	190	200	210	220	230	240	250	260	270	280	290
Nothofagus fusca type	1	2	0	2	0	0	2	0	1	2	4
Agathis australis	2	1	0	2	3	1	0	2	0	2	2
Dacrycarpus dacrydioides	1	3	0	9	2	0	1	3	2	2	1
Dacrydium cupressinum	83	77	79	170	76	73	86	86	79	61	57
Libocedrus	0	0	0	0	0	0	0	0	0	0	0
Halocarpus	0	0	0	0	0	0	0	0	0	0	0
Halocarpus biformis	0	0	0	0	0	0	0	0	0	0	0
Phyllocladus	0	2	1	1	3	2	4	0	0	4	4
Pinus	0	0	0	0	0	0	0	0	0	0	0
Podocarpus type	17	17	7	7	18	11	4	14	17	14	4
Prumnopitys ferruginea	0	0	0	1	2	0	0	0	0	0	0
Prumnopitys taxifolia	0	2	0	2	1	8	1	0	2	0	5
Prumnopitys/Podocarpus g	4	3	1	2	2	3	3	2	6	2	3
Total conifers	108	107	88	196	107	98	101	107	107	87	80
Alectryon excelcus	0	0	0	0	0	0	0	0	0	0	0
Dysoxylum spectabile	0	1	1	1	1	0	1	0	0	1	0
Griselinia	0	0	0	0	0	0	0	0	0	0	0
Knightia excelsa	0	0	1	0	0	0	0	0	0	2	0
Laurelia novae-zelandiae	0	0	0	0	0	0	0	0	0	0	1
Metrosideros	0	0	0	0	0	0	3	0	0	0	0
Syzygium marie	0	0	0	0	0	0	0	0	0	0	0
Weinmannia	0	0	0	0	0	0	0	0	0	0	0
Total angiosperm trees	0	1	2	1	1	0	4	0	0	3	1
Alepis flavida	0	0	0	0	0	0	0	0	0	0	0
Araliaceae	0	1	0	0	0	0	0	0	0	0	0
Ascarina	1	4	2	4	5	2	9	0	4	4	19
Asteraceae	0	0	0	0	0	0	0	0	0	0	0

Depth	190	200	210	220	230	240	250	260	270	280	290
Coprosma	2	2	4	3	3	4	3	2	4	6	2
Dodonaea viscosa	0	1	0	0	0	0	0	1	0	0	0
Epacridaceae	2	0	1	0	0	0	0	0	0	0	0
Ericaceae	0	0	0	0	1	0	1	0	0	1	0
Fushia	0	0	0	0	0	0	0	0	0	0	0
Gentianaceae	0	0	0	0	0	0	0	0	0	0	0
Hebe	0	0	0	0	0	0	0	0	0	0	0
Leptospermum type	0	1	0	0	0	0	0	0	0	0	0
Liliaceae	0	0	0	0	0	0	0	1	0	1	0
Malvaceae gp	0	0	1	0	1	0	0	0	0	0	0
Muehlenbeckia	0	0	0	0	0	0	0	0	0	1	0
Palm	0	0	0	0	0	0	0	0	1	0	0
Pseudopanax	1	0	0	0	0	0	1	1	1	0	0
Pseudowintera	1	0	0	0	1	0	0	0	0	0	0
Scrophulariaceae	0	0	0	0	0	0	0	0	0	0	0
Total shrubs	197	209	218	227	241	246	264	265	280	293	498
Unknown	0	0	0	0	0	0	0	0	0	0	0
Chenopodiaceae	0	0	0	0	0	0	0	0	0	0	0
Plantago	0	0	0	0	0	0	0	0	0	0	0
Phormium	0	0	0	0	0	0	0	0	0	0	0
Poaceae	0	0	0	0	0	0	0	1	0	0	0
Total herbs	0	0	0	0	0	0	0	1	0	0	0
Cyathea dealbata	86	78	95	89	78	88	66	77	74	100	83
Cyathea smithii	17	11	30	6	20	8	25	14	14	20	19
Dicksonia squarrosa	0	0	0	0	0	0	0	0	0	0	0
Gleichenia	0	0	0	0	0	0	0	0	0	0	0
Histiopteris	0	0	0	0	0	0	0	0	0	0	0
Lycopodium unspecified	1	0	0	1	0	0	1	0	0	0	0

Depth	190	200	210	220	230	240	250	260	270	280	290
L:ycopodium varium	0	0	0	0	0	0	0	0	0	0	0
Monolete spores	52	15	44	508	29	7	38	41	17	13	12
Phymatosorus	1	4	2	2	0	3	2	3	2	6	5
Pteridium esculentum	0	0	0	0	0	0	0	0	0	0	0
Trilete unspec	1	2	2	0	0	4	2	0	1	0	0
Ferns & fern allies	158	110	173	606	127	110	134	135	108	139	119
Cyperaceae	10	2	1	48	45	12	59	19	57	46	108
Drosera auriculata	0	0	0	0	0	0	0	0	0	0	0
Haloragis	2	0	0	4	0	0	0	0	1	0	0
Myriophyllum	1	0	0	0	1	0	0	2	1	0	3
Restionaceae	3	1	0	1	4	0	7	1	2	7	5
Wetland species	16	3	1	53	50	12	66	22	61	53	116
Spores unidentified	0	0	0	7	0	0	0	0	0	0	0
Lycopodium marker	45	40	11	24	68	65	69	38	85	146	158
Charcoal											
<20	0	0	0	0	0	0	0	0	0	0	1
20-50	0	0	0	1	1	0	0	0	0	0	0
>50	1	0	1	0	0	11	1	5	0	10	0

Depth	300	310	320	330	340	350	360	370	380	390	400
Nothofagus fusca type	1	2	0	0	2	2	1	1	1	0	2
Agathis australis	1	1	0	2	5	3	1	1	0	0	1
Dacrycarpus dacrydioides	7	4	0	2	5	12	0	1	4	4	7
Dacrydium cupressinum	78	69	119	97	154	83	100	54	73	49	64
Libocedrus	0	0	0	0	0	0	0	0	0	0	0
Halocarpus	0	0	0	0	0	0	0	0	0	0	0
Halocarpus biformis	0	0	0	1	0	0	0	0	0	0	0
Phyllocladus	1	0	2	0	1	5	2	3	0	0	0
Pinus	0	0	0	0	0	0	0	0	0	0	0
Podocarpus type	13	16	12	4	11	8	7	7	2	8	5
Prumnopitys ferruginea	1	0	1	0	1	0	0	0	0	0	1
Prumnopitys taxifolia	3	6	4	7	1	5	2	4	0	3	2
Prumnopitys/Podocarpus g	2	6	3	3	1	6	2	3	2	2	2
Total conifers	107	104	141	116	181	124	115	74	82	66	84
Alectryon excelcus	0	0	0	0	0	0	0	0	0	0	0
Dysoxylum spectabile	0	0	0	0	0	0	0	0	0	0	0
Griselinia	0	0	0	0	0	0	0	0	0	0	0
Knightia excelsa	0	0	0	0	1	1	1	1	0	0	0
Laurelia novae-zelandiae	0	0	0	0	0	0	0	0	0	0	0
Metrosideros	0	0	1	1	0	0	0	0	0	0	0
Syzygium marie	0	0	0	0	0	0	0	0	0	0	0
Weinmannia	0	0	0	0	0	0	0	0	0	0	0
Total angiosperm trees	0	0	1	1	1	1	1	1	0	0	0
Alepis flavida	0	0	0	0	0	0	0	0	0	0	0
Araliaceae	0	0	0	0	0	0	0	0	0	0	0
Ascarina	12	1	2	8	9	11	0	22	0	3	15
Asteraceae	0	0	0	0	0	0	0	0	0	0	0

Depth	300	310	320	330	340	350	360	370	380	390	400
Comprosma	13	47	1	10	9	15	9	9	72	74	72
Dodonaea viscosa	0	0	0	0	0	0	0	0	0	0	1
Epacridaceae	0	0	0	0	0	0	0	0	0	0	0
Ericaceae	0	0	0	0	0	0	0	0	0	0	0
Fushia	0	0	0	0	0	0	0	0	0	0	0
Gentianaceae	0	0	0	0	0	0	0	0	0	0	0
Hebe	0	0	0	0	0	0	0	0	0	0	0
Leptospermum type	0	0	0	0	0	0	0	0	0	0	0
Liliaceae	0	0	0	0	0	0	0	0	0	0	0
Malvaceae gp	0	0	0	1	0	0	0	0	0	0	0
Muehlenbeckia	0	0	0	0	0	0	0	0	0	0	0
Palm	0	0	0	0	0	0	0	0	0	0	0
Pseudopanax	0	0	0	0	1	0	2	0	1	0	0
Pseudowintera	2	0	0	0	1	1	0	3	2	4	0
Scrophulariaceae	0	0	0	0	0	0	0	0	0	0	0
Total shrubs	327	358	323	349	360	377	371	404	455	471	688
Unknown	0	0	0	0	0	0	0	0	1	1	0
Chenopodiaceae	0	0	0	0	0	0	0	0	0	0	0
Plantago	0	0	0	0	0	0	0	0	0	0	0
Phormium	0	0	0	0	0	0	0	0	0	0	0
Poaceae	0	0	0	0	0	0	0	0	0	1	0
Total herbs	0	0	0	0	0	0	0	0	0	1	0
Cyathea dealbata	59	67	115	88	140	86	84	82	114	69	62
Cyathea smithii	12	11	2	10	28	23	20	17	24	2	6
Dicksonia squarrosa	0	0	0	0	0	0	0	0	0	0	0
Gleichenia	0	0	0	0	0	0	0	0	0	0	0
Histiopteris	0	0	0	0	0	0	0	0	0	0	0
Lycopodium unspecified	0	0	0	0	0	0	0	0	0	0	0

Depth	300	310	320	330	340	350	360	370	380	390	400
L:ycopodium varium	0	0	0	0	2	0	0	0	0	1	0
Monolete spores	23	12	7	25	345	13	15	42	14	3	5
Phymatosorus	5	4	0	1	1	1	4	4	3	7	3
Pteridium esculentum	0	0	0	0	0	0	0	0	0	0	2
Trilete unspec	1	0	0	0	1	0	4	2	2	3	2
Ferns & fern allies	100	94	124	124	517	123	127	147	157	85	80
Cyperaceae	76	9	2	8	37	13	15	50	4	7	12
Drosera auriculata	0	0	0	0	0	0	0	0	0	0	0
Haloragis	0	0	0	11	144	24	158	58	0	13	45
Myriophyllum	0	0	1	6	18	1	0	0	0	0	0
Restionaceae	12	2	2	4	1	0	1	12	2	1	2
Wetland species	88	11	5	29	200	38	174	120	6	21	59
Spores unidentified	0	0	0	0	0	0	0	0	0	0	0
Lycopodium marker	81	30	33	14	63	45	46	48	13	8	34
Charcoal											
<20	0	0	0	0	0	0	0	0	0	0	0
20-50	0	0	0	0	0	0	0	0	0	0	0
>50	1	0	1	0	1	0	0	0	0	0	0

Depth	410	420	430	440	450	460	470	480	490
Nothofagus fusca type	0	2	1	0	1	1	1	2	3
Agathis australis	1	1	3	3	0	1	1	0	2
Dacrycarpus dacrydioides	2	5	9	4	2	7	2	1	2
Dacrydium cupressinum	80	139	135	96	161	135	81	56	83
Libocedrus	0	0	0	0	0	0	0	0	0
Halocarpus	0	0	0	0	0	1	0	0	0
Halocarpus biformis	0	0	0	0	0	0	0	0	0
Phyllocladus	3	1	1	3	2	3	1	4	1
Pinus	0	0	0	0	0	0	0	0	0
Podocarpus type	5	32	14	11	6	22	7	12	11
Prumnopitys ferruginea	0	0	3	1	0	0	2	0	0
Prumnopitys taxifolia	4	4	6	2	5	6	1	5	2
Prumnopitys/Podocarpus g	3	3	4	1	3	3	3	3	1
Total conifers	98	187	176	121	180	179	99	83	105
Alectryon excelcus	0	1	0	0	0	0	0	0	0
Dysoxylum spectabile	0	0	0	1	1	1	0	0	0
Griselinia	0	0	0	0	0	0	1	0	0
Knightia excelsa	0	1	0	1	3	1	1	0	1
Laurelia novae-zelandiae	0	0	0	0	0	0	0	0	0
Metrosideros	0	1	1	1	0	2	0	0	0
Syzygium marie	0	0	0	0	0	0	0	0	0
Weinmannia	0	0	0	0	0	0	0	0	0
Total angiosperm trees	0	3	1	3	4	4	2	0	1
Alepis flavida	0	0	0	0	0	0	0	0	0
Araliaceae	0	0	0	0	0	0	0	0	0
Ascarina	8	5	16	13	12	7	14	17	17
Asteraceae	0	0	0	0	0	0	0	0	0

	Depth	410	420	430	440	450	460	470	480	490
Comprosma		2	4	6	70	8	13	2	2	1
Dodonaea viscosa		0	1	1	0	0	0	0	1	0
Epacridaceae		0	0	0	0	0	0	0	0	0
Ericaceae		0	0	0	0	0	0	0	0	1
Fushia		0	0	0	0	0	0	0	0	0
Gentianaceae		1	0	0	0	0	0	0	0	0
Hebe		0	0	0	0	0	0	0	0	0
Leptospermum type		0	0	0	0	0	0	0	0	0
Liliaceae		0	0	0	0	0	0	0	0	0
Malvaceae gp		0	1	0	0	1	2	0	0	0
Muehlenbeckia		0	0	0	0	0	0	0	0	0
Palm		0	1	0	0	0	5	0	0	1
Pseudopanax		0	1	2	1	1	0	1	1	2
Pseudowintera		1	2	1	2	0	1	2	0	0
Scrophulariaceae		0	0	0	0	0	0	0	0	0
Total shrubs		422	435	456	526	472	488	489	501	715
Unknown		1	1	0	0	1	1	3	2	2
Chenopodiaceae		0	0	0	0	0	0	0	0	0
Plantago		0	0	0	0	0	0	0	0	0
Phormium		0	0	0	0	0	0	0	0	0
Poaceae		0	1	0	0	1	0	0	0	0
Total herbs		0	1	0	0	1	0	0	0	0
Cyathea dealbata		73	146	157	115	138	165	98	113	103
Cyathea smithii		19	9	8	30	53	12	7	13	6
Dicksonia squarrosa		0	0	0	0	0	0	0	0	0
Gleichenia		0	0	0	0	2	2	13	0	0
Histiopteris		0	0	0	0	0	0	0	0	0
Lycopodium unspecified		0	11	0	7	32	8	0	0	0

Depth	410	420	430	440	450	460	470	480	490
L:ycopodium varium	0	1	0	0	0	1	0	0	0
Monolete spores	9	91	1413	101	53	72	18	4	17
Phymatosorus	2	3	5	1	1	4	0	0	1
Pteridium esculentum	0	0	0	0	0	1	0	0	0
Trilete unspec	3	3	1	2	0	1	2	1	0
Ferns & fern allies	106	264	1584	256	279	266	138	131	127
Cyperaceae	41	27	34	176	14	33	1	3	4
Drosera auriculata	0	0	0	0	0	0	0	0	1
Haloragis	118	51	497	10	42	92	39	0	3
Myriophyllum	0	0	0	1	0	0	0	0	0
Restionaceae	19	1	4	17	1	2	0	0	3
Wetland species	178	79	535	204	57	127	40	3	11
Spores unidentified	0	3	13	16	5	2	0	0	0
Lycopodium marker	76	33	69	78	31	85	12	6	8
Charcoal									
<20	0	0	0	0	0	0	0	0	0
20-50	0	0	0	0	0	0	0	0	0
>50	0	0	0	0	0	0	0	0	0

Original-counts data for the numbers of pollen grains, spores, and charcoal fragments from the wetland in the Rawhitiroa crater

Depth	**0**	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**
Nothofagus fusca type	0	0	0	0	0	2	1	2	0
Agathis australis	0	0	0	2	1	1	5	7	9
Dacrycarpus dacrydioides	7	8	10	17	14	8	6	3	2
Dacrydium cupressinum	4	1	26	61	86	84	79	99	78
Halocarpus	0	0	0	0	0	0	0	0	0
Halocarpus biformis	0	0	0	0	0	0	0	0	0
Libocedrus	0	0	0	0	0	0	0	0	0
Phyllocladus	1	3	0	10	2	6	2	3	6
Pinus	21	0	0	0	0	0	0	0	0
Podocarpus type	54	26	28	51	36	11	32	17	16
Prumnopitys ferruginea	0	3	2	2	1	1	3	2	2
Prumnopitys taxifolia	1	0	4	4	7	7	10	7	10
Prumnopitys/Podocarpus	5	2	4	9	5	4	5	5	4
Total conifers & beech	93	43	74	156	152	124	143	145	127
Dysoxylum spectabile	0	1	4	1	0	4	0	1	2
Knightia excelsa	0	0	1	0	1	1	0	0	0
Litsea calcaris	0	0	0	0	0	0	0	0	0
Metrosideros	0	4	1	0	0	40	6	0	2
Weinmannia	0	2	0	0	0	0	0	0	0
Total angiosperm trees	0	7	6	1	1	45	6	1	4
Ascarina	0	0	0	0	0	12	3	14	6
Asteraceae	0	2	2	2	0	0	2	0	0
Comprosma	1	0	7	79	25	4	3	5	7
Coriara	0	0	0	0	0	0	3	0	2
Ericaceae	0	0	0	0	0	0	0	0	0
Dodonaea viscosa	2	3	0	0	1	0	1	0	0

Depth	0	5	10	15	20	25	30	35	40
Griselinia	0	0	0	0	0	4	0	0	4
Leptospermum type	0	30	1	0	0	1	0	0	0
Liliaceae	0	3	0	0	0	0	0	0	0
Malvaceae	1	0	1	2	0	0	1	1	0
Myrsine	0	0	0	0	0	0	0	0	0
Pseudopanax	0	0	1	1	1	1	0	0	2
Pseudowinteria	0	0	0	0	0	0	0	2	0
Quintinia	0	0	0	0	0	0	2	0	0
Rhamnaceae	0	0	0	0	0	0	0	0	0
Scrophulariaceae	0	0	0	0	0	0	0	0	0
Total shrubs	4	43	22	99	47	47	45	57	267
Caryophyllaceae	0	0	0	0	0	0	0	0	0
Chenopodiaceae	1	0	0	0	0	0	0	0	0
Lobeliaceae	0	0	0	0	0	0	0	0	0
Plantago	24	18	11	1	0	0	0	0	0
Phormium	0	0	0	0	0	0	0	0	0
Poaceae	69	98	8	3	3	0	5	0	3
Ranunculus	3	1	0	0	0	0	0	0	0
Total herbs	97	117	19	4	3	0	5	0	3
Cyathea dealbata	6	9	89	20	24	26	41	41	44
Cyathea smithii	0	0	0	0	0	3	1	1	3
Dicksonia lanata	0	0	0	0	0	0	2	0	0
Dicksonia squarrosa	1	4	1	0	0	0	1	0	0
Gleichinia	0	0	0	0	0	0	1	0	0
Histiopteris	0	0	2	0	0	0	0	0	0
Isoetes	0	0	0	0	0	0	0	0	0
Lycopodium varium	0	0	0	1	0	0	0	0	0
Lycopodium unspecified	3	10	13	69	1	0	14	0	8
Monolete spores	4	6	6	7	9	0	3	1	3
Phymatosorus	1	2	3	4	3	4	2	1	4

Depth	**0**	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**
Pyrrosia eleagnifolia	1	0	0	0	0	0	0	0	0
Pteridium esculentum	0	0	12	91	8	6	16	0	4
Trilete unspecified	0	0	7	8	3	3	3	3	2
Ferns and fern allies	16	31	133	200	48	42	84	47	68
Cyperaceae	95	53	24	137	5	42	14	43	46
Drosera	0	0	0	0	0	0	0	0	0
Haloragis	0	0	0	2	0	0	0	0	2
Myriophyllum	622	44	2	3	0	0	2	0	2
Restionaceae	27	21	8	10	6	11	5	3	6
Wetland species	744	118	34	152	11	53	21	46	56
Unidentified spores	0	3	0	2	1	0	3	5	2
Unidentified spores - damaged	0	0	0	0	1	3	2	1	0
Lycopodium marker	167	283	179	215	28	166	75	345	262
Charcoal									
<20	0	7	24	23	3	0	1	0	15
20-50	2	30	50	39	22	11	7	1	18
>50	12	45	432	1008	490	66	127	4	147

Depth	**50**	**55**	**60**	**65**	**70**	**75**	**80**	**85**	**90**	**95**
Nothofagus fusca type	0	1	1	0	0	1	0	4	0	3
Agathis australis	5	5	9	5	8	12	6	5	6	6
Dacrycarpus dacrydioides	9	3	1	1	1	3	0	4	2	1
Dacrydium cupressinum	91	60	72	74	78	104	88	78	101	57
Halocarpus	0	0	0	0	0	0	0	0	0	0
Halocarpus biformis	0	0	0	0	0	0	0	0	0	0
Libocedrus	0	1	0	0	0	0	0	0	0	5
Phyllocladus	8	12	8	5	8	0	1	8	1	16
Pinus	0	0	0	0	0	0	0	0	0	0
Podocarpus type	19	12	6	14	13	13	9	15	13	8
Prumnopitys ferruginea	6	2	1	0	0	1	1	2	1	1
Prumnopitys taxifolia	12	5	20	4	8	18	21	9	20	27
Prumnopitys/Podocarpus	9	5	4	6	3	6	5	5	5	8
Total conifers & beech	159	106	122	109	119	158	131	130	149	132
Dysoxylum spectabile	0	3	3	4	5	0	2	0	0	6
Knightia excelsa	0	0	0	0	0	0	0	0	0	1
Litsea calcaris	0	0	0	0	0	0	0	0	0	0
Metrosideros	1	27	0	24	0	4	0	27	0	26
Weinmannia	0	0	0	0	0	0	0	0	0	0
Total angiosperm trees	1	30	3	28	5	4	2	27	0	33
Ascarina	6	10	13	18	10	5	1	11	2	4
Asteraceae	0	0	0	0	1	0	0	0	0	0
Comprosma	2	1	5	5	3	2	1	2	3	1
Coriara	0	0	0	0	0	0	0	0	0	0
Ericaceae	0	0	0	0	0	0	0	0	0	0
Dodonaea viscosa	0	0	0	0	0	0	1	0	0	0

Depth	50	55	60	65	70	75	80	85	90	95
Griselinia	0	4	0	1	0	0	1	5	0	3
Leptospermum type	0	1	0	1	0	0	0	5	0	1
Liliaceae	0	0	0	0	0	0	0	0	0	0
Malvaceae	0	0	0	0	2	1	0	1	1	1
Myrsine	0	0	0	0	0	0	0	0	0	0
Pseudopanax	0	0	0	1	2	0	3	2	0	1
Pseudowinteria	2	0	0	0	0	0	0	0	1	0
Quintinia	0	0	0	0	0	0	0	0	0	0
Rhamnaceae	0	0	0	0	0	1	0	0	1	0
Scrophulariaceae	0	5	1	1	0	0	0	0	0	2
Total shrubs	60	76	79	92	88	84	87	111	98	317
Caryophyllaceae	0	0	0	0	0	0	0	0	0	0
Chenopodiaceae	0	0	0	0	0	0	0	0	0	0
Lobeliaceae	0	0	0	0	0	0	0	0	0	0
Plantago	0	0	0	0	0	0	0	0	0	0
Phormium	0	0	0	0	0	0	0	0	0	0
Poaceae	1	1	0	0	0	0	0	1	0	0
Ranunculus	0	0	0	0	0	0	0	0	0	0
Total herbs	1	1	0	0	0	0	0	1	0	0
Cyathea dealbata	45	51	70	47	65	39	61	25	76	45
Cyathea smithii	2	6	6	5	5	2	4	0	1	0
Dicksonia lanata	0	0	0	0	0	0	0	0	0	0
Dicksonia squarrosa	0	0	0	1	0	0	0	0	0	0
Gleichinia	0	0	0	0	0	1	0	0	0	0
Histiopteris	0	0	0	0	0	0	0	0	0	0
Isoetes	0	0	0	0	0	0	0	0	0	0
Lycopodium varium	0	0	0	0	0	0	0	0	0	0
Lycopodium unspecified	0	3	1	1	0	0	0	0	0	0
Monolete spores	2	1	3	2	1	2	2	2	0	1
Phymatosorus	1	2	0	0	0	0	0	0	0	0

Depth	**50**	**55**	**60**	**65**	**70**	**75**	**80**	**85**	**90**	**95**
Pyrrosia eleagnifolia	0	0	0	0	0	0	0	0	0	0
Pteridium esculentum	6	3	0	0	0	0	0	0	0	0
Trilete unspecified	1	3	0	1	0	0	1	0	0	0
Ferns and fern allies	57	69	80	57	71	44	68	27	77	
Cyperaceae	12	68	2	0	8	1	5	6	1	1
Drosera	0	0	0	0	0	0	0	0	0	0
Haloragis	0	2	12	21	7	1	1	0	5	27
Myriophyllum	2	6	0	0	0	0	0	0	1	0
Restionaceae	0	5	2	5	4	1	3	3	0	0
Wetland species	14	81	16	26	19	3	9	9	7	28
Unidentified spores	0	19	11	16	2	0	8	18	1	11
Unidentified spores - damaged	0	4	0	0	0	0	0	0	0	0
Lycopodium marker	69	313	110	190	352	75	132	106	31	297
Charcoal										
<20	1	0	0	0	0	0	0	0	0	0
20-50	6	19	0	1	1	0	0	1	0	0
>50	18	90	3	1	3	1	1	2	1	2

Depth	**105**	**110**	**115**	**120**	**130**	**140**	**150**	**160**	**170**	**180**
Nothofagus fusca type	1	1	3	1	1	1	2	2	1	0
Agathis australis	1	8	5	2	5	2	6	2	3	5
Dacrycarpus dacrydioides	4	1	0	1	0	1	4	1	3	1
Dacrydium cupressinum	72	86	69	86	83	95	120	95	71	85
Halocarpus	0	0	0	0	0	0	0	0	0	0
Halocarpus biformis	0	0	0	0	0	0	0	1	1	0
Libocedrus	11	0	5	1	0	0	0	0	2	0
Phyllocladus	17	4	7	3	11	1	0	1	3	2
Pinus	0	0	0	0	0	0	0	0	0	0
Podocarpus type	8	13	10	10	11	17	17	21	12	18
Prumnopitys ferruginea	6	3	2	2	2	3	3	0	0	3
Prumnopitys taxifolia	14	19	16	15	20	14	17	9	17	13
Prumnopitys/Podocarpus	6	5	6	5	6	6	4	5	6	7
Total conifers & beech	140	140	123	126	139	140	173	137	119	134
Dysoxylum spectabile	3	1	4	1	6	0	0	0	0	0
Knightia excelsa	0	0	0	0	0	0	0	0	0	1
Litsea calcaris	0	0	0	0	0	0	0	0	0	0
Metrosideros	35	1	2	0	0	1	0	0	0	0
Weinmannia	0	0	0	0	0	0	0	0	0	0
Total angiosperm trees	38	2	6	1	6	1	0	0	0	1
Ascarina	18	2	18	13	8	1	2	3	8	3
Asteraceae	0	0	0	0	0	0	0	0	0	0
Comprosma	2	2	3	3	0	1	2	1	3	2
Coriara	0	0	0	0	1	0	0	0	0	0
Ericaceae	0	1	1	0	0	0	0	0	0	0
Dodonaea viscosa	0	0	0	0	0	0	0	2	0	0

Depth	**105**	**110**	**115**	**120**	**130**	**140**	**150**	**160**	**170**	**180**
Griselinia	0	0	3	0	0	0	0	0	1	2
Leptospermum type	3	0	0	0	0	0	0	0	0	0
Liliaceae	0	0	0	0	0	0	0	0	0	0
Malvaceae	1	1	0	0	2	1	0	1	0	2
Myrsine	0	0	0	0	0	0	0	0	0	0
Pseudopanax	2	0	0	0	1	1	1	1	0	0
Pseudowinteria	0	0	2	0	0	0	0	0	1	0
Quintinia	1	0	0	0	0	0	0	0	0	0
Rhamnaceae	0	0	0	0	0	0	0	0	0	0
Scrophulariaceae	1	0	0	0	0	0	0	0	0	0
Total shrubs	133	116	142	136	142	144	155	168	183	401
Caryophyllaceae	0	0	0	0	0	0	0	0	0	0
Chenopodiaceae	0	0	1	0	0	0	0	0	0	0
Lobeliaceae	0	0	0	0	0	0	0	0	0	0
Plantago	0	0	0	0	0	0	0	0	0	0
Phormium	0	0	0	0	0	0	0	0	0	0
Poaceae	0	0	1	0	0	0	0	0	0	0
Ranunculus	0	0	0	0	0	0	0	0	0	0
Total herbs	0	0	2	0	0	0	0	0	0	0
Cyathea dealbata	16	55	58	69	46	76	38	65	60	64
Cyathea smithii	1	4	1	7	5	5	1	8	11	3
Dicksonia lanata	0	0	0	0	0	0	0	0	0	0
Dicksonia squarrosa	0	0	2	0	0	0	0	0	0	0
Gleichinia	0	0	0	0	0	0	0	0	0	0
Histiopteris	0	0	0	0	0	0	0	0	0	0
Isoetes	0	0	0	0	0	7	0	0	0	0
Lycopodium varium	1	0	0	0	0	1	0	0	0	0
Lycopodium unspecified	1	1	7	0	0	1	0	0	0	0
Monolete spores	1	4	0	2	1	4	0	4	0	2
Phymatosorus	0	0	2	0	0	0	2	1	0	0

Depth	**105**	**110**	**115**	**120**	**130**	**140**	**150**	**160**	**170**	**180**
Pyrrosia eleagnifolia	0	0	0	0	0	0	0	0	0	0
Pteridium esculentum	0	0	0	0	0	0	0	0	0	0
Trilete unspecified	0	0	1	0	0	0	1	1	0	1
Ferns and fern allies	20	64	71	78	52	94	42	79	71	
Cyperaceae	2	4	14	10	7	2	8	17	12	15
Drosera	0	0	0	0	0	0	0	0	0	0
Haloragis	24	3	0	47	5	2	5	13	59	109
Myriophyllum	2	0	0	0	0	64	0	13	0	0
Restionaceae	2	2	3	2	0	4	1	3	1	0
Wetland species	30	9	17	59	12	72	14	46	72	124
Unidentified spores	15	1	2	1	2	1	2	4	3	1
Unidentified spores - damaged	0	0	0	0	0	0	0	0	0	0
Lycopodium marker	191	64	220	38	138	39	30	92	91	48
Charcoal										
<20	0	0	0	0	0	0	0	0	0	0
20-50	1	0	0	0	0	0	0	0	0	0
>50	3	1	0	0	2	0	10	0	0	1

Depth	200	210	220	230	240	250	260	270	280	290
Nothofagus fusca type	0	0	0	5	7	0	1	2	0	0
Agathis australis	10	7	5	6	7	11	4	6	11	9
Dacrycarpus dacrydioides	6	2	2	5	0	2	7	3	5	1
Dacrydium cupressinum	88	81	107	74	86	64	103	82	101	97
Halocarpus	0	0	0	0	0	0	0	0	0	0
Halocarpus biformis	0	0	0	0	0	0	0	0	0	0
Libocedrus	0	3	1	3	2	2	1	13	1	0
Phyllocladus	1	2	2	3	8	4	1	12	6	3
Pinus	0	0	0	0	0	0	0	0	0	0
Podocarpus type	16	7	16	20	9	10	6	5	13	20
Prumnopitys ferruginea	3	3	3	2	2	3	0	1	3	2
Prumnopitys taxifolia	20	12	13	8	26	13	5	13	18	12
Prumnopitys/Podocarpus	4	7	2	5	1	5	3	4	3	4
Total conifers & beech	148	124	151	131	148	114	131	141	161	148
Dysoxylum spectabile	3	1	0	0	10	4	1	6	3	0
Knightia excelsa	0	0	0	0	0	1	0	0	0	0
Litsea calcaris	0	0	0	0	0	3	1	0	0	0
Metrosideros	0	0	0	1	0	0	0	0	1	0
Weinmannia	0	0	0	0	0	0	0	0	0	0
Total angiosperm trees	3	1	0	1	10	8	2	6	4	0
Ascarina	1	8	0	4	13	7	7	9	5	5
Asteraceae	0	0	0	0	2	0	0	0	0	0
Comprosma	0	1	2	0	0	3	5	6	2	6
Coriara	0	0	0	0	0	0	0	0	0	0
Ericaceae	0	0	0	0	0	0	0	0	0	0
Dodonaea viscosa	0	0	0	1	0	0	0	0	0	2

Depth	200	210	220	230	240	250	260	270	280	290
Griselinia	0	0	0	0	0	1	0	1	0	0
Leptospermum type	0	0	0	0	0	0	0	0	0	0
Liliaceae	0	0	0	0	0	0	0	0	0	0
Malvaceae	3	3	0	2	4	5	1	1	0	1
Myrsine	0	0	0	0	0	1	0	0	0	0
Pseudopanax	0	0	0	0	0	0	0	1	0	0
Pseudowinteria	2	0	2	0	2	0	0	0	0	0
Quintinia	0	0	0	0	0	0	0	0	0	0
Rhamnaceae	0	0	0	0	0	0	0	0	0	0
Scrophulariaceae	0	0	0	0	0	0	0	1	0	0
Total shrubs	206	222	224	237	261	267	273	289	287	519
Caryophyllaceae	0	0	0	0	0	0	0	0	0	0
Chenopodiaceae	0	0	0	0	0	0	0	0	0	0
Lobeliaceae	0	0	0	0	0	0	0	0	0	0
Plantago	0	0	0	0	0	0	0	0	0	0
Phormium	0	0	0	0	0	0	0	0	0	0
Poaceae	0	0	0	0	0	0	0	0	0	1
Ranunculus	0	0	0	0	0	0	0	0	0	0
Total herbs	0	0	0	0	0	0	0	0	0	1
Cyathea dealbata	70	75	52	82	35	71	62	43	34	62
Cyathea smithii	13	4	5	5	3	11	4	7	1	3
Dicksonia lanata	0	0	0	0	0	0	0	0	0	0
Dicksonia squarrosa	0	0	0	0	0	0	0	0	0	0
Gleichinia	0	0	0	0	0	0	0	0	0	0
Histiopteris	0	0	0	0	0	0	0	0	0	0
Isoetes	0	0	9	0	0	0	10	0	0	15
Lycopodium varium	0	0	0	0	0	0	0	0	0	0
Lycopodium unspecified	0	0	0	0	1	0	0	0	0	0
Monolete spores	0	1	5	0	0	1	0	0	1	4
Phymatosorus	3	0	1	1	0	0	0	0	1	1

Depth	**200**	**210**	**220**	**230**	**240**	**250**	**260**	**270**	**280**	**290**
Pyrrosia eleagnifolia	0	0	0	0	0	0	0	0	0	0
Pteridium esculentum	0	0	0	0	0	0	1	1	0	0
Trilete unspecified	3	1	0	1	2	2	1	2	3	1
Ferns and fern allies	89	81	72	89	41	85	78	53	40	
Cyperaceae	13	20	4	9	30	34	18	13	3	8
Drosera	0	0	0	0	0	0	0	0	0	0
Haloragis	70	29	0	53	9	31	18	7	38	21
Myriophyllum	0	0	1	2	0	0	0	87	5	4
Restionaceae	1	1	0	2	2	1	4	2	0	0
Wetland species	84	50	5	66	41	66	40	109	46	33
Unidentified spores	1	1	0	2	6	1	2	3	4	3
Unidentified spores - damaged	0	0	0	0	0	0	0	0	0	0
Lycopodium marker	32	193	17	125	279	184	85	227	124	102
Charcoal										
<20	0	0	0	0	0	0	0	0	0	0
20-50	0	0	0	0	0	0	0	0	0	0
>50	0	3	2	1	2	3	1	1	1	2

Depth	**310**	**320**	**330**	**340**	**350**	**360**	**370**	**375**	**380**	**390**
Nothofagus fusca type	0	3	2	1	0	1	1	2	0	0
Agathis australis	4	4	7	6	5	14	6	2	0	0
Dacrycarpus dacrydioides	5	7	1	3	4	5	0	0	0	0
Dacrydium cupressinum	84	92	96	75	56	80	82	47	9	1
Halocarpus	0	0	0	1	0	0	1	0	0	0
Halocarpus biformis	0	0	0	0	0	0	0	0	0	0
Libocedrus	1	3	1	0	4	0	0	3	0	0
Phyllocladus	4	7	7	1	4	1	0	9	1	0
Pinus	0	0	0	0	0	0	0	0	0	0
Podocarpus type	11	11	16	22	17	21	26	17	3	1
Prumnopitys ferruginea	1	0	0	0	2	3	3	3	0	0
Prumnopitys taxifolia	9	9	12	14	12	17	9	13	0	0
Prumnopitys/Podocarpus	5	4	4	4	5	4	6	3	0	1
Total conifers & beech	124	140	146	127	109	146	134	99	13	3
Dysoxylum spectabile	0	1	1	0	10	3	1	7	0	0
Knightia excelsa	0	1	0	0	0	0	0	1	0	0
Litsea calcaris	0	0	0	0	0	0	0	0	0	0
Metrosideros	1	0	1	0	0	1	1	0	0	0
Weinmannia	0	0	0	0	0	0	0	0	0	0
Total angiosperm trees	1	2	2	0	10	4	2	8	0	0
Ascarina	10	13	4	1	22	3	5	18	3	1
Asteraceae	0	0	0	0	0	0	0	0	0	0
Comprosma	2	2	2	7	4	4	9	10	0	0
Coriara	1	0	0	0	0	2	0	0	0	0
Ericaceae	0	0	1	0	0	0	0	0	0	0
Dodonaea viscosa	0	0	0	1	0	0	1	0	0	0

Depth	**310**	**320**	**330**	**340**	**350**	**360**	**370**	**375**	**380**	**390**
Griselinia	1	0	0	0	2	0	0	1	0	0
Leptospermum type	0	0	0	0	0	0	0	0	0	0
Liliaceae	0	0	0	0	0	0	0	0	0	0
Malvaceae	1	2	0	1	1	2	2	0	0	0
Myrsine	0	0	0	0	0	0	0	0	0	0
Pseudopanax	1	0	0	0	1	0	0	0	1	0
Pseudowinteria	2	0	0	0	0	0	1	1	1	0
Quintinia	0	0	0	0	0	0	0	0	0	0
Rhamnaceae	0	0	0	0	0	0	0	0	0	0
Scrophulariaceae	0	0	1	0	1	0	0	0	0	0
Total shrubs	328	337	338	350	381	371	388	405	385	609
Caryophyllaceae	0	0	0	0	1	0	0	0	0	0
Chenopodiaceae	0	0	0	0	0	0	0	0	1	0
Lobeliaceae	0	0	0	0	0	0	0	1	0	0
Plantago	0	0	0	0	0	0	0	0	0	0
Phormium	0	0	0	0	0	0	0	0	0	1
Poaceae	0	2	1	1	1	0	0	1	0	1
Ranunculus	0	0	0	0	0	0	0	0	0	0
Total herbs	0	2	1	1	2	0	0	2	1	2
Cyathea dealbata	52	47	62	58	57	45	52	78	161	205
Cyathea smithii	8	3	2	9	2	4	4	6	90	24
Dicksonia lanata	0	0	0	0	0	0	0	0	0	0
Dicksonia squarrosa	0	0	0	0	0	0	0	0	0	1
Gleichinia	0	0	0	0	0	0	0	0	0	0
Histiopteris	0	0	0	0	0	0	0	0	0	0
Isoetes	0	0	0	1	0	0	0	0	0	0
Lycopodium varium	0	0	0	0	0	0	0	0	0	2
Lycopodium unspecified	0	1	0	0	0	0	2	0	0	0
Monolete spores	3	4	4	2	5	1	4	6	9	2
Phymatosorus	0	0	2	3	0	2	18	12	92	4

Depth	**310**	**320**	**330**	**340**	**350**	**360**	**370**	**375**	**380**	**390**
Pyrrosia eleagnifolia	0	0	0	0	0	0	0	0	0	0
Pteridium esculentum	0	0	0	0	0	0	1	0	0	0
Trilete unspecified	0	5	0	1	4	3	2	6	3	0
Ferns and fern allies	63	60	70	74	68	55	83	108	355	238
Cyperaceae	1	24	15	39	44	102	7	5	2	0
Drosera	0	0	0	0	0	0	0	0	0	0
Haloragis	2	0	0	0	0	1	0	0	0	0
Myriophyllum	8	268	215	0	3	1	5	0	0	0
Restionaceae	4	0	2	0	2	3	0	0	2	0
Wetland species	15	292	232	39	49	107	12	5	4	0
Unidentified spores	2	2	1	0	0	0	0	0	0	0
Unidentified spores - damaged	0	0	0	0	16	107	5	0	9	0
Lycopodium marker	277	180	90	71	150	113	74	75	101	85
Charcoal										
<20	0	0	0	0	0	0	0	0	0	0
20-50	0	0	0	0	0	0	0	0	0	0
>50	1	0	3	2	0	0	1	0	1	0