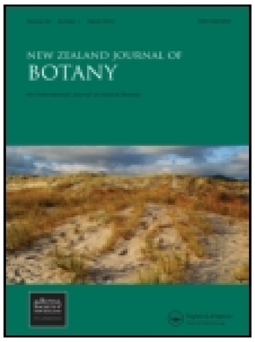

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The late Pleistocene and Holocene vegetation history of Taranaki, North Island, New Zealand

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Abstract Pollen diagrams are presented from four lowland Taranaki sites which collectively span the last 13 000 years. At c. 13 000 years ago, lowland Taranaki was occupied by an open grassland in which shrubland was restricted and forest scarce. Beginning c. 12 500 years ago, there was a rapid transition, essentially complete by 11 000 years ago, to tall complex conifer/broad-leaved forest in which *Prumnopitys taxifolia* was the most abundant tall tree. By 9500 years ago, the last of the cool temperate forest elements (most notably *Nothofagus menziesii* and *Libocedrus bidwillii*) had been eliminated from the forest, and *Dacrydium cupressinum* had supplanted *Prumnopitys taxifolia* as the most abundant tall podocarp tree. In coastal regions, *Ascarina lucida* and *Dodonaea viscosa* were abundant. From 5000 years ago, *Ascarina lucida* and *Dodonaea* became much less common, and *Ascarina lucida* is now nearly extinct in the Taranaki region. *Knightia excelsa* and *Lagarostrobos colensoi* spread during the late Holocene.

The early grassland phase suggests harsh climatic conditions, perhaps characterised by severe drought and frost, although annual average temperatures cannot have been much more than 4–5°C below those of the present. The subsequent spread of tall conifer/broad-leaved forest indicates a prolonged and apparently uninterrupted climatic amelioration. Early Holocene conditions seem to have been close to those of the present, although climatic variability and extremes were much reduced. From 9500 years ago to the present, climatic change was slight, but there is some indication of increasing summer water deficits and increased disturbance to the vegetation after 5000 years.

Keywords Taranaki; late-glacial; Holocene; Pleistocene; pollen analysis; tephra; volcanoes; climatic change; conifer/broad-leaved forests

INTRODUCTION

The prominent recent volcanic cone of Mt Taranaki (Egmont Volcano) (altitude 2518 m), and the two extinct and eroded volcanoes to the north which form the Pouakai and Kaitake Ranges, dominate the Taranaki region (Fig. 1), and are here collectively referred to as the Taranaki volcanoes.

At a number of exposures, mainly in coastal cliffs and streambanks, peat and lignite layers are interbedded with volcaniclastics. At various sites on the volcanoes and in inland sites, extensive recent wetlands have formed. These interbedded layers and peatlands collectively preserve a continuous pollen and macrofossil record of late Quaternary vegetation. McGlone et al. (1984a) and Bussell (1990, 1993) have described the vegetation history of the Last Glaciation and Last Interglacial in this region, and McGlone et al. (1988) and Lees & Neall (1993) have described the history of the last 3000 years. Despite its mild, oceanic setting and fertile soils, the vegetative cover of Taranaki has been reduced to scrub and grassland during glacial periods, whereas dense conifer/broad-leaved forests have dominated during interglacials. Volcanic eruptions, while significantly affecting vegetation close to the eruption site, seem to have had little direct effect on the course of vegetation change. In this paper we present pollen results from four late-glacial and Holocene sites that provide the first information about the late-glacial transition in Taranaki.

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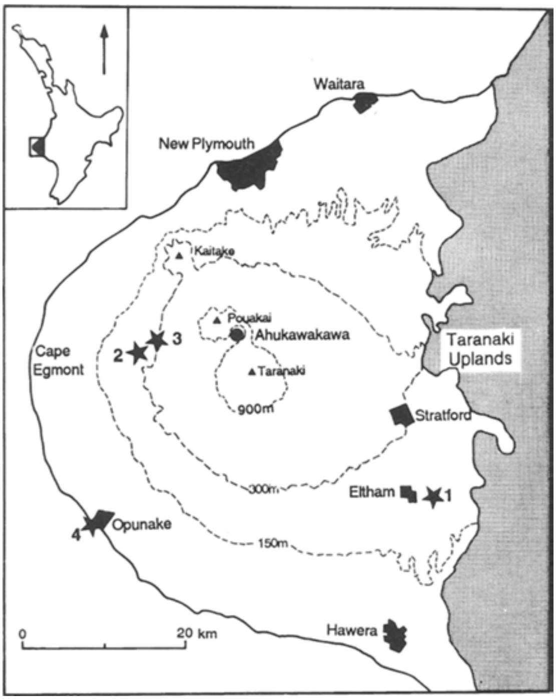

Fig. 1 The Taranaki district. Pollen core sites marked by stars: 1, Eltham Swamp; 2, Warea River; 3, Waiweranui Stream; 4, Middletons Bay.

PRESENT LANDSCAPE AND CLIMATE

Mt Taranaki is an active andesitic stratovolcano, and the most recent (10 000 years) in a chain of volcanoes that originated near the present city of New Plymouth at least 1.75 m.y. ago (Neall 1979). Some of the tephras erupted from the Taranaki cones are thick and widespread and have been radiocarbon dated (Neall 1972, 1979), and thus provide a chronology in rapidly accumulating sediments such as peat and alluvium.

Surrounding the Taranaki volcanoes are extensive ring plains of volcaniclastics, graded to one or other of the volcanic centres, which are here referred to as the Taranaki lowlands (Fig. 1). In the north and south of the Taranaki region the volcaniclastics overlie uplifted marine benches, which form a broad coastal plain. Inland, to the east of Stratford, deeply dissected Tertiary mudstones and sandstones form extensive hill and steepland country (here referred to as the east Taranaki uplands), which has only a thin covering of volcaniclastics (Fig. 1).

The Taranaki lowlands are mild, wet, and windy (Garnier 1958; New Zealand Meterological Service 1973). The volcanic uplands have a cool, wet, mountain climate. Annual mean temperature at sea level is 12–13°C, and over most of the rest of the Taranaki lowlands it ranges between 10° and 12°C. Frosts are infrequent and light near the coast (av. 6–12 ground frosts a year), but inland at Stratford over 70 ground frosts are recorded annually. Snow is an unusual event below 300 m altitude. Wind flow is predominantly from the west, but just to the east of Mt Taranaki the flow tends more to the north and south because of a wind-channelling effect between the volcanic ranges and the east Taranaki uplands.

Rainfall is even and reliable throughout the year, but there is more rainfall in north than in south Taranaki (the line separating these two rainfall zones runs approximately from Cape Egmont ESE to Eltham). North Taranaki averages 1500–2500 mm/yr, and south Taranaki receives 1100–1600 mm/yr. Further south towards Wanganui, rainfall is lower. South Taranaki has a relatively high water deficit in summer.

