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Palynology, vegetation and climate of the Waikato lowlands, North Island, New Zealand, since *c.* 18,000 years ago

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The vegetational and climatic history of the Waikato lowlands during the last *c.* 18,000 years is inferred from the palynology of sediment cores from Lakes Rotomanuka, Rotokauri, and Okoroire. Intra- and inter-lake correlations were aided by multiple tephra layers interbedded with the lake sediments. The detailed chronological resolution given by these tephra sequences shows that late glacial-post glacial vegetational and climatic changes were nearly simultaneous throughout the Waikato lowlands.

From *c.* 18,000 to just before 14,000 radiocarbon years ago, the region remained largely unforested. There were successive peaks of herb and shrub taxa: Gramineae, *Phyllocladus*, *Halocarpus*, *Coprosma*. Tree taxa, mostly *Nothofagus* and *Libocedrus*, increased, probably because the harsh climates—windy, relatively dry and cool (*c.* 4°C below present temperatures)—were gradually abating. Tall podocarp trees were rare but not absent from the region.

Reafforestation proceeded rapidly, beginning *c.* 14,500 years ago soon after the deposition of Rerewhakaaitu Ash. The earliest forests were dominated by *Prumnopitys taxifolia* and, until *c.* 13,000 years ago, the persistence of *N. menziesii* suggests that temperatures may have been as much as 3°C colder than present. After that time, *N. menziesii* disappeared and *Dacrydium* predominated, reflecting a trend towards moister and warmer conditions.

From *c.* 11,000 years ago the expansion of angiosperms (especially *Metrosideros*, *Nestegis* and *Ascarina*) and tree ferns within *Dacrydium*-dominated assemblages is consistent with evidence from elsewhere in New Zealand of an early postglacial period of maximum wetness and warmth. However, by *c.* 8,500 years ago, *Ascarina* was already declining, perhaps because of increased frostiness or droughtiness, or both. Regular cycles in the *Dacrydium* pollen curves are interpreted to result from abundant emergent *D. cupressinum* trees being felled by low frequency, high intensity storms.

From *c.* 5,500 years ago this drying trend continued as indicated by rarity of *Ascarina*, increases of *Phyllocladus* and *Agathis*, more microscopic charcoal, and decreases of *Dacrydium* relative to the other tall podocarps. At all three sites *Agathis* is most prominent after *c.* 3,000 years ago, reaching maximum levels *c.* 1,000 years ago.

Many tree taxa (most notably *Agathis* at Lake Rotokauri) were adversely affected by Polynesian burning. The earliest recorded fires were about 800 years ago.

Keywords: palynology, tephrochronology, radiocarbon ages, reafforestation, forest disturbance, human deforestation, late Quaternary palaeoenvironment, Rerewhakaaitu Ash, Waikato lakes, lake sediment cores

INTRODUCTION

Late Quaternary palynology in New Zealand began in southern South Island (Cranwell and von Post, 1936) and subsequent work generally favoured southern and central sites. The northern North Island received attention only comparatively recently (Harris, 1963; McGlone *et al.*, 1978; McGlone, 1983b; McGlone *et al.*, 1984; Kershaw and Strickland, 1988; Dodson *et al.*, 1988; Enright *et al.*, 1988; Pocknall *et al.*, 1989). Previous

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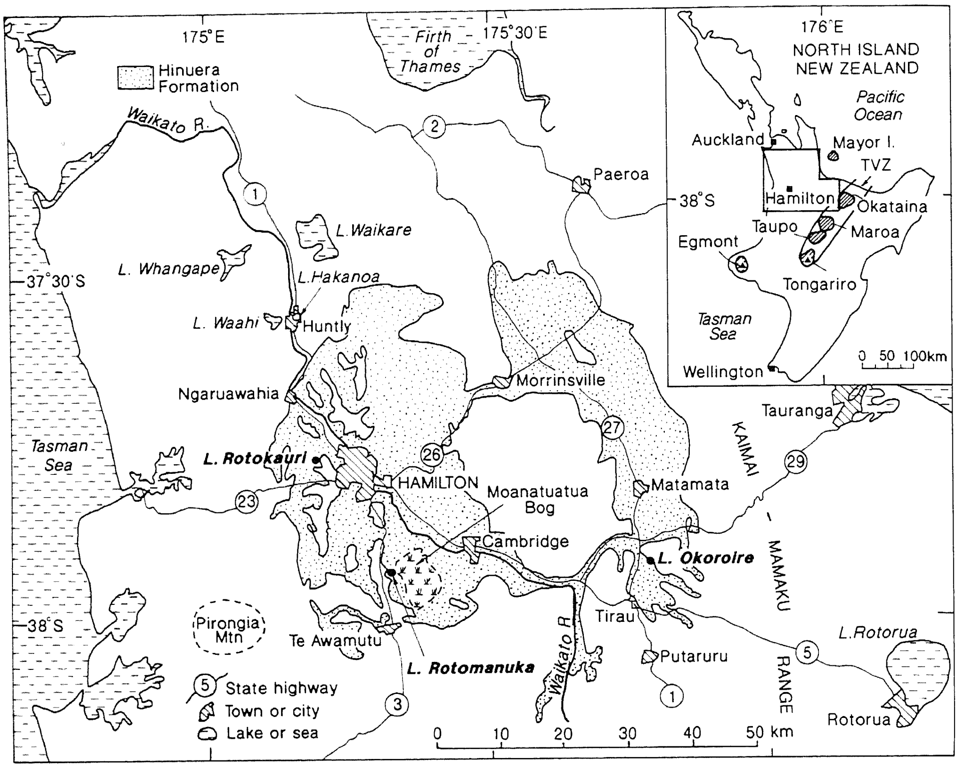


Fig. 1 — Locations of Lakes Rotomanuka, Rotokauri, and Okoroire in the Waikato region, North Island. Inset shows main late Quaternary tephra eruption centres; TVZ = Taupo Volcanic Zone. Distribution of Hinuera Formation (stippled) is after Hume *et al.* (1975).

investigations in the Waikato region have either lacked age control (Harris, 1963) or span relatively short periods of time (McGlone *et al.*, 1978: 20,000-18,000 years B.P.; McGlone *et al.*, 1984: *c* 6,000-2,000 years B.P.) [All ages reported and discussed here are conventional radiocarbon ages based on the Libby (old) half life of 5568 years (Hogg et al., 1987)].

We present here the results of an analysis of pollen assemblages in sediment cores from three lakes near latitude 38°S in the Waikato lowlands, northern North Island (Fig. 1), which provide a continuous and well-dated record of vegetational history spanning the last *c.* 18,000 years. The three Waikato riverine lakes — Rotomanuka, Rotokauri, and Okoroire — contain the longest and most complete sequence of dated tephra layers yet investigated in New Zealand lakes and bogs (Lowe, 1988). Such detailed chronologic control permits the construction of continuous time scales for the pollen series as well as the determination of pollen accumulation rates. The lakes are small (4-74 ha) and their sediments are expected to record the deposition of predominantly extralocal and regional (sensu Janssen, 1973) pollen (Jacobson and Bradshaw, 1981). A more comprehensive analysis of the data including discussion of local wetland vegetation changes at each of these sites will be presented elsewhere.

Waikato Vegetation

Historic

Various evidence indicates that, before human settlement, much of the region was covered in conifer-broadleaf forest. Taylor and Pohlen (1958) suggested from studies of soils that the ranges to the west and east of the Waikato lowlands were probably dominated by broadleaf and podocarp forests, respectively. Lowland soils show evidence of tree overturn, and pieces of kauri gum have occasionally been found in them. The isolated relict stands of forest trees (Edmonds and Henshaw, 1984), the presence of stumps and logs buried in peats (Cranwell, 1939, 1953; Gudex, 1963; Lowe, 1985), and pollen analyses of peat profiles (Harris, 1963; McGlone *et al.*, 1984), all point towards extensive forest cover in the recent past.

The Waikato area has been settled for possibly *c.* 1,000 years or more (Roberton, 1965; Bellwood, 1978; Lowe *et al.*, 1984). The effects of Polynesian settlement on the vegetation were probably substantial and extensive, because the first European settlers in the early nineteenth century found much of the area covered with manuka scrub and fern, with some scattered clumps of forest and, in the wetter parts, swamp and bog communities (Kirk, 1871; Cranwell, 1939).

Modern

The native vegetation of the Waikato has been discussed in detail by several authors (*e.g.* Gudex, 1963; Clayton-Greene, 1976, 1978) and McKelvey and Nicholls (1957) classify forests on hilly areas in the west and south of the region as podocarp-angiosperm, with *Dacrydium cupressinum* and *Beilschmiedia tawa* listed as prominent species. *Nothofagus truncata* grows throughout the region, in a range of habitats, most notably on drier ridges where it is often found in association with *Agathis australis* and *Phyllocladus trichomanoides*. *N. fusca* and *N. menziesii* are generally restricted to higher altitudes (>650 m) in the Kaimai Range (Clayton-Greene, 1978) where there is a well-marked altitudinal zonation of forest ecotones (Jane and Green, 1983). The distribution of *A. australis* may be related in part to soil type and terrain (Clayton-Greene, 1978), but probably also reflects forest clearance patterns (P.J. de Lange, pers. comm., 1988). In the northern Hamilton Basin the presence of kauri stumps and logs in peat swamps (Cranwell, 1939; Gudex, 1963), together with the isolated occurrence of old living kauri in natural environments (Edmonds and Henshaw, 1984; de Lange, 1986, 1989) suggests that there were once extensive tracts of *A. australis* in the lowlands north of latitude 38°S.

One of three major floristic boundaries first recognised by Cockayne (1910) crosses the Waikato, close to the three sites investigated. A number of northern species, including *Agathis australis*, *Avicennia resinifera*, *Beilschmiedia taraire* and *Phebalium nudum* are close to their southern boundaries at latitude 38°S, while southern species are either rare further north (*e.g. Libocedrus bidwillii*, *Nothofagus menziesii*), or are found only at the highest altitudes (*e.g. Phyllocladus aspleniifolius* var *alpinus*, *Halocarpus bidwillii*, *Podocarpus nivalis*).

Climate

Annual rainfall in the Waikato lowlands usually exceeds 1100 mm and increases with altitude to over 2500 mm on Mts Te Aroha and Pirongia (de Lisle, 1967; Maunder, 1974). Soil moisture deficits are recorded on average one year in two, more commonly in the northern Hamilton Basin than in the south. Mean annual temperatures are *c.* 14°C, with temperatures slightly higher in the east than in the west. Frosts may be recorded in any month, and ground frosts up to 70 or 80 days each year.

Lake Sites

The three lakes (Fig. 1) originated *c.* 18,000-16,000 years ago during the final stages of alluvial aggradation of the Hinuera Formation by the ancestral Waikato river (McCraw, 1967; Green and Lowe, 1985; Lowe and Green, 1987). Lake Rotomanuka has an area of *c.* 14 ha, a maximum depth of 8 m, and lies at 33 m altitude on the western edge of the large ombrogenous Moanatuatua peat bog. Lake Rotokauri, at altitude 50 m a.s.l., is 74 ha and has a maximum depth of 4 m. Lake Okoroire is 4 ha with a maximum depth of 2.3 m and lies at 90 m a.s.l. These lakes were more extensive in the past, but water tables varied during their history (*e.g.* Green and Lowe, 1985) and in particular have been lowered during European times by drainage for agriculture. Today they are surrounded by pastoral farmland and the local vegetation has been much modified, although part of the Moanatuatua bog remains as a protected area (see Matheson, 1978).

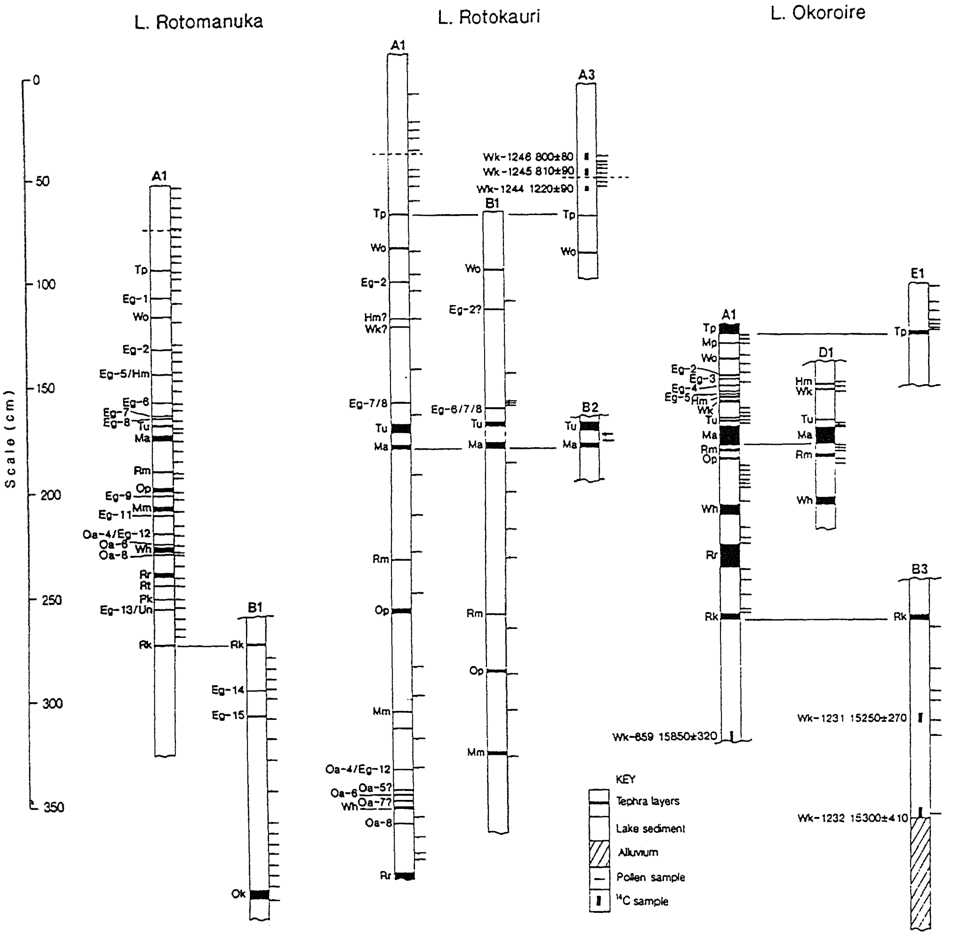


Fig. 2—Stratigraphic columns of sediment cores extracted at Lakes Rotomanuka, Rotokauri, and Okoroire showing horizons sampled for palynology (arrowed). Abbreviations and radiocarbon ages of the tephra layers are given in Table 1. Numbers prefixed Wk- are those of the University of Waikato Radiocarbon Dating Laboratory. Wk-659 from Lowe (1988); others, this paper.

METHODS

Core Extraction

The sediment cores were taken using Livingstone or Mackereth piston corers operated from the stern of a small boat or barge (Fig. 2; see Green and Lowe, 1985; Kellett, 1985). One core was taken on the peaty shores of Lake Okoroire. Several cores were taken from each lake, and matched with one another using the tephra layers as marker beds (Fig. 2).

Stratigraphy and Chronology of the Cores

The lakes contain 2.5-4 m of soft, brownish-black to olive-grey, peaty lacustrine muds. Embedded within the lake sediments is a sequence of mainly ash grade tephra layers, ranging in thickness from *c.* 2-110 mm (Fig. 2). The tephra layers were identified from their mineralogical assemblages and glass and mineral compositions, and their ages determined from multiple radiocarbon dates (Lowe, 1988). These results are summarised in Table 1; more detailed descriptions are available in Lowe (1988:129; see also Hogg *et al.*, 1987). The slow sedimentation rates (*c.* 0.1-0.3 mm/yr; Fig. 3) reduce the accuracy of the age estimates for tephra deposition because the sediment samples from which

Table 1 — Ages and sources of tephra layers identified in sediment cores from Lakes Rotomanuka, Okoroire, or Rotokauri (after Lowe, 1988).

Tephra name and symbol	Source (see Fig. 1)	Age (years B.P.)
Taupo Pumice (Tp)	Taupo	1,800
Mapara Tephra (Mp)	Taupo	2,200
Egmont — 1 (Eg-1)[1]	Egmont	2,500
Whakaipo Tephra (Wo)	Taupo	2,800
Egmont — 2 (Eg-2)	Egmont	3,700
Egmont — 3 (Eg-3)	Egmont	3.750
Egmont — 4 (Eg-4)	Egmont	4,100
Egmont — 5 (Eg-5)	Egmont	4,400
Hinemaiaia Tephra (Hm)	Taupo	4,500
Whakatane Ash (Wk)	Okataina	4,800
Egmont — 6 (Eg-6)	Egmont	5,250
Egmont — 7 (Eg-7)	Egmont	5,850
Egmont — 8 (Eg-8)	Egmont	5,900
Tuhua Tephra (Tu)	Mayor Is	6,200
Mamaku Ash (Ma)	Okataina	7,000
Rotoma Ash (Rm)	Okataina	8,500
Opepe Tephra (Op)	Taupo	8,900
Egmont — 9 (Eg-9)	Egmont	9,300
Egmont — 10 (Eg-10)	Egmont	9,600
Mangamate Tephra (Mm)[2]	Tongariro	9,950
Okupata Tephra (Oa-1)[3]	Tongariro	10,100
Egmont — 11 (Eg-11)	Egmont	10,100
Okupata Tephra (Oa-2)	Tongariro	10,500
Okupata Tephra (Oa-3)	Tongariro	10,800
Okupata Tephra (Oa-4)	Tongariro	11,050
Egmont — 12 (Eg-12)	Egmont	11,050
Okupata Tephra (Oa-5)	Tongariro	11,200
Okupata Tephra (Oa-6)	Tongariro	11,700
Okupata Tephra (Oa-7)	Tongariro	12,100
Waiohau Ash (Wh)	Okataina	12,200
Okupata Tephra (Oa-8)	Tongariro	12,700
uncorrelated (un)	Tongariro	13,100
Rotorua Ash (Rr)	Okataina	13,300
Rotoaira Lapilli (Rt)	Tongariro	13,700
Puketarata Ash (Pk)	Maroa	14,000
Egmont — 13 (Eg-13)	Egmont	14,500
uncorrelated (un)	Mayor Is	14,500
Rerewhakaaitu Ash (Rk)	Okataina	14,700
Egmont — 14 (Eg-14)	Egmont	15,000
Egmont — 15 (Eg-15)	Egmont	15,500
Okareka Ash (Ok)	Okataina	18,000

[1] Informally named Egmont derived tephras

[2] Possibly Te Rato Lapilli member

[3] Members of Okupata Tephra Formation informally designated Oa-1 to Oa-8.

N.B.: Some tephra deposits are more reliably dated than others; in most cases, the 1 std. dev. dating laboratory counting errors associated with each tephra are within 100-200 years (see Lowe, 1988).

radiocarbon dates were obtained (adjacent to each tephra layer) may represent a time span of 100-200 years (Lowe, 1988). However, this potential reduction in accuracy is partly offset by obtaining a stratigraphic succession of ages in the cores from several sites, and by the availability (via correlation) of dates on many of the tephra deposits in other environments (*e.g.* Hogg *et al.*, 1987; Froggatt and Lowe, in press). Five additional radiocarbon ages (three from L. Rotokauri, two from L. Okoroire) were obtained using a low-level liquid scintillation spectrometer (Quantulus), and are given in Fig. 2.

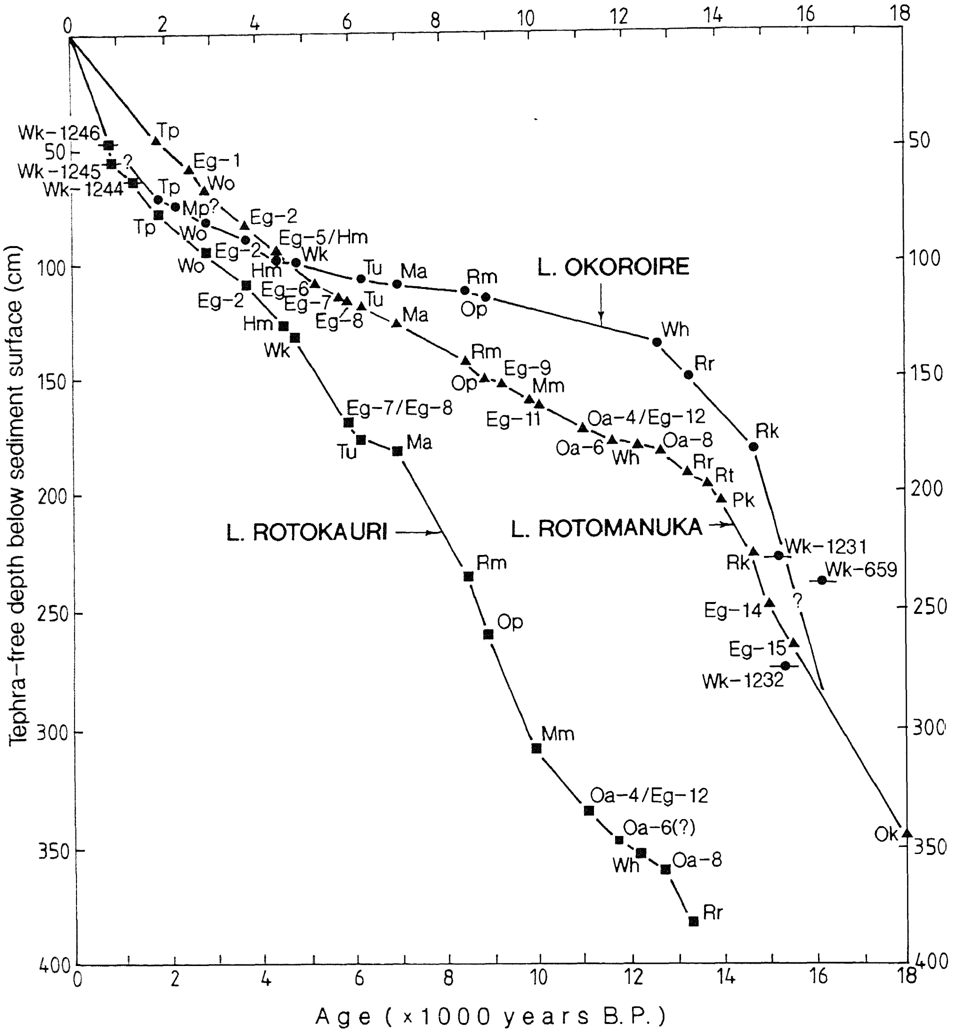


Fig. 3—Sediment depth—age curves for pollen cores from Lakes Rotomanuka, Rotokauri, and Okoroire. Sedimentation rates are based on linear interpolation between dated tephra layers. Tephra abbreviations and ages are based on Table 1 and Fig. 2.

Palynology

Sampling

Sample positions are shown in Fig. 2. At each lake a master core—A1—was designated for each site and subsequent cores for the site correlated to the master using the tephra layers as marker horizons, so palynological samples could be referenced to a single site profile (Fig. 2), and more detailed and longer palynostratigraphies could be provided. As well, this strategy allowed a flexible approach, with some replication, to sampling for palynology, tephra analysis and radiocarbon dating. Although we are concerned here primarily with events on the regional scale, there is clearly much potential in these tephra-bearing, polleniferous lake sediments for examining spatial and temporal variations in pollen deposition across a single lake basin.

Age of pollen samples

By assuming a linear sedimentation rate for the deposition of a section of lake sediment separating two tephra layers (Fig. 3), the age of each sample was estimated from its downcore depth. Slow sedimentation rates mean that most pollen samples (each comprising *c.* 10 mm vertically of sediment) encapsulate the history of perhaps 100 years or so of pollen deposition.

Slide preparation and counting

Pollen samples were prepared following standard procedures (*e.g.* Faegri and Iversen, 1964). About one half of the L. Rotomanuka samples were prepared by Department of Scientific and Industrial Research (DSIR) Botany Division staff, Christchurch, and the remaining samples were prepared at Auckland University (AU). The AU samples were passed through 10 μm mesh sieves to concentrate the palynomorphs (Cwynar *et al.*, 1979). The DSIR samples were not sieved, but were instead bleached with sodium chlorate to remove residual organic material following acetolysis. Counting proceeded until a sum of at least 250 pollens from dryland taxa (including *Leptospermum*, excluding *Pteridium*) was achieved.

Tablets of exotic *Lycopodium* spores of known concentrations were added to each sample to facilitate the estimation of pollen concentrations (Benninghof, 1962). Pollen accumulation rates (in grains/cm^2/yr) were estimated by multiplying pollen concentration (grains/cm^3) by the appropriate estimated sedimentation rate (cm/yr). Similarly, estimates of (microscopic) charcoal accumulation rates (mm^2/cm^2/year) were obtained for each pollen sample (following Clark, 1982) and are included in the pollen diagrams.

RESULTS

The palynostratigraphies (Fig. 4-6) have been subdivided into local pollen assemblage zones (LPAZ) and subzones according to changes in the dominant tree taxa. Because the changes that distinguish zones are usually gradual rather than distinct, the zone boundaries are difficult to define precisely. This is particularly so for the pre-Rerewhakaaitu Ash sediments that have accumulated more rapidly and contain fewer tephra layers than the overlying sediments. Nevertheless, the zonation scheme assists the comparative description of the palynostratigraphies. The LPAZ are described in the captions at the base of each diagram (Fig. 4-6).

The last glacial stage: before 14,500 years ago. (Zones Ro1, Ok1 in Fig. 4, 5).

The earliest sediments in the Rotomanuka and Okoroire cores indicate that from *c.* 18,000 years ago, around the maximum of the last glacial stage in New Zealand (Nelson *et al.*, 1985), until just before 14,000 years ago, the Waikato lowlands remained largely unforested. Areas of open ground were common within a scrub-dominated landscape. Subalpine shrubs (e.g. *Phyllocladus aspleniifolius* var *alpinus*, *Halocarpus*, *Coprosma* spp.), grasses and herbaceous Compositae species were probably growing close to these sites at this time, together with plants from genera typically under-represented in pollen assemblages (*e.g. Pseudopanax*, *Hoheria*, *Pittosporum*, *Hebe*, *Dracophyllum*). In contrast, the *Nothofagus* and *Libocedrus* pollen could have travelled long distances, and these trees were not necessarily present locally. However, the high percentages (15-30%) at Lake Rotomanuka of *Nothofagus menziesii* pollen, which is not widely dispersed (McKellar, 1973; Macphail and McQueen, 1983), indicate that stands of silver beech almost certainly grew near this site. Similar percentages of *N. menziesii* pollen are found in inland Taranaki in peats containing silver beech leaves (R.M. Newnham, unpublished data).

Comparable pollen assemblages, but with more Gramineae and fewer tree pollen, are reported from *c.* 20,000 year old peat deposits from Hamilton and Cambridge (McGlone *et al.*, 1978), within 20 km of Lake Rotomanuka. These assemblages were interpreted to indicate a cool, possibly dry and windy climate (see also Gates, 1976; Thiede, 1979; Kennedy *et al.*, 1978; Stewart and Neall, 1984; Salinger, 1984), but the presence of *Leptocarpus similis* and *Phormium tenax* possibly restricts maximum temperature depression for this period to not more than *c.* 4°C (McGlone *et al.*, 1978). A younger sample from Rototuna peat near Hamilton, aged 18,000 years B.P. (McGlone *et al.*, 1978), contained more tree pollen, indicating that *N. fusca* group trees were spreading at this time.

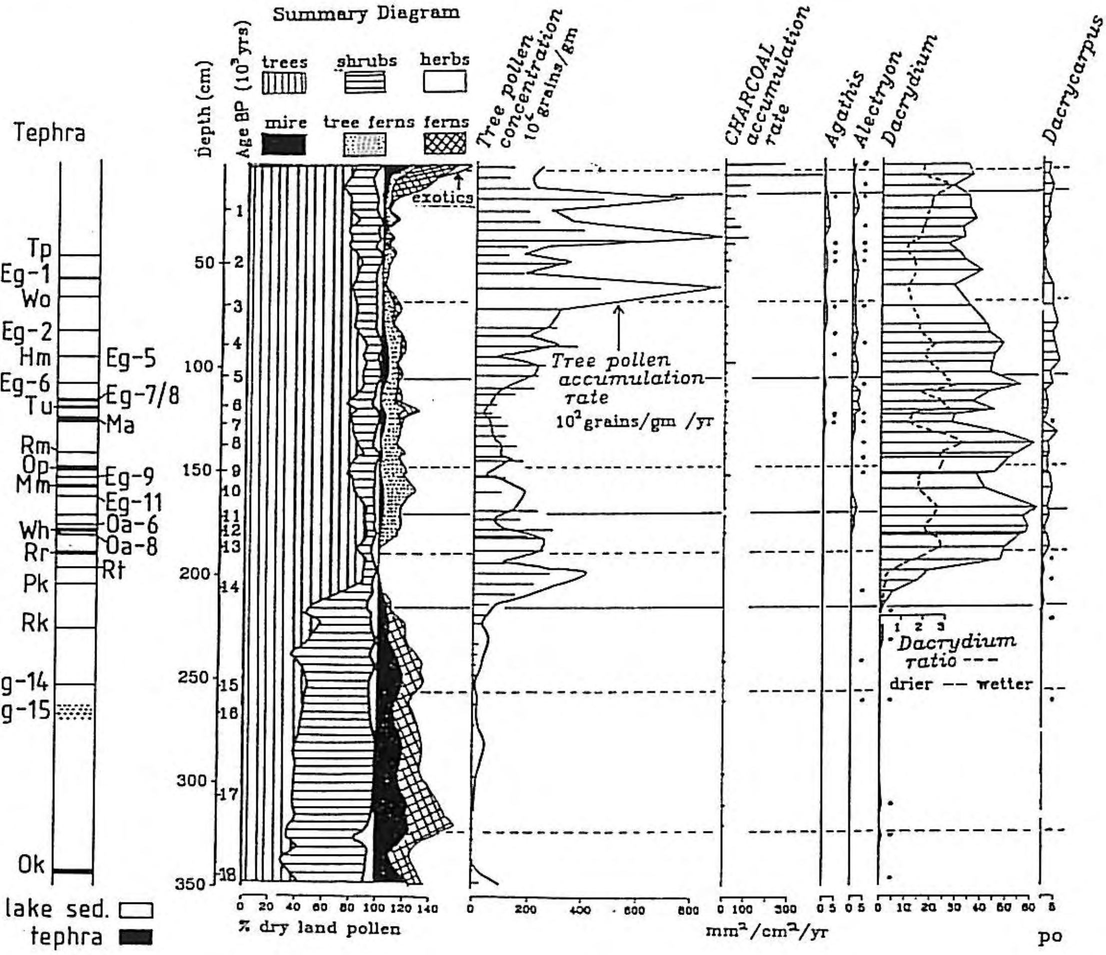
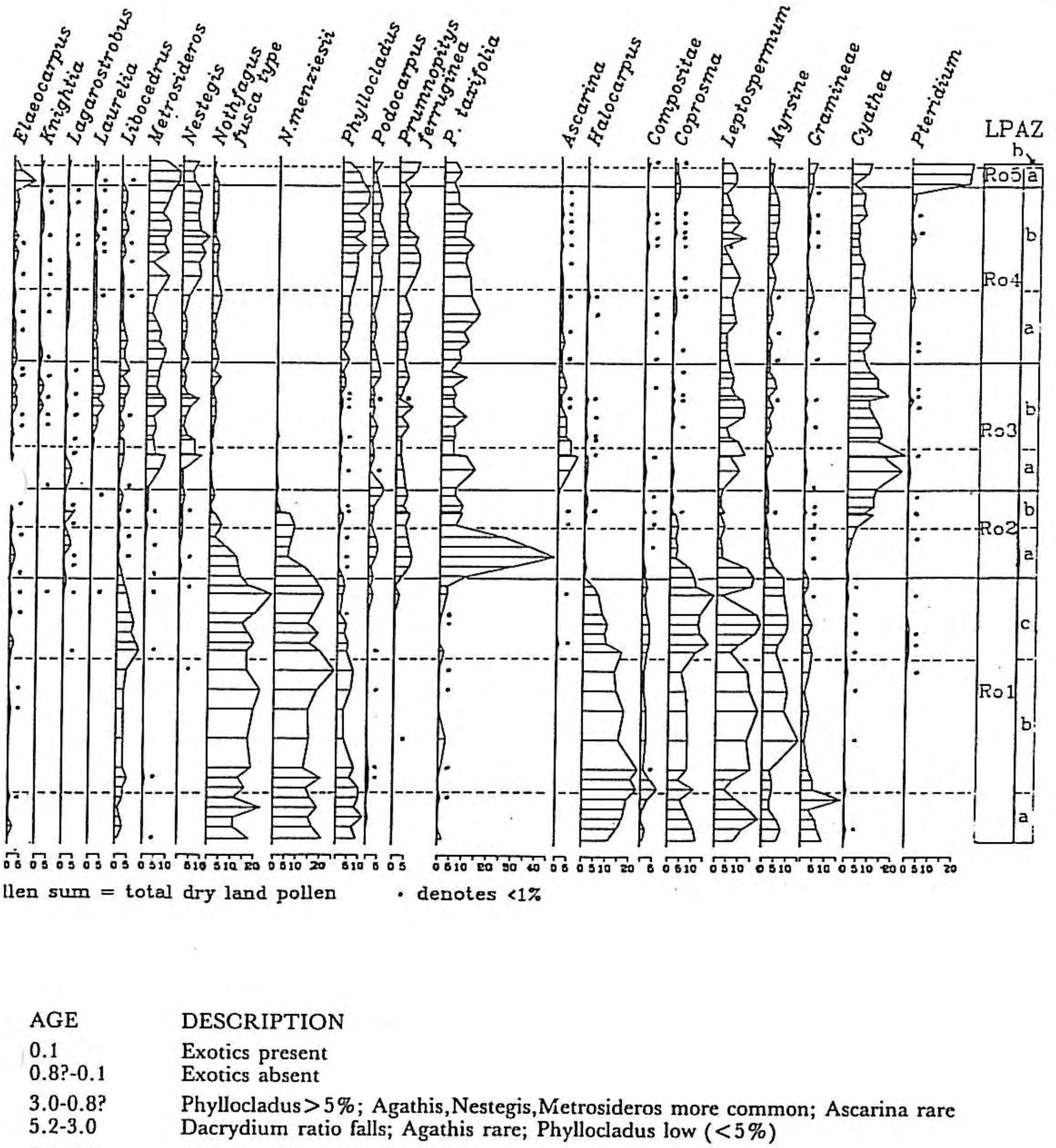


Fig. 4—Lake Rotomanuka dry land pollen percentage diagram. Local pollen assemblage zones (LPAZ) described as follows:

ZONE	AGE	MAIN TAXA	SUBZONE
Ro5	0.8?-top of core	Dacrydium-Pteridium-charcoal	b a
Ro4	5.2-0.8?	Dacrydium-Phyllocladus	b a
Ro3	11.0-5.2	Dacrydium-hardwoods-tree ferns	b a
Ro2	14.5-11.0	Prumnopitys taxifolia-Dacrydium	b a
Ro1	18.1-14.5	Nothofagus-Halocarpus-Coprosma-Leptospermum	c b a



llen sum = total dry land pollen • denotes <1%

AGE	DESCRIPTION
0.1	Exotics present
0.8?-0.1	Exotics absent
3.0-0.8?	Phyllocladus>5%; Agathis,Nestegis,Metrosideros more common; Ascarina rare
5.2-3.0	Dacrydium ratio falls; Agathis rare; Phyllocladus low (<5%)
8.8-5.2	Ascarina falls gradually; Alectryon, Laurelia rise
11.0-8.8	Dacrydium relatively low; Ascarina,Metrosideros,Nestegis, Cyathea rise
13.3-11.0	Dacydium dominant; P.taxifolia prominent; Nothofagus rare
14.5-13.3	P.taxifolia dominant; Nothofagus fall
15.5-14.5	Halocarpus,Phyllocladus,Libocedrus low; Nothofagus, Coprosma high
17.5-15.5	Gramineae lower; Halocarpus,Phyllocladus high but falling
18.1-17.5	Gramineae & Phyllocladus high

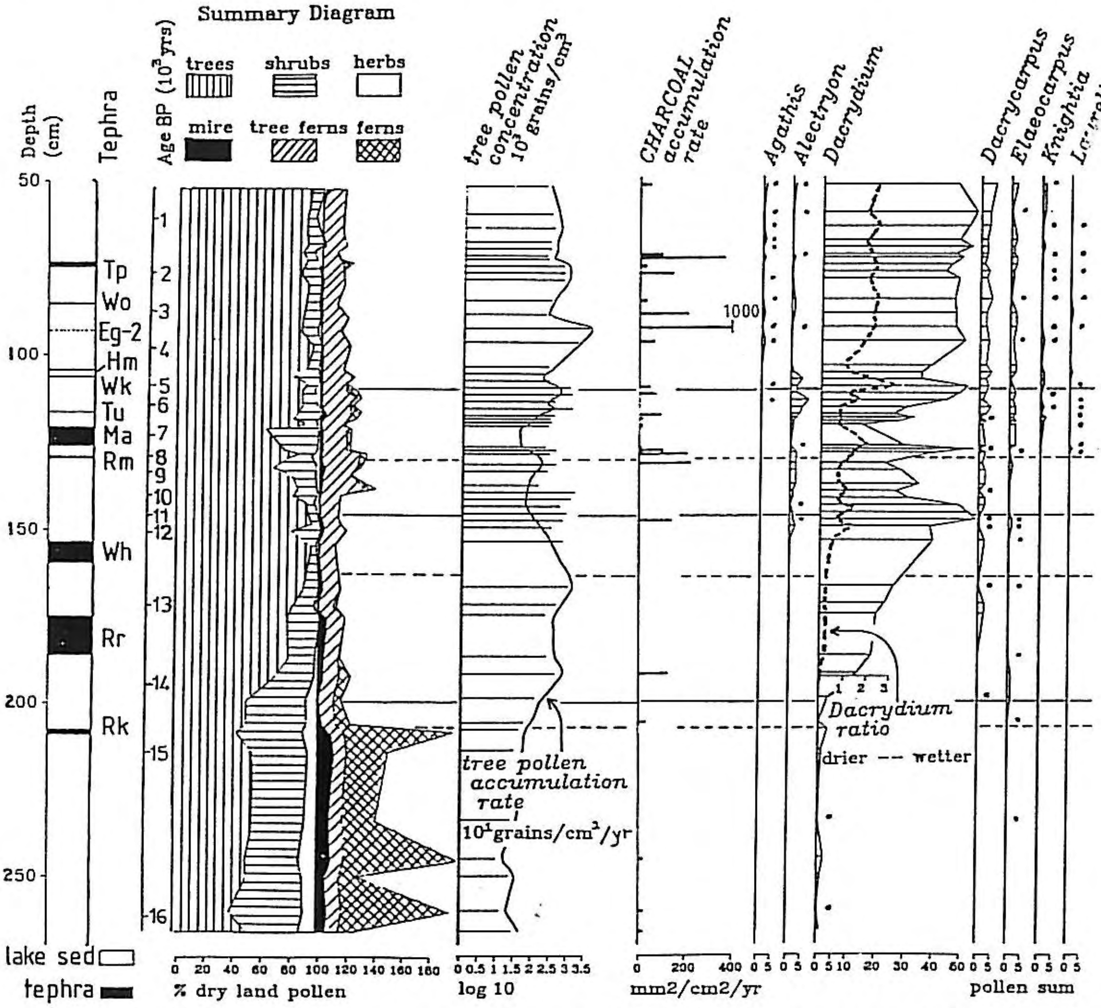
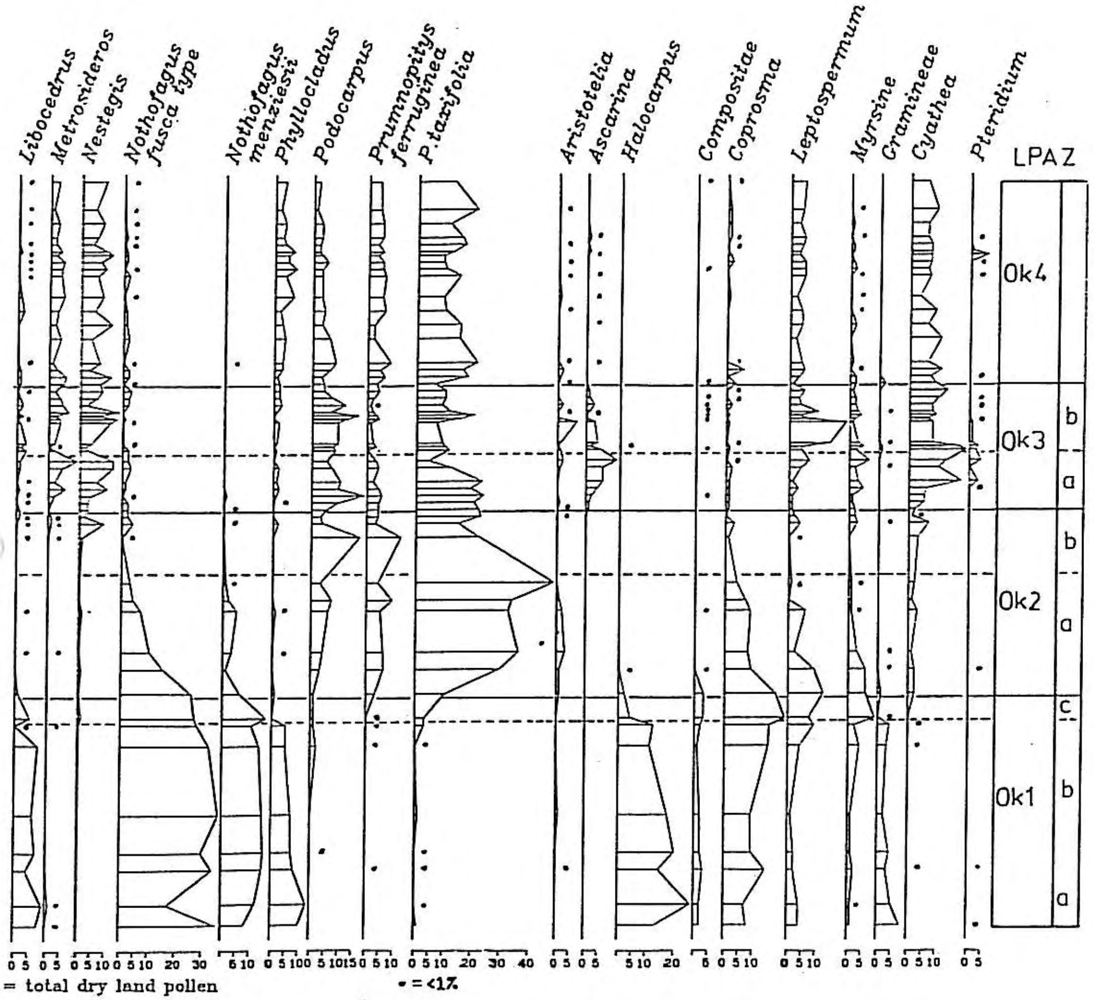


Fig. 5 — Lake Okoroire dry land pollen percentage diagram. Local pollen assemblage zones (LPAZ) described as follows:

ZONE	AGE	MAIN TAXA	SUBZONE
Ok4	5.5-top of core	Dacrydium-Prumnopitys	
Ok3	11.0-5.5	Dacrydium-Prumnopitys -hardwoods-tree ferns	b a
Ok2	14.5-11.0	Prumnopitys taxifolia-Dacrydium	b a
Ok1	?16.0-14.5	Nothofagus-Halocarpus-Coprosma-	b a



AGE	DESCRIPTION
	No subzones recognised: zone characterised by increasing Phyllocladus and Agathis (esp. after 3.0); Ascarina rare, Prumnopitys taxifolia higher
8.5-5.5	Dacrydium high; Ascarina,Metrosideros,Nestegis,Cyathea, P.taxifolia low
11.0-5.5	reverse of above,i.e. Dacrydium lower; Ascarina,etc. high
12.7-11.0	Dacydium dominant; P.taxifolia prominent; Nothofagus rare
14.5-12.7	P.taxifolia dominant; Nothofagus fall
14.7-14.5	Halocarpus,Phyllocladus,Libocedrus low; N.menziesii, Coprosma,Myrsine high
?16.0-14.7	Gramineae,Halocarpus and Phyllocladus falling

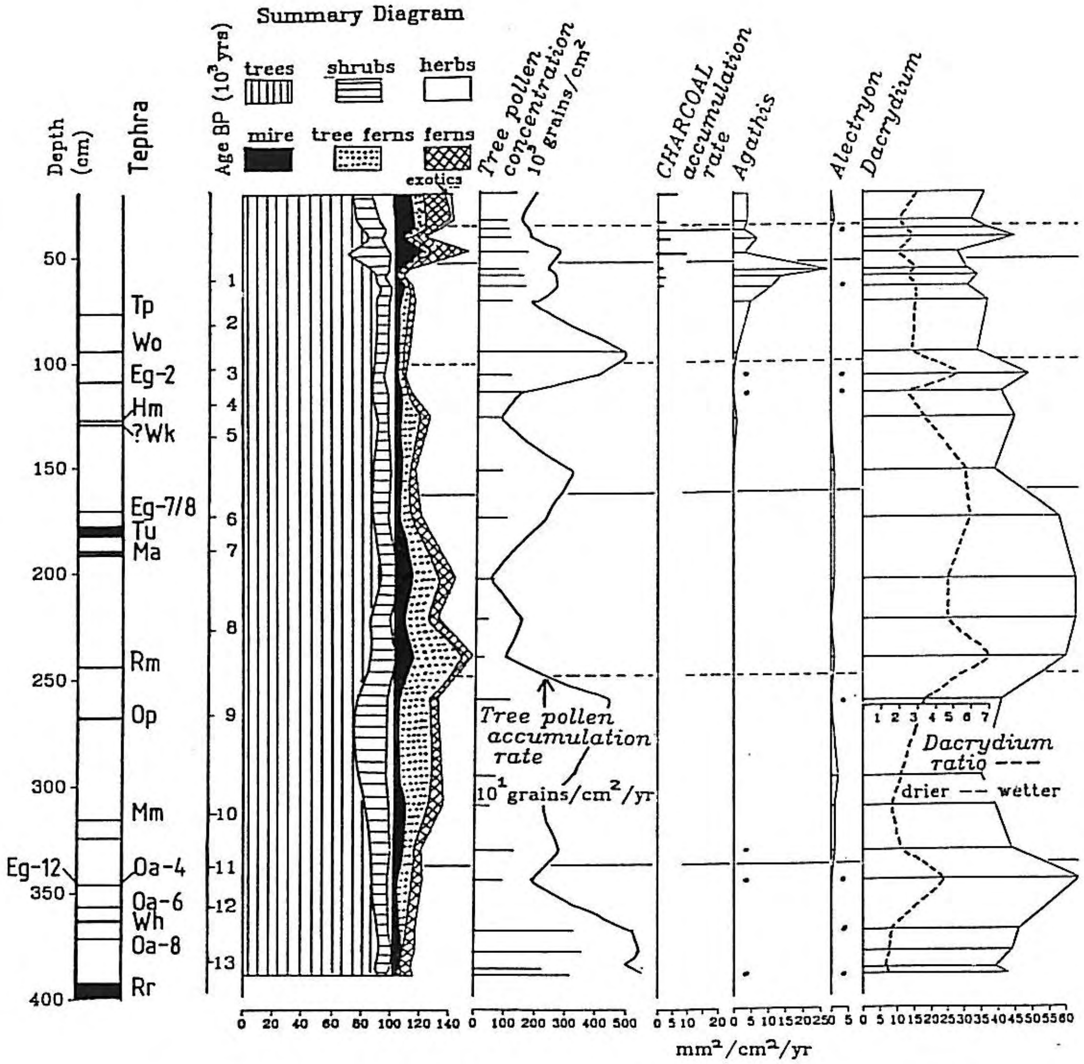
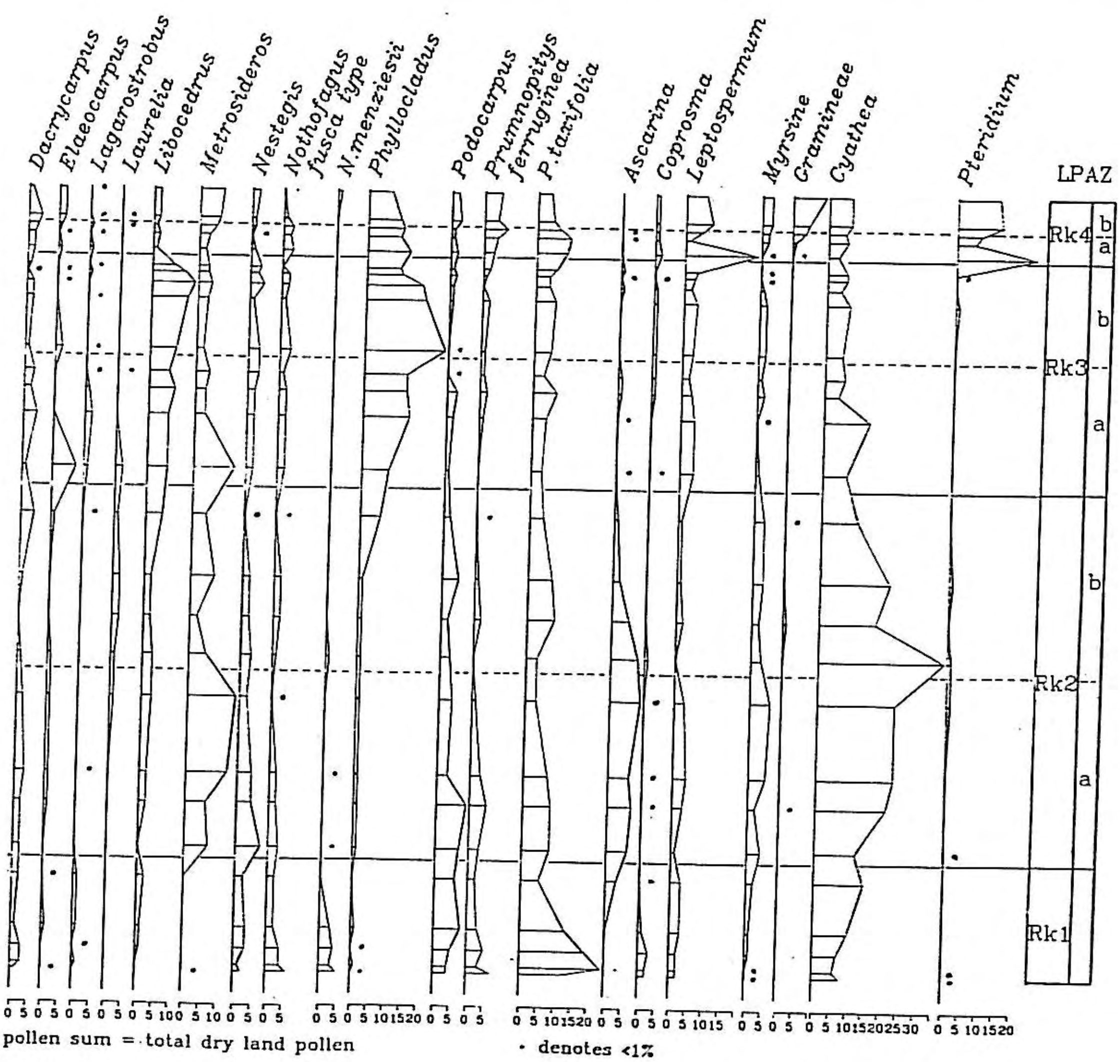


Fig. 6—Lake Rotokauri dry land pollen percentage diagram. Local pollen assemblage zones (LPAZ) described as follows:

ZONE	AGE	MAIN TAXA	SUBZONE
Rk4	0.8-top of core	Dacrydium-Pteridium-charcoal	b a
Rk3	5.7-0.8	Dacrydium-Phyllocladus	b a
Rk2	11.0-5.7	Dacrydium-hardwoods-tree ferns	b a
Rk1	13.3-11.0	Prumnopitys taxifolia-Dacrydium	



AGE	DESCRIPTION
0.1	Exotics present
0.8-0.1	Exotics absent
3.0-0.8	Phyllocladus common but falls; Agathis rises; Dacrydium decline continues
5.7-3.0	Dacrydium ratio falls; Phyllocladus increasing
8.5-5.7	Ascarina,Metrosideros fall; Dacrydium high
11.0-8.5	Dacrydium relatively low; Ascarina,Metrosideros, Cyathea high
	Dacydium rises; P.taxifolia falls

This trend away from open grasslands and subalpine shrubs towards *Nothofagus* trees appears to have continued in the earliest pollen zones at Lakes Rotomanuka (Fig. 4) and Okoroire (Fig. 5) between *c.* 18,000-14,000 years ago. The temporal succession is to some extent paralleled in modern altitudinal plant distributions, allowing some estimations of paleotemperature changes. *Phyllocladus aspleniifolius* var *alpinus* and *Halocarpus biformis* are today restricted to very high ground (> 760 m) in the Kaimai/Mamaku Range bordering eastern Waikato (Fig. 1; B.D. Clarkson, pers. comm., 1988), but were almost certainly flourishing in the Waikato lowlands until about 16,000-15,000 years ago, after which they declined. A temperature drop of 4.2°C estimated from a lapse rate of 0.6°C/100 m, which may apply in the Kaimai Range today (Jane and Green, 1983), is less than the 6-7°C postulated by Willett (1950), but accords with more recent estimates for the late glacial maximum temperature depression for New Zealand (*e.g.* Wardle, 1963; Porter, 1975; Gates, 1976; McGlone *et al.*, 1978; Wilson, 1978; Soons, 1979; Salinger, 1984). Similarly, the persistence in the vicinity of Lake Rotomanuka until around 13,000-14,000 years ago of *N. menziesii*, a tree that today is generally restricted to altitudes above 550 m in the Kaimai/Mamaku Range (B.D. Clarkson, pers. comm., 1988; *cf.* Clayton-Greene, 1978), may indicate that temperatures, although increasing, were still as much as 3°C below present levels at that time.

Lateglacial transition: 14,500-11,000 years ago (Zones Ro2, Ok2, Rk1 in Fig. 4-6)

Soon after the deposition of Rerewhakaaitu Ash (Rk), *c.* 14,700 years ago, substantial changes show in the pollen assemblages as the subalpine elements are progressively replaced by pollen from the tall podocarp trees, initially *Prumnopitys taxifolia* and then *Dacrydium cupressinum*. The expansion of podocarp forest is recorded simultaneously at Lakes Okoroire and Rotomanuka (the oldest sediments in the Lake Rotokauri pollen profile are less than 14,000 years in age), and appears to have been synchronous throughout the north-central North Island (McGlone, 1983a, 1985).

The early forests were dominated by *P. taxifolia*, and for about 1,000 years, one or more cohorts of these trees prospered in the western Waikato, probably on terraces left in the wake of the subsiding ancestral Waikato River system. To the east, at Lake Okoroire (Fig. 5), they persisted longer, perhaps for two generations. The late glacial abundance of *P. taxifolia* and concomitant suppression of *D. cupressinum* is consistent with a relatively cool and dry, but ameliorating, climate. Because of its ability to withstand frosts and drier conditions (Nicholls, 1983), *P. taxifolia* may have held a competitive advantage over *D. cupressinum*, which prefers moister areas (Franklin, 1968) and may be more susceptible to drought (Atkinson and Greenwood, 1972; Ogden, 1976) and to frost (Sakai *et al.*, 1981). However, the dominance of *P. taxifolia* was almost certainly not due to climate alone; it is an early coloniser of fresh alluvial soils (Beveridge, 1983), which had recently become available as fluvial aggradation diminished, and may also have benefitted from the addition of airfall volcanic material deposited as the Rerewhakaaitu and other subsequent tephra layers (Lowe, 1988).

Temporal succession from *P. taxifolia*-dominant forests to *D. cupressinum*-dominant forest is documented at a number of New Zealand palynological sites covering the late glacial to Holocene transition period. Although reafforestation was completed at different times in New Zealand—around 10,000 years ago in Southland (McGlone and Bathgate, 1983) and north Westland (Moar,1971); around 12,000 to 13,000 years ago in Taranaki (McGlone and Neall pers. comm., 1988) and Manawatu (Lees, 1986); around 14,000 years ago in the central North Island (McGlone and Topping, 1977) and Waikato lowlands (this study)—palynological evidence from all these regions shows a local temporal sequence from shrubland-grassland through *P. taxifolia*-dominated forest to *D. cupressinum*-dominant forest. The general trend, of reafforestation proceeding later at more southern sites, is consistent with other evidence for warming during this period (*e.g.* Suggate, 1965; Hendy and Wilson, 1978; Chinn, 1983). We therefore prefer the explanation that climate, drier and cooler initially (at *c.* 14,500 years ago), but becoming increasingly wetter and warmer, was the dominant factor favouring the expansion of *P. taxifolia* ahead of *D. cupressinum*. We suggest, moreover, that at some sites (*e.g.* in the Waikato lowlands), the availability of fresh alluvial or tephra-derived soils accentuated the early dominance of *P taxifolia*.

This may also explain why *P. taxifolia* persisted longer in the eastern Waikato than in the west; Lake Okoroire is closer to most of the Late Quaternary eruptive centres and in particular to the Okataina source than the Hamilton Basin lakes, and accordingly its sediments contain much thicker tephra (see Fig. 2, 4-6).

The rapidity of forest expansion, and the presence of *Prumnopitys*, *Dacrydium*, and *Podocarpus* pollen in low frequencies in the late glacial sediments of these lakes, corroborate McGlone's (1983a, 1985) suggestion that these podocarps were probably present in low numbers in this region before reafforestation, occupying sites that permitted survival but not expansion. In addition to a cooler and windier climate, the extensive high-energy fluvial aggradation of the Hinuera Formation in the Waikato lowlands (Fig. 1) during the late glacial, between *c.* 19,000 and 16,000 years ago (Hume *et al.*, 1975; McGlone *et al.*, 1978; Green and Lowe, 1985) must have presented a formidable barrier to the spread of forests.

There is now strong evidence for major environmental changes developing throughout New Zealand during the period from *c.* 14,500 to 11,000 years ago. As forests of lowland, warm-temperate character were replacing subalpine, cool-temperate vegetation in the Waikato lowlands and central North Island, glaciers were retreating from their maximum extension in western South Island (Suggate, 1965; Suggate and Moar, 1970; Burrows, 1979; Chinn, 1983); the accumulation of terrigenous wind-borne quartz off the coast of eastern North Island, which had been rapid, decreased abruptly, presumably as westerly winds subsided and as aggradational surfaces on land became forested (Stewart and Neall, 1984); tephric-sand dunes stabilised in northern Taranaki (Neall, 1975); deposition of loess in southern North Island and South Island virtually ceased (McCraw, 1975; Milne and Smalley, 1979); erosion of interfluves ceased (Leamy *et al.*, 1973); and rates of soil formation increased in central North Island (Vucetich and Pullar, 1963, 1969; Birrell and Pullar, 1973; Birrell *et al.*, 1977; Lowe, 1986).

We are able directly to compare many of these events and so establish their synchroneity because of the widespread deposition of Rerewhakaaitu Ash throughout central and north-central North Island. Furthermore, its dispersal at a time when much of this region was at the threshold of reafforestation increases its value as a stratigraphic marker.

Early postglacial: 11,000-5,500 yrs B.P. (Zones Ro3, Ok3, Rk2 in Fig. 4-6)

After *c.* 11,000 years ago, all three sites record increases of tree ferns and of several angiosperm trees (especially *Nestegis*, *Metrosideros*, *Alectryon*, *Laurelia*, *Elaeocarpus*). Evidently the early podocarp-dominated forests were opening out, so providing space and light for other canopy and subcanopy species to exploit. Previous palynological evidence from throughout New Zealand indicates the period from 10,000 to 8,000 years ago to be the time of maximum postglacial forest expansion (Moar, 1971; Lintott and Burrows, 1973; McGlone and Topping, 1977; Mildenhall, 1979; Mildenhall and Brown, 1987) and Pittock and Salinger (1983) refer to this period as a "climatic optimum". The three sites investigated here all record maximum levels of *Dacrydium* and *Ascarina* pollen, suggesting a wetter and perhaps warmer climate than during any other period covered here. These conclusions agree with the findings of Hendy and Wilson (1968), Green (1979), and Green and Lowe (1985).

Marked fluctuations in the *Dacrydium* pollen curve during late- and early post-glacial times appear to be synchronous at the three lake sites. There are peaks in *Dacrydium* pollen percentages from Lakes Rotomanuka and Okoroire at around 11,000, 8,000 (between the deposition of Rotoma Ash and Mamaku Ash), and 5,500 years ago, and both sites record a smaller peak at around 6,300 years ago (Fig. 4, 5). Samples from the Lake Rotokauri cores, although more widely spaced, nevertheless also show peaks at *c.* 11,000 and 8,000 years ago (Fig. 6). The analysis of L. Rotokauri core A2 (R. M. Newnham, unpublished data) shows *Dacrydium* peaks at *c.* 11,000, 8,000, and 6,300 years ago. The *Dacrydium* peaks are terminated abruptly, and followed by gradual recovery during which a range of ecologically diverse species flourish. Some of these (*e.g. Cyathea*, *Leptospermum*, *Pteridium*, *Aristotelia*) are plants that typically respond quickly to disturbance within forests, whereas others (*e.g. Prumnopitys taxifolia*, *Metrosideros*, *Nestegis*) are competitors for canopy space. The cyclic nature of these *Dacrydium* peaks and their sudden terminations suggest they are not due to long term climatic change. We suggest instead an ecological control, as follows. *D. cupressinum* trees, which are slow growing and long-lived (generally about 600 years, and some live 1200 years: Norton *et al.*, 1988; C.H. Lusk, unpublished data), were well suited to the warm and wet climates of this time. At all three sites the evidence consistently shows that at around 12,500 years ago, *P. taxifolia* was replaced by *D. cupressinum* as the most important canopy species in these young forests. By 11,000 years ago, tall, mature *D. cupressinum* trees must have dominated the canopy and emergent layers. Older emergents were particularly susceptible to windthrow during low-frequency, high-intensity storms. These storms would therefore have created new opportunities for canopy competitors and smaller seral species (Norton *et al.*, 1988), as well as increasing the susceptibility of the whole forest to fire in drier summers. There is strong evidence for increased burning at Lake Okoroire (Fig. 5), where the *Dacrydium* peaks (especially at *c.* 8,000 years ago) correspond with charcoal peaks, and subsequent assemblages record increases in taxa which typically feature in post-fire succession, notably *Pteridium*, *Leptospermum*, and *Aristotelia*. *Dacrydium* pollen remains important, but diminished, in the subsequent assemblages; hence it took perhaps 2,000-3,000 years for *D. cupressinum* to achieve its former dominance.

These regular *c.* 3,000 year cycles of *Dacrydium* dominance are most evident in late-glacial and early postglacial assemblages, but similar and possibly analagous fluctuations recur throughout the *Dacrydium* pollen curves at these lake sites and may be detectable at other pollen sites with adequate age control. Recent studies in New Zealand plant demography (*e.g.* Veblen and Stewart, 1982; Ogden, 1985) suggest that periodic, catastrophic disturbances play an important role in the regeneration and population dynamics of modern forests.

Ascarina pollen curves are remarkably similar at all three sites. Rare or absent before the initial *Dacrydium* peak at *c.* 11,000 years ago, *Ascarina* pollen percentages rise rapidly afterwards, suggesting that it was also responding to forest disturbance. The *Ascarina* pollen curves peak between *c.* 10,000-9,000 years ago, then taper off. This pattern conforms with that described by McGlone and Moar (1977) except that their postulated recovery between 3,400 and 1,800 years ago is not apparent at these sites. Apart from its paleoclimatic significance, there is clearly much potential for the use of *Ascarina* as a biostratigraphic index in late- and post-glacial terrestrial sediments (Fig. 7).

As well as *Ascarina*, *Cyathea* tree ferns were common in the subcanopy of these early postglacial forests. *Nestegis*, *Alectryon*, *Elaeocarpus*, and *Laurelia* formed the forest canopy, presumably with *Beilschmiedia tawa* which is grossly under-represented in pollen spectra (Macphail, 1980). *D. cupressinum*, probably supporting *Metrosideros* lianes, was the most common emergent. *M. robusta* is likely to have been more common than its pollen percentages would suggest. *M. robusta* pollen can normally be distinguished from other *Metrosideros* species, except *M. excelsa* (McIntyre, 1963), but this distinction cannot always be confidently made with fossil specimens. Thus the *M. robusta* percentages are minimum estimates, and some grains, conservatively recorded as *Metrosideros*, are possibly *M. robusta*. *Prumnopitys* spp. and *Podocarpus* spp. were also common canopy and emergent trees, although they had been more abundant before 11,000 years ago and increased after 5,500 years ago when, except at L. Okoroire, *Dacrydium* steadily declined.

Late postglacial: 5,500 years ago to recent (Zones Ro4, Ok4, Rk3 in Fig. 4-6)

Shifts in the relative prominence of *Prumnopitys* and *Podocarpus* species compared with *Dacrydium*, as reflected in the *Dacrydium* ratio, have been used previously (Harris, 1963; McGlone and Topping, 1977; McGlone *et al.*, 1984), along with other evidence, to indicate drier climates during the late Holocene, after about 5,000 years ago (see also Green, 1979; Green and Lowe, 1985). Lakes Rotokauri and Rotomanuka provide ample evidence for drier conditions after about 5,500 years ago: the *Dacrydium* ratio shows the increasing importance of the more drought-tolerant tree podocarps; *Ascarina* and *Cyathea*, which today favour moister areas, decline; *Phyllocladus* and *Agathis*, two associated species favouring drier sites, become increasingly important; and increasing rates of charcoal accumulation indicate more frequent fires around the lakes.

At Lake Okoroire (Fig. 5), the decline of *Ascarina* and *Cyathea* and the increasing percentages of *Prumnopitys*, *Podocarpus*, *Phyllocladus*, and *Agathis* pollen plus greater charcoal accumulation suggest that these characteristics of increasing dryness were extensive throughout the region. However, the high *Dacrydium* ratio and high *Dacrydium* pollen percentages appear to contradict this trend. *D. cupressinum* can persist in regionally drier areas today by occupying the moister low-lying sites (Franklin, 1968), and commonly grows on boggy ground. As all the evidence from these three sites—with this one exception—points unequivocally to drier climates, the falling water levels and the availability of boggy ground around Lake Okoroire after *c.* 6,000 years ago may have allowed *D. cupressinum* trees, although declining regionally, to thrive locally, thus contradicting the regional decline in *Dacrydium* pollen at the other Waikato sites at Lakes Rotokauri and Rotomanuka (see also Harris, 1963; McGlone *et al.*, 1984). Falling lake levels may also explain the late postglacial increase in concentration and rate of accumulation of tree pollens observed at all three sites (Fig. 4-6), because they enabled source plants to grow closer to the point of pollen deposition on the lake floor.

At about the same time *Dacrydium* was spreading on to the previously submerged peaty substrates surrounding Lake Okoroire, *A. australis* was also spreading around Lake Rotokauri, possibly invading previously swampy marginal areas that were drying out as the lake level dropped. *Agathis* is often poorly represented in New Zealand pollen assemblages (Macphail and McQueen, 1983), unless large *A. australis* stands are nearby (R.M. Newnham, unpublished data), and the 25% *Agathis* pollen in the *c.* 1,000 year old Lake Rotokauri sample (Fig. 6) is among the highest yet recorded. It seems likely, therefore, that the largest of the *Agathis* logs, reported by earlier workers and still to be seen around Lake Rotokauri, date from around this time. The three records for *Agathis* presented here are consistent with other published evidence from northern localities (McGlone *et al.*, 1984; Kershaw and Strickland, 1988) in showing increasing *Agathis* after *c.* 6,000 years ago, but there is a second, more substantial expansion at around *c.* 3,000 years ago in the Waikato lowlands.

The Taupo eruption

Sediments sampled immediately above Taupo Pumice at each of the lake sites show evidence, in the form of shortlived peaks of *Pteridium* and charcoal accumulation, of forest fires (Fig. 4-6). Vegetation disturbance following tephra fall, in particular Kaharoa Ash and Taupo Pumice, has been discussed by McGlone (1980), who suggested that fires were more likely to follow these eruptions because they occurred during periods of drier climate. Apart from the immediately post-Taupo Pumice sediments there is little direct evidence in the lake sediments examined here of vegetation disturbance after the numerous pre-Taupo tephra deposits, even though several of these (*e.g.* Rotorua Ash, Waiohau Ash, and Mamaku Ash) are much thicker deposits and represent major eruptions (Lowe, 1988). Tephra-related fires must have been extensive, because they are recorded at some distance (100-120 km) upwind of the postulated centre of the Taupo eruption (Wilson, 1985). We therefore agree with McGlone's (1980) view that conditions during and immediately following the Taupo Pumice eruption must have been exceptional to allow such damage. Since the land was uninhabited, perhaps this indicates an exceptionally dry climate.

Deforestation and Human Settlement

After the Taupo Pumice eruption 1,800 years ago and before the arrival of European settlers, the lowland Waikato forests suffered more dramatic changes than recorded over the previous 13,000 years. The sharp rise and sustained peak of the *Pteridium* curve, together with increases in other indicators of disturbance; the considerable increase in charcoal accumulation rates; and the decline of many forest tree taxa follow precisely the pattern that McGlone (1980, 1983c) attributed to the burning of forests by early Polynesian settlers. There is no evidence in these sediments for climate-related erosional events in post-Taupo time as postulated by Grant (1985) and by McFadgen (1985). Instead, the scale of disturbance, and the clear distinction between the pre-disturbance and post-disturbance character of these post-Taupo sediments undoubtedly point to human agency.

Anthropogenic forest clearance at L. Rotokauri began around 800 radiocarbon years ago, based on the radiocarbon age of 810 ± 90 years B.P. (Wk-1245; Fig. 2), obtained from lake sediment containing the earliest significant evidence of post-Taupo Pumice disturbance (the *Pteridium* content of the 2 cm-thick dated sample increased from 2% at the base to 40% at the top of the slice, and the *Agathis* content fell from 25% to 3%). Based on the corrections and calibration procedures of Stuiver and Pearson (1986), Wk-1245 corresponds to a calibrated age of A.D. 1259 (with 1 std. dev. errors, age is between A.D. 1175-1280, *i.e.* 775-670 calibrated years B.P.). The date is similar to others from nearby Lake Hakanoa (Fig. 1; Hogg *et al.*, 1987) and corroborates McGlone's (1983c) estimates for the timing of widespread Polynesian deforestation elsewhere in New Zealand.

A distinct sedimentary transition (marked by a dashed line in Fig. 2) from firm, compact lake sediment below to wetter, uncompacted lake sediment above, coincides with the initiation of the *Pteridium*-charcoal phase *c.* 800 years ago. The sediments below this point show no significant palynological or sedimentary evidence of catchment disturbance, apart from that immediately following the deposition of Taupo Pumice noted above. An age of 1220 ± 90 years B.P. (Wk-1244; Fig. 2) was obtained from a 2 cm-thick slice of these sediments 5 cm below the *Pteridium*-charcoal transition point (*i.e.* below Wk-1245). The rate of sedimentation since 1800 years ago increases from *c.* 0.23 mm/yr before to *c.* 0.56 mm/yr after the deforestation around L. Rotokauri.

At Lake Rotomanuka, a parallel pattern of pre- and post-forest disturbance is evident (Fig. 4). Based on estimated sedimentation rates (radiocarbon dates have not yet been obtained for this part of the record at L. Rotomanuka), we consider that deforestation began here at around the same time as at L. Rotokauri. We found no comparable evidence for deforestation in post-Taupo Pumice sediments at Lake Okoroire (Fig. 5), probably because of difficulty in adequately sampling the topmost sediments, which were very sloppy in this lake.

Table 2 — Summary of palynology and inferred regional vegetation and climate since *c.* 18,000 years ago.

Yrs BP	RPAZ	Key Pollen Taxa	Regional Vegetation	Climate
0.15	5b	*Pteridium*-exotics	Cleared ground &	
			podocarp-hardwood	?
0.8	5a	*Pteridium*-charcoal	forest	
1				
2	4b	*Agathis*		
3		*Phyllocladus*	Podocarp hardwood	Cooler and
				drier;
4	4a	*Dacrydium* ratio (−)	& kauri forest	droughts,
5		*Phyllocladus*		frosts
6				
7	3b	Tree ferns decline		Warm &
8		*Ascarina* decline	Extensive	moist
			Podocarp-hardwood	
9		*Dacrydium* ratio (+)	Forest	Warmest &
10	3a	*Metrosideros*		wettest
11		*Ascarina*		
12	2b	*Nestegis, Cyathea*		
13		*Dacrydium*	Early podocarp	Warmer &
			forest	wetter
14	2a	*Prumnopitys*		
15	1a	*Nothofagus, Libocedrus*		
				?Moistening
16	1b	*Halocarpus, Coprosma*	*Nothofagus* scrub	
17		*Phyllocladus*	& grasslands	
				Cool & dry
18	1a	*Gramineae, Phyllocladus*		

RPAZ = Regional Pollen Assemblage Zone; Yrs BP = radiocarbon years ago (× 1000)

The earliest European pollen (chiefly *Pinus*, Cupressaceae, *Plantago lanceolata*) at Lake Rotokauri is recorded, in low concentrations (*c.* 5%), about 5 cm above the deforestation transition dated at 810 ± 90 years B.P. (Wk-1245) and about 35 cm below the surface of the lake sediments. A 2 cm-thick sample containing these first adventives returned an age of 800 ± 80 years B.P. (Wk-1246; Fig. 2). Clearly these uppermost sediments record a major disturbance in the catchment, or the sediment has been mixed by some other mechanism (*e.g.* bioturbation or wind-induced wave mixing — see Schicker, 1987; Lowe, 1988), because the earliest European settlers did not arrive until about A.D. 1840.

These results indicate that lake sediments with minor percentages of European pollen may not always be of European age. Furthermore, if (European) pollen can be dislocated downwards within lake sediments after deforestation of the catchment, the same may be true at other wetland sites indicating pre-European forest disturbance. It may therefore be unwise, in the absence of independent supporting evidence, to attribute the relatively minor *Pteridium*-charcoal levels in sediments underlying a precipitous *Pteridium*-charcoal rise to coeval Polynesian burning (*cf.* Chester, 1986; Sutton, 1987).

SUMMARY AND CONCLUSIONS

The vegetational and climatic history of the Waikato lowlands region during the last *c.* 18,000 years is inferred from the palynology of sediment cores from three lowland lake sites (Lakes Rotomanuka, Rotokauri and Okoroire). The cores were dated and correlated using radiocarbon methods and multiple tephra layers interbedded with the sediments. Our main findings are summarised in Table 2 and Figure 7.

From *c.* 18,000 to just before 14,000 years ago, the Waikato lowlands remained largely unforested. The pollen assemblages record successive peaks of herb and shrub taxa: Gramineae, *Phyllocladus*, *Halocarpus*, *Coprosma*. Tree pollens, mostly *Nothofagus* and *Libocedrus*, increase through this zone, probably because harsh climates — windy, relatively dry and cool (c. 4°C below present temperatures) — were gradually abating. Tall podocarp trees were rare but not absent from the region.

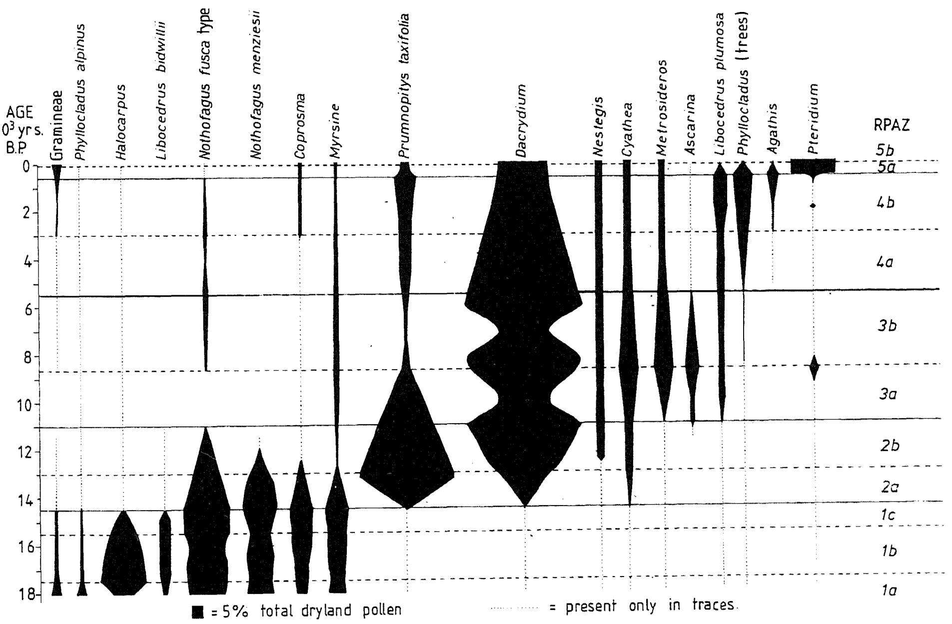


Fig. 7 — Summary of Waikato regional palynostratigraphy since *c.* 18,000 years ago, based on pollen analyses of Lakes Rotomanuka, Okoroire and Rotokauri.

Reafforestation proceeded rapidly, beginning about 14,500 years ago, soon after the deposition of Rerewhakaaitu Ash. The earliest forests were dominated by *Prumnopitys taxifolia* and the persistence of *N. menziesii* around 13,000-14,000 years ago suggests that temperatures may have been as much as 3°C colder than present. After that time *N. menziesii* disappeared from the Waikato lowlands and the predominance of *Dacrydium* pollen, which is maintained in all the overlying assemblages, reflects a trend towards moister and warmer conditions.

Cycles of *Dacrydium* dominance between 11,000 and 5,500 years ago are evidently synchronous at the three sites, and are interpreted as evidence for regionally extensive storms that destroyed emergent *Dacrydium cupressinum* trees by windthrow, allowing competitors for canopy space to flourish. These *D. cupressinum* perturbations indicate that palynology of postglacial pollen records can provide past analogues to modern disturbance events. The podocarp forests of New Zealand, with several long-lived, wind-pollinated canopy and emergent species, appear to be well suited to the reconciliation of modern ecological observation with the fossil record.

Beginning around 11,000 years ago, the dispersal of angiosperm trees (especially *Metrosideros*, *Nestegis*, and *Ascarina*) and tree ferns within *Dacrydium*-dominated assemblages is consistent with evidence from elsewhere in New Zealand for an early postglacial period of maximum warmth and wetness. However by *c.* 8,500 years ago, *Ascarina* was already declining, perhaps because of increasing droughtiness or increasing frostiness, or both.

A continuation of this drying trend is evident after *c.* 5,500 years ago when *Ascarina* was rare, *Phyllocladus* and *Agathis* increased, more microscopic charcoal is recorded, and *Dacrydium* declined relative to the other tall podocarp trees. Increases in tree pollen concentrations and tree pollen accumulation rates may be due to falling lake levels. At all three sites investigated, *Agathis* pollen is most prominent after *c.* 3,000 years ago, reaching maximum levels around one thousand years ago.

Many tree taxa (most notably *Agathis* at Lake Rotokauri) were adversely affected by Polynesian burning of forests. The earliest firings are dated (Wk-1245) at 810 ± 90 radiocarbon years B.P. (between A.D. 1175-1280).

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