HISTORICAL VEGETATION PATTERN

Clearance by Maori and European settlers has left little natural vegetation in the Taranaki lowlands. The only substantial areas of forest remaining are on the slopes of the Taranaki volcanoes within Egmont National Park. The lowland vegetation during historical times can be broadly reconstructed from the work of Druce (1970) and Clarkson (1985, 1986). [Plant nomenclature in this paper is according to Allan (1961), Moore & Edgar (1970), and Connor & Edgar (1987)].

By the time of European settlement in the 1840s, Maori had cleared the forest back from the coastline in an irregular strip up to 7.5 km wide. A dense cover of tall fern and scrub grew in place of the previous coastal forest. Little of the once-continuous coastal forest remains, but it is likely to have been mainly a broad-leaved association in which the canopy trees *Alectryon excelsus*, *Beilschmiedia tawa*, *Corynocarpus laevigatus*, *Dodonaea viscosa*, *Dysoxylum spectabile*, *Hedycarya arborea*, *Melicytus ramiflorus*, *Myoporum laetum*, and *Rhopalostylis sapida* were prominent.

Most of the Taranaki lowlands outside the coastal zone were covered with tall, dense, multistoreyed conifer/broad-leaved forest. Prominent tall tree emergents in this forest were *Dacrydium cupressinum* and *Metrosideros robusta*. *Prumnopitys taxifolia* and *Podocarpus totara* were common only on alluvial terraces of the largest rivers. Below 250 m in altitude, the canopy was commonly dominated by *Beilschmiedia tawa* and *Alectryon excelsus*. *Elaeocarpus dentatus*, *Dysoxylum spectabile*, *Knightia excelsa*, and *Nestegis* spp. were frequently present. Above 250 m, *Beilschmiedia tawa* still dominated, but common associates were *Weinmannia racemosa*, *Elaeocarpus dentatus*, *Nestegis*, and *Melicytus ramiflorus*. Tree ferns were abundant, especially in canopy gaps. Forest on poorly drained or swampy ground often had dense stands of *Dacrycarpus dacrydioides*, *Laurelia novae-zelandiae*, and *Syzygium maire*.

On the slopes of the Taranaki volcanoes, lowland forest elements were gradually replaced with increasing altitude by upland trees and shrubs. *Beilschmiedia tawa* gave way to *Weinmannia racemosa* as the dominant tree at 450 m on the well-drained soils on the south-eastern to north-eastern sides of Mt Taranaki. The equivalent change in dominance occurred at 150 m on the western debris fans, but there terrestrially established *Metrosideros robusta* also became abundant.

Weinmannia racemosa is still the predominant canopy tree on the mountain, reaching its peak abundance between 760 and 840 m but not persisting above 990 m. *Dacrydium cupresssinum* and *Metrosideros robusta* are the main emergents up to 750 m, but above this altitude they decline rapidly. The extreme upper limit for *Dacrydium cupressinum* on Mt Taranaki is c. 880 m. *Cyathea smithii*, the most abundant tree fern, reaches its limit some 30 m lower. Above 800 m altitude, hardier tree species form a montane forest. With increasing altitude, *Podocarpus hallii* quickly becomes subdominant or codominant with *Weinmannia racemosa*. *Libocedrus bidwillii* appears above 800 m, but is not abundant until 900 m, and then only in sectors of the belt least affected by recent eruptions. The *Libocedrus*/*Podocarpus hallii* forest does not form a sharp treeline but gradually gives way to subalpine scrub and shrubland. The most important species of this belt—*Brachyglottis elaeagnifolia*, *Pseudopanax colensoi*, and *Griselinia littoralis*—are common as subdominants in the upper montane forest. Above 1200 m, forest trees are absent. Shrubland including abundant *Coprosma* spp., *Dracophyllum longifolium*, *Myrsine divaricata*, and *Hebe* spp. extends another 200 m. At c. 1400 m, shrubland is replaced by grassland dominated by *Chionochloa rubra*. The limit to vegetation is at c. 1800 m.

Inland to the east of the volcanic ring plain, the original vegetation of the now partly cleared rugged hill country has been described by Nicholls (1956). The main lowland to submontane forest trees were *Beilschmiedia tawa* and *Weinmannia racemosa*, with various tall podocarp species as low-density co-dominants—mainly *Dacrydium cupressinum* and *Prumnopitys ferruginea*. Other tree species associated with this broad forest type were *Metrosideros robusta*, *Elaeocarpus dentatus*, *Knightia excelsa*, and *Laurelia novae-zelandiae*. *Nestegis* spp. were common on fertile alluvial silt soils, and *Dacrycarpus dacrydioides* was common on some riparian flats. *Podocarpus hallii* was largely confined to ridge tops, and *Prumnopitys taxifolia* occurred only on the most fertile valley bottom soils.

Nothofagus fusca-group species are now found throughout the eastern uplands, with *N. truncata* in the north and *N. solandri* in the south. *Nothofagus fusca* itself is absent from the Taranaki region. *Nothofagus* forest occurs mainly on the razor-back ridges and spurs that characterise the steep topography of the eastern uplands. *Nothofagus menziesii* occurs only as a single small patch in north Taranaki. *Phyllocladus trichomanoides* is found in the north of the upland region in low numbers and at low altitudes. *Phyllocladus glaucus* occurs in *Nothofagus truncata* forest immediately north of the Awakino River mouth, just outside of the Taranaki district; and *Halocarpus* likewise does not occur at all in Taranaki.

SITE LOCATION, GEOMORPHOLOGY, AND STRATIGRAPHY

Site 1 Eltham Swamp: NZMS 260, Q20/245966; altitude 244 m

Eltham Swamp (not an approved Geographic Board name) is one of two 6 km long, peat-filled valleys directly to the east of Eltham township (Fig. 2). The other, Ngaere Swamp, adjoins the Eltham Swamp to the north, and is about 15 m higher. The two peatlands are separated by a low, east–west trending ridge. The Eltham Swamp is drained to the west by Mangawhero Stream, which flows into the Waingongoro River, and by Mangimangi Stream to the south. The peatlands have formed at the junction between the west Taranaki lowlands and the east Taranaki uplands. Lahar and debris avalanche deposits belonging to the Opunake and Ngaere Formations (Neall 1979), emplaced between 50 000 and 23 000 years ago, have been responsible for the aggradation at the western exit of these two valleys, resulting in drainage impedance and peat accumulation.

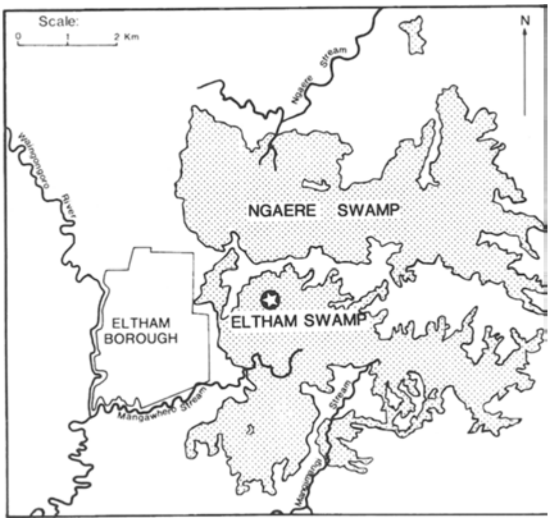

Fig. 2 Eltham and Ngaere Swamps. The shaded area represents the extent of peat soils. A star marks the drillhole site.

In early European times, Eltham Swamp was partially covered with a dense swamp forest of *Dacrycarpus dacrydioides*, *Laurelia novae-zelandiae*, *Syzygium maire*, and other trees tolerant of poor drainage. Towards the centre of the peatland there was scrub, mire herbs, and, in places, shallow lagoons (Every 1974). Clearance and drainage of the Eltham Swamp has left only two depauperate patches of the original swamp forest. Near the western edge, a small remnant includes abundant *Dacrycarpus dacrydioides* and *Beilschmiedia tawa*, and also *Weinmannia racemosa*, *Laurelia novae-zelandiae*, *Myrsine australis*, *Myrsine salicina*, *Dacrydium cupressinum*, and *Melicytus ramiflorus*. A small remnant at the northern edge is similar in composition but has additional swamp forest species such as *Syzygium maire*, *Pennantia corymbosa*, and *Coprosma tenuicaulis*. *Schoenus carsei*, *Drosera binata*, and *Gratiola nana* (Cheeseman 1925) were collected from the Ngaere Swamp in 1885 by Cheeseman; their presence suggests pockets of oligotrophic bog vegetation were scattered through the swamp forest.

Drainage has lowered the peatland through shrinkage and decay of the surface layers. Evidence of the higher peat level can be found in the soils of a low knoll (NZMS 260, Q20/249970), at the western side of the basin, 600 m northeast of the core site (Fig. 2). On this knoll a clearly marked transition from gleyed soils to non-gleyed soils occurs at c. 3 m above the present basin level. We interpret this soil transition as marking the previous height of the basin peats. However, subsidence of the peat has not been uniform. In the western forest remnant, the height of exposed roots of *Dacrycarpus dacrydioides* indicates that the surface has lowered by only 1.0–1.5 m.

The core site is adjacent to and within a drain c. 450 m from the western side of the basin. The basin surface is now in pasture, and cultivation has left a compact top layer of dry, decayed peat. This layer, and the thick deposits of wood that occur throughout the peat column, made it impractical to attempt a stratigraphic traverse of the peat deposits. The top 0.6 m of the peat column was not sampled because of obvious disturbance as a result of shrinkage, cultivation, and stock trampling. The summer water table was 1.45 m below the surface when the samples were taken.

Several andesitic tephras derived from Mt Taranaki were encountered in the peat core (Fig. 3). Radiocarbon dates for some of these tephras have been obtained nearer to the source, where they are better preserved and can be more precisely dated. The youngest tephra, the Burrell Lapilli (295 yr B.P.), is found elsewhere in the basin, but at the pollen site it is a barely distinguishable scatter of lapilli in the uppermost peat layers. The informally named Kaupokonui tephra is the first undisturbed and recognisable tephra bed in the profile. Peat from beneath it in the Potaema Bog on Mt Taranaki has been dated at 1390 ± 150 yr B.P. (NZ 6508A). The next identified tephra bed is the informally named Manganui tephra. On Mt Taranaki this tephra has been encountered in the Ahukawakawa Swamp (McGlone et al. 1988), where it lies between peat layers dated at 2890 ± 100 yr B.P. (NZ 3423A) and 3320 ± 60 yr B.P. (NZ 3139A). Further down the Eltham Swamp profile is the Inglewood Tephra, which is underlain by abundant *Lagarostrobos colensoi* logs and stumps. A wood sample from 0.25 m beneath the Inglewood Tephra, collected 50 m south of the drillhole site, has been dated at 3950 ± 50 yr B.P. (NZ 5527A). Beneath this woody layer, and close to the summer water table, is the Korito Tephra. Beneath the Korito Tephra to a depth of 6.5 m, the peat contains scattered fine lapilli and coarse ash, with few distinctive tephra marker beds. Below 6.5 m there is a marked increase in tephra concentration, and an unnamed grey lapilli bed is particularly prominent. Peat from above and beneath this tephra was combined to provide enough material for radiocarbon dating, and it yielded a date of

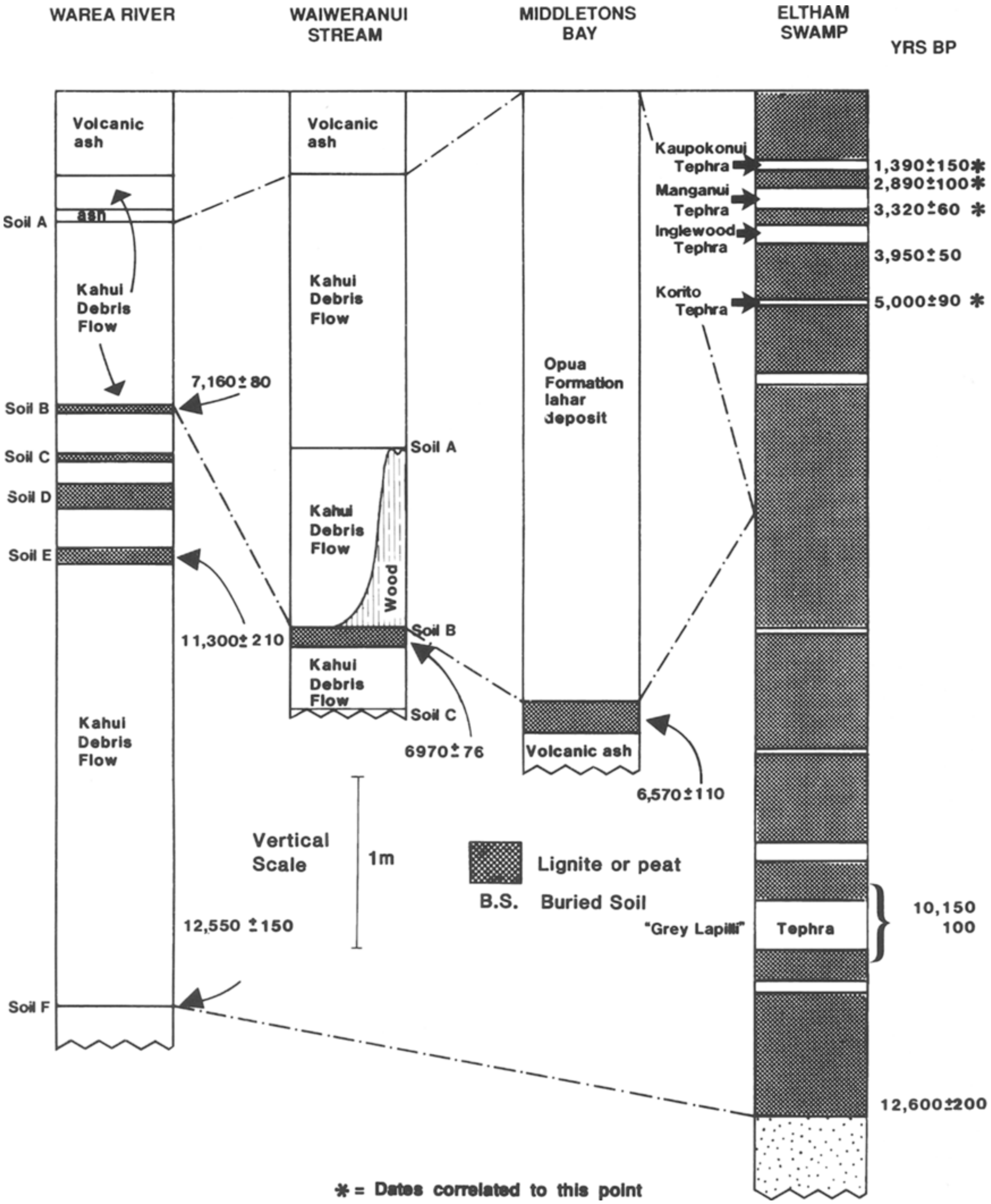

Fig. 3 Stratigraphic columns for Warea River, Waiweranui Stream, Middletons Bay, and Eltham Swamp pollen profiles.

10 150 ± 100 yr B.P. (NZ 3153A). The lowermost peat in the core, overlying a dark yellowish brown silty medium sand, was dated at 12 600 ± 200 yr B.P. (NZ 4038A).

The presence of tree roots through the upper part of the core made it unsuitable for radiocarbon dating. From the inferred ages of the tephras in the upper 1.0 m of peat, it seems that either peat growth slowed dramatically after 4000 yr B.P. or that nearly all the post-European shrinkage and loss of peat has taken place above the water table. If the estimated level of peat in the basin before drainage is taken into account, there was c. 4 m of peat above the Inglewood Tephra, giving a peat accumulation rate of close to 1.0 mm/yr. The accumulation rate between 6.8 m (10 150 yr B.P.) and the Manganui tephra (c. 3000 yr B.P.) at 0.8 m is c. 0.8 mm/yr, close to the accumulation rate inferred for the uppermost layers. From the radiocarbon dates, tephra layers, and derived accumulation rates, we have estimated ages for the palynological zones.

Site 2 Warea River: NZMS 260, P20/897147; altitude 280 m

This 5 m high section is exposed in a bank of the Warea River, 0.5 km north of upper Newall Road (Fig. 1), where a sequence of debris flow deposits (part of the Kahui Debris Flows) is preserved (Fig. 3). Sediments range from gravel to sand, with admixtures of volcanic ash and entrained logs. Interbedded between the flow deposits are eight, highly organic, buried soil deposits from 0.02 m to 0.25 m thick, which contain pollen of variable preservation. The polliniferous soils are designated A–F; A is the uppermost soil and F is the lowermost. Soil A had highly degraded pollen and spores and is therefore not included in the pollen diagram.

Buried soils B and F both contain wood of *Dacrydium cupressinum*. The wood from soil F has been dated at 12 550 ± 150 yr B.P. (NZ 1143A); from soil E at 11 300 ± 210 yr B.P. (NZ 1255A); and from soil B at 7160 ± 80 yr B.P. (NZ 1142A).

Site 3 Waiweranui Stream: NZMS 260, P20/910153; altitude 310 m

Upright stumps of *Dacrydium cupressinum* trees in growth position are exposed in the bank of Waiweranui Stream (Fig. 3) and form part of a forest buried by Kahui debris flows from Mt Taranaki (Neall 1979). They appear to have been partially buried by a flow to a depth of 2 m and then snapped off at this height by a subsequent flow. The stumps are associated with three buried soils. The lowermost soil (C) is 0.65 m below the base of the stumps. Above this is a 0.5 m thick flow deposit, followed by 0.15 m of peaty soil (B) in which the stumps are rooted. On the flow deposit that surrounds the stumps, and level with their tops, is a thin soil (A) buried by further flow deposits. Wood from the outermost part of one of the stumps rooted in soil B is dated at 6970 ± 76 yr B.P. (NZ 1144A).

Site 4 Middletons Bay (not an approved Geographic Board name) Opunake: NZMS 260, P20/831942; altitude 14.5 m above high water mark

This section (Fig. 3) is exposed in an 18 m high coastal cliff at the southeast corner of Middletons Bay, 0.6 km northwest of Opunake Beach (Fig. 1). There is a 0.22 m lens of peaty soil lying on volcanic ash preserved directly beneath the Opua Formation. The Opua Formation was deposited as a widespread, 3–5 m thick lahar in this sector, and at most localities it removed soil and peat from the ground surface as it was emplaced. At this site the peaty soil was preserved within a slight depression. Wood of a myrtaceous tree or shrub in the peaty soil is dated at 6570 ± 110 yr B.P. (NZ 1781A).

METHODS

All sites except Eltham Swamp were sampled from fresh exposures in the field. Eltham Swamp was drilled with a hand-operated Hiller borer. Pollen extraction followed standard palynological procedures of disaggregation of samples in 10% KOH, digestion in 40% HF, oxidation with a chlorine bleach, and acetolysis (Faegri & Iversen 1964). Pollen percentages are based on a pollen sum of all dryland plants, excluding those confined to or characteristic of mires, aquatic plants, and ferns and fern allies. A sum of 250 or more was used for nearly all percentage calculations.

Preservation of pollen and spores was poor in the Eltham Swamp site and in the Warea River buried soils.

The following pollen types are recognised and are listed with their constituent taxa:

Cyathea smithii type: *C. smithii*, *C. colensoi*
Cyathea dealbata type: *C. dealbata*, *C. medullaris*
Neomyrtus type: *Neomyrtus* spp., *Lophomyrtus* spp.
Nothofagus fusca type: *N. solandri*, *N. fusca*, *N. truncata*
Taraxacum type: all species in the tribe Lactuceae (Asteraceae)

POLLEN ANALYSES AND INTERPRETATION

Modern pollen rain for the Taranaki region has been studied by McGlone (1982) and Bussell (1988a), and pollen rain for similar vegetation types was reported and discussed in Pocknall (1978, 1980), Macphail (1980), Macphail & McQueen (1983), and Norton et al. (1986). The interpretations presented here are based on this work.

Tall podocarp trees, *Libocedrus*, *Ascarina lucida*, *Nothofagus fusca* type, and *Cyathea* are over-represented, and tend to dominate the regional pollen rain. Many pollen types are under-represented in the Taranaki flora (Bussell 1988a). In particular, pollen of *Beilschmiedia* is virtually absent from modern and fossil records, despite *Beilschmiedia* being one of the most abundant trees in undisturbed lowland forest. *Melicytus ramiflorus* is abundant in nearly all lowland forests but is seldom recorded in the pollen rain. Most other canopy and understorey plants are, to a greater or lesser extent, under-represented in the pollen rain.

Site 1: **Eltham Swamp** (Fig. 4)

Zone E1: 9.3–8.3 m depth; estimated age 14–13 000 – 12 600 yr B.P.

High levels of grass pollen (>80% at peak, av. 60–70%), tall-tree pollen <5% (mainly *Nothofagus* type), and the presence of only traces of conifer/broad-leaved taxa define this zone. Shrub pollen is not abundant and is dominated by *Phyllocladus* and Asteraceae. Herbaceous taxa are diverse, present in low amounts, and are characteristic of wet open sites.

The site was a herb-rich sedgy mire. The surrounding landscape was open grassland-shrubland, with low-growing woody plants. There was no substantial area of forest in the district.

Zone E2: 8.3–7.4 m depth; estimated age 12 600–11 100 yr B.P.

The abundance of grass pollen drops steadily from 25% to 5%, and *Prumnopitys-Podocarpus* rises steeply from 3% to 55% of the pollen sum. At the top of the zone, tree ferns, *Dacrydium cupressinum*, and *Dacrycarpus dacrydioides* are strongly represented, and virtually the full complement of conifer/broad-leaved taxa typical of the present-day forests have been recorded. Herbs and shrubs common in zone E1 either vanish or drop to low levels.

This zone represents a rapid transition from grassland, through a brief shrubland phase dominated by *Coprosma*, Asteraceae, and *Dracophyllum*, to a tall *Prumnopitys taxifolia* dominated conifer/broad-leaved forest. *Nothofagus menziesii* and *Libocedrus* appear to have persisted nearby, perhaps on the slopes of Mt Taranaki or scattered in forest near the site.

The sedge mire underwent successional changes, with first an invasion by small shrubs then *Leptospermum* and *Phormium*, and finally formed a *Leptospermum*/*Gleichenia*-sedge community. This is a typical sequence in present-day Egmont National Park mires (Bruce Clarkson pers. comm. 1993).

Zone E3: 7.4–6.8 m depth; 11 100–10 150 yr B.P.

Tall-tree pollen percentages remain similar to those prevailing at the top of zone E2, with *Nothofagus menziesii* and *Libocedrus* still consistently present. *Plagianthus regius* pollen is abundant. Grass pollen abundance decreases to trace amounts. *Empodisma* becomes a major contributor to the mire pollen total.

During this time, grassland was eliminated from the region, but *Nothofagus menziesii* and *Libocedrus* remained in the local forest. At the site, the spread of oligotrophic mire elements, perhaps in response to a rising water table, eliminated most shrubby plants with the exception of *Leptospermum*, which grows well on nutrient-poor, water saturated soils.

Zone E4: 6.8–6.3 m depth; 10 150–9600 yr B.P.

The *Prumnopitys*-dominated pollen assemblage of this zone is similar to that of E3. *Nothofagus menziesii* is eliminated, *Libocedrus* is reduced to trace levels, and *Ascarina lucida* and *Alectryon excelsum* are now consistently represented.

Although these pollen changes are slight, they record major changes in the local forests. From this time on, *Nothofagus menziesii* was extinct in western Taranaki, and *Libocedrus* was confined to higher altitude forests. The forest was now clearly lowland in character.

Zone E5: 6.3–2.2 m depth; 9600–4900 yr B.P.

This zone is defined by the abrupt rise to dominance of *Dacrydium cupressinum* pollen as *Prumnopitys*/*Podocarpus* percentages reduce to about one-third of those prevailing in zones E3 and E4. Levels of *Dacrydium cupressinum* pollen continue above 25% and *Prumnopitys*/*Podocarpus* below 15% for the remainder of the profile. *Metrosideros* pollen (the majority of grains identified under "Myrtaceous undiff." most likely belong to *Metrosideros*) becomes abundant shortly after the beginning of the zone, quickly achieving a transitory dominance, and

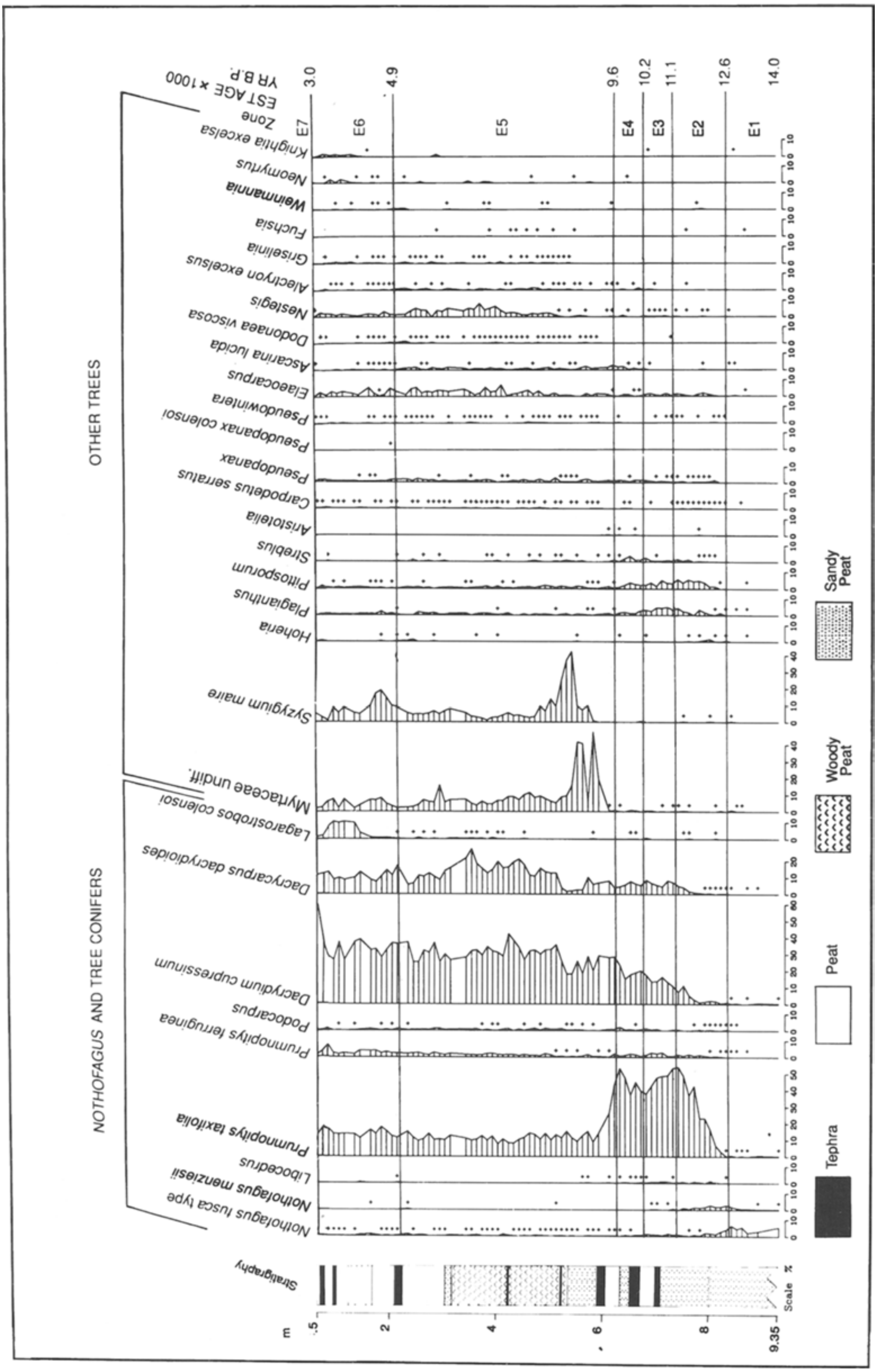

Fig. 4 Percentage pollen diagram, Eltham Swamp.

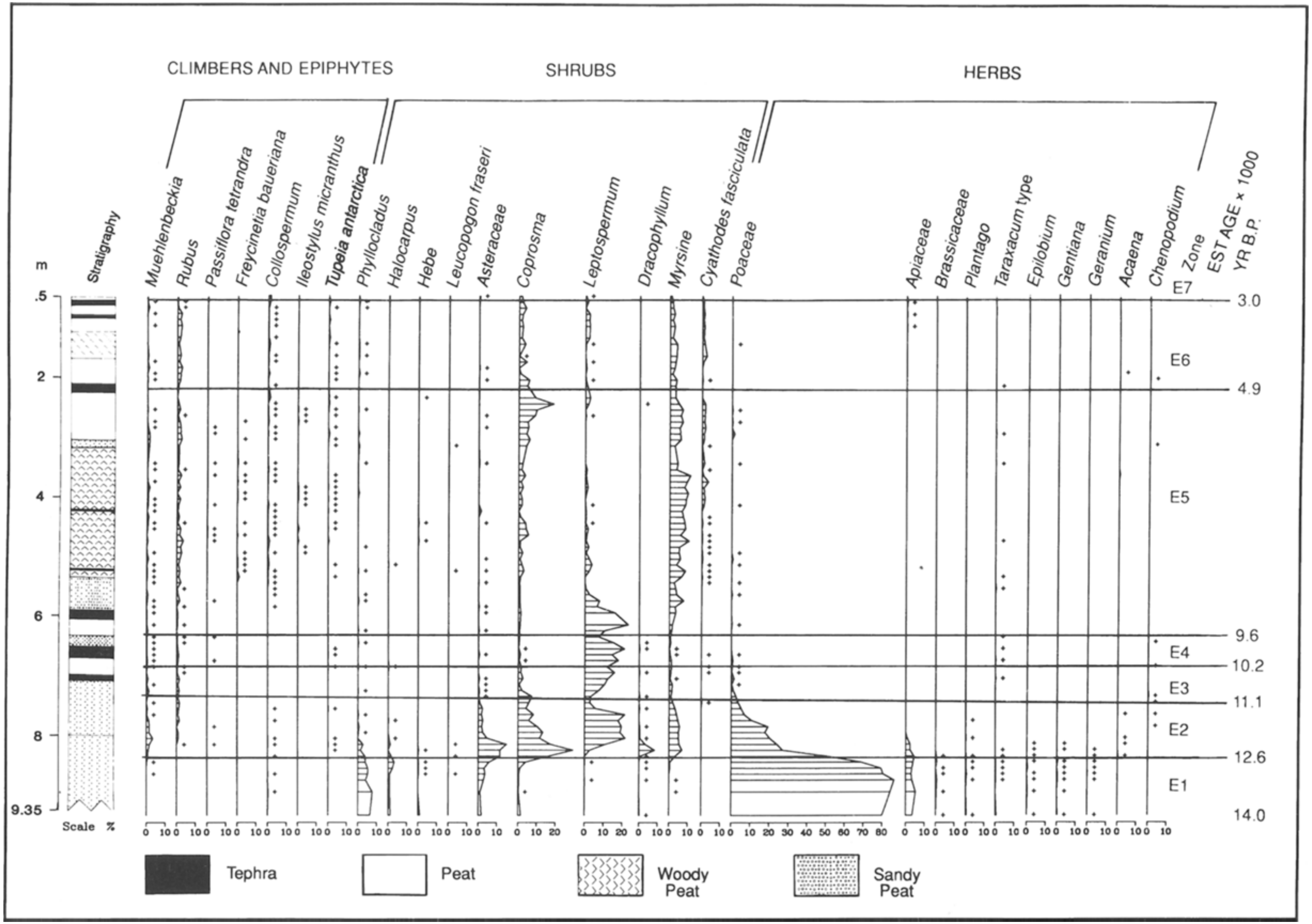

Fig. 4 *(continued)*.

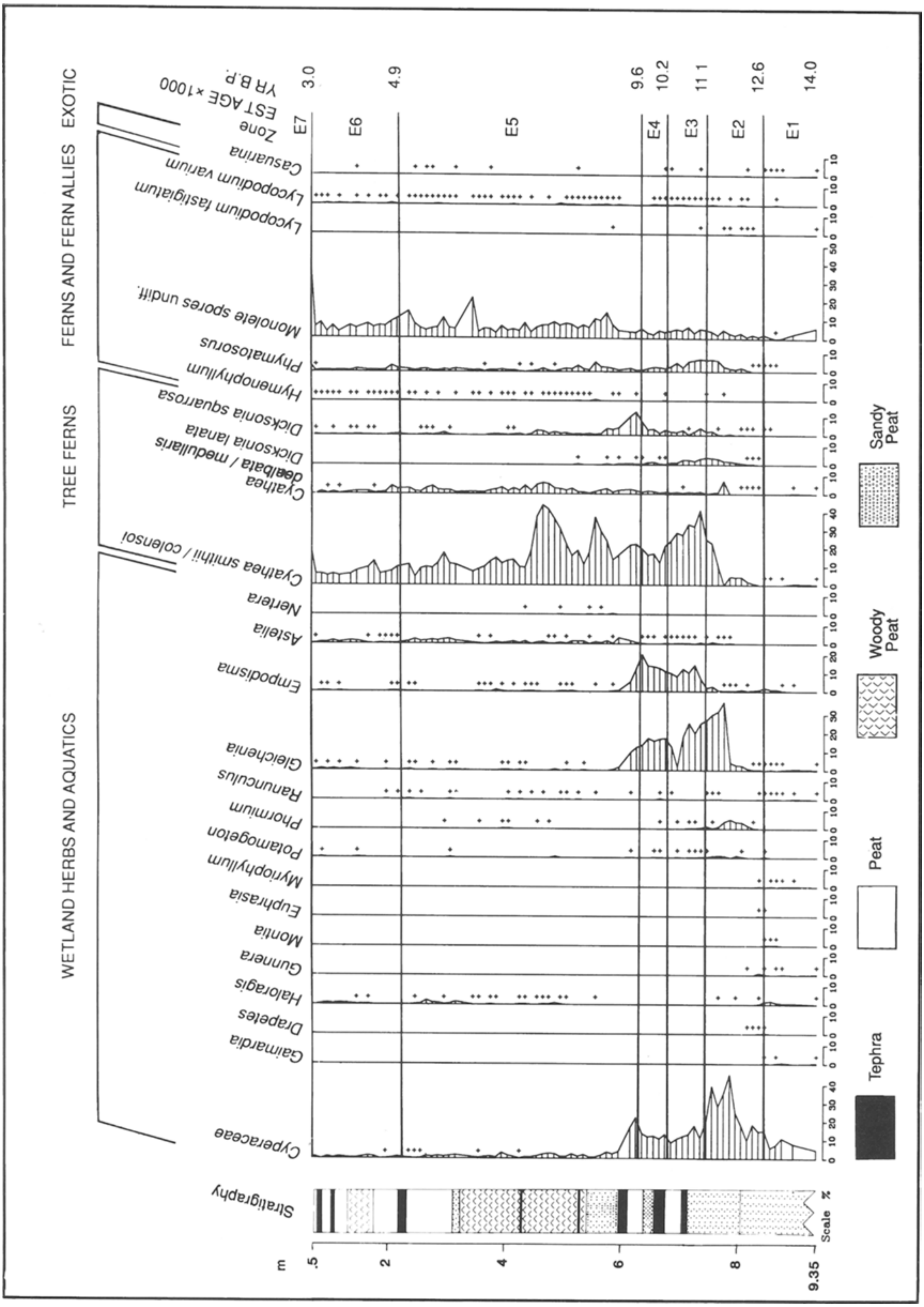

Fig. 4 *(continued).*

remains common throughout this zone and the next. *Ascarina lucida* has continuous representation throughout this zone.

The regional forest changed from a *Prumnopitys taxifolia*-dominant association to one in which *Dacrydium cupressinum* was the major tall-tree podocarp, and *Metrosideros* (both tall trees and vines) was a prominent constituent of the canopy. The previous oligotrophic mire complex of sedges, *Empodisma*, and *Leptospermum* was replaced by a swamp forest of *Syzygium maire*, that in turn was invaded by *Dacrycarpus dacrydioides*. At the point where *Dacrycarpus dacrydioides* pollen became abundant in the profile (5.3 m), unidentified wood fragments became common. Scrub pollen types (*Coprosma*, *Leucopogon fasciculatus*, and *Myrsine*) were common, indicating that the swamp forest had a discontinuous canopy. However, it supported a rich flora of epiphytes and lianas, including *Collospermum*, *Passiflora*, and *Freycinetia*.

Zone E6: 2.2–0.7 m depth: 4900–3000 yr B.P.

Continuous percentages of *Lagarostrobos colensoi* and the decline of *Ascarina lucida* from the previous levels of 1–2% to <1% define this zone. *Knightia excelsa* has significant representation, indicating local presence, in the upper half of the zone.

Swamp forest and shrubland remained dominant at the site. High levels of *Lagarostrobos colensoi* pollen, the presence of its wood in the peat, and an increase in *Gleichenia* and *Leptospermum*, indicate a retreat of *Dacrycarpus dacrydioides* and its supplantation by an open *Lagarostrobos colensoi* bog forest.

Zone E7: one sample only (0.6 m); c. 2900 yr B.P.

Dacrydium cupressinum pollen increases to its highest level (60%). Tree ferns and monolete fern spores increase sharply.

The local forest abruptly altered when *Dacrydium cupressinum* invaded out onto the mire surface. There is no significant change in the regional forest.

Site 2: **Warea River** (Fig. 5)

Buried soil A has a poorly preserved pollen spectrum and was not analysed. The remaining buried soils fall into three groups on the basis of their pollen spectra.

Zone W1: Buried soil F; 12 500 ± 150 yr B.P.

The pollen spectrum indicates a conifer/broad-leaved forest dominated by *Prumnopitys taxifolia*, with much lesser amounts of other tall podocarp trees. The local site was a sedge mire with a *Leptospermum* overstorey.

Zone W2: Buried soils E, D, and C; soil E dated at 11 300 ± 210 yr B.P.

Dacrydium cupressinum is the major tall-tree type, and tree ferns are abundant. *Prumnopitys taxifolia* is the only other significant contributor to the arboreal pollen sum, but there is a significant level of *Libocedrus* in soil E. As in zone W1, there is very little pollen of understorey trees, but small amounts of *Ascarina lucida* pollen are found in the upper two buried soils, and *Metrosideros* (possibly mainly vines) is recorded in all soils.

Zone W3: Buried soil B; dated at 7160 ± 80 yr B.P.

Dacrydium cupressinum almost completely dominates the arboreal pollen sum, and *Prumnopitys taxifolia* falls to its lowest value. *Ascarina lucida* and tree fern spores are abundant.

Site 3: **Waiweranui Stream** (Fig. 5)

The pollen spectra of the two lowermost buried soils (C and B) are dominated by *Dacrydium cupressinum* pollen, and *Metrosideros* spp. and *Cyathea smithii* type spores are abundant. *Ascarina lucida* has exceptionally high levels. These soils formed beneath the canopy of *Dacrydium cupressinum*/*Metrosideros* forest, with a dense understorey of *Ascarina lucida* and *Cyathea smithii*.

The pollen spectrum from buried soil A is dominated by *Coriaria*, and the pollen percentages of all other trees and shrubs are correspondingly low, but essentially they reflect an unchanged forest composition. One of the Kahui debris flows devastated the forest at this site, as indicated by the buried tree stumps. *Coriaria*, which is an early successional shrub, proliferated after this event, as it does on slips on Mt Taranaki at present.

Site 4: **Middletons Bay, Opunake** (Fig. 5)

Pollen of tall podocarp trees makes up only 16% of the pollen sum; *Dodonaea viscosa* is the most abundant pollen type (25%), and there are relatively high percentages of *Metrosideros*, *Myrsine*, *Neomyrtus* type, *Ascarina lucida*, and *Cyathea dealbata* type spores.

The site was covered with a low-growing shrubby coastal forest, consisting mainly of *Metrosideros* spp., *Myoporum laetum*, *Myrsine* spp., *Dodonaea viscosa*, and *Ascarina lucida*.

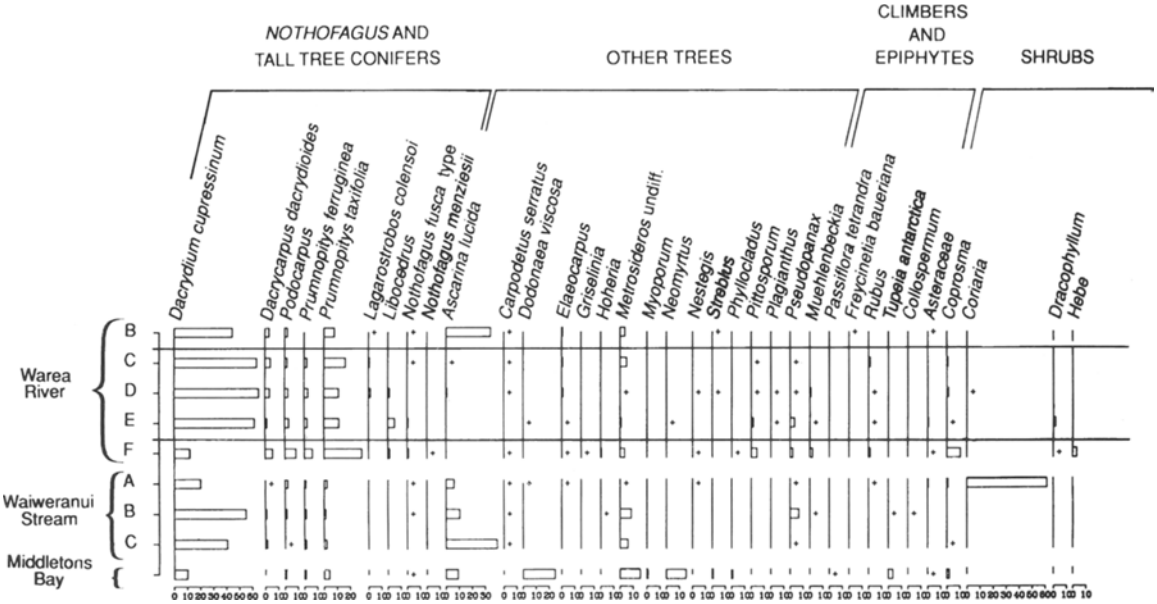

Fig. 5 Percentage pollen diagrams, Warea River, Waiweranui Stream, and Middletons Bay.

VEGETATION AND CLIMATIC HISTORY

Late-glacial: 14 000–10 000 yr B.P.

Shortly before 13 000 yr B.P., when the first organic sediments began to accumulate in the Eltham Swamp basin, a treeless, grassland-covered landscape surrounded the site. There is no indication that forest or tall scrub formed a significant part of the local vegetation. Possibly forest and tall scrub grew on the sea-facing slopes of the Taranaki volcanic ranges, but if it did, it did not influence the Eltham Swamp pollen record. There was a constant influx of sand and silt into the open herb-rich mire that grew at the site, suggesting that the surrounding grassland either did not provide a complete ground cover, or that it was subjected to periodic disruption by fire, frost-heave, or heavy rainstorms.

The almost complete absence of forest or scrub from inland Taranaki at a time when forest had already substantially occupied the inland Tongariro region (McGlone & Topping 1977), at an altitude some 300 m higher and with a significantly cooler climate (1–2°C colder), is anomalous. Although the basal radiocarbon date at the Eltham sites could possibly be contaminated by younger carbon, a peat and tephra profile some 30 km to the northwest records an essentially similar pollen sequence with the same dating (Alloway et al. 1992). Sites in south-eastern and northern North Island districts (Lees 1986; McGlone 1988; Newnham et al. 1989) had tall podocarp forest cover by at least 13 000 yr B.P. The local topography of the Eltham Basin, with high well-drained ground to the east and west, and the considerable elevation of the site (300 m), could be invoked to explain this anomaly. However, although the resulting cool, windy, frost and drought-prone nature of the local area could explain why grassland was dominant within the basin rather than shrubland, it is unlikely to account for the almost complete absence of forest in the surrounding district. The Waikato Basin, the inland south-eastern North Island, and the Volcanic Plateau have an even more continental climatic regime, which did not inhibit the earlier spread of forest in these locations.

CLIMAP sea-surface temperature estimates for 18 000 yr B.P. indicate an offset of 2–4°C from the cooler west to the warmer east across the southern half of the North Island (CLIMAP 1981). If this sea-surface temperature offset persisted into the late-glacial, it could provide an explanation for the delayed spread of forest. A cool Tasman sea would depress temperatures and decrease rainfall along the Taranaki coastline and southwards. Although the temperature depression alone would not exclude forest, hard frosts, low rainfall, and high wind speeds may have done so.

The replacement of the late-glacial grasslands by forest was rapid; probably the entire sequence lasted

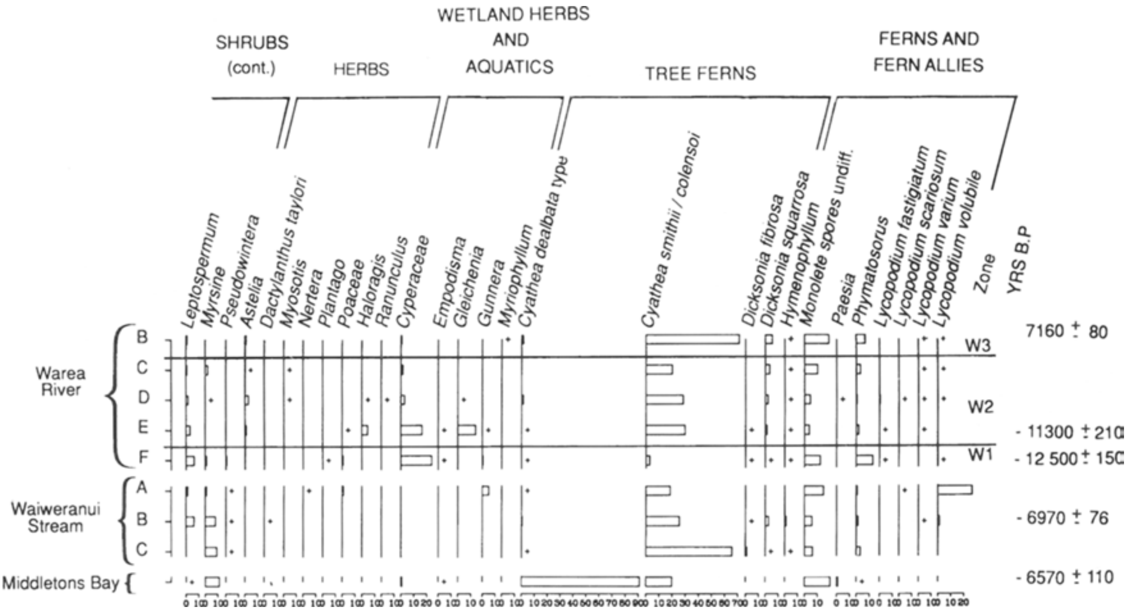

Fig. 5 *(continued).*

no more than 1000 radiocarbon years at Eltham. There is some indication of a brief period of scrub dominance on the poorly drained frosty basin site at the time that conifer/broad-leaved forest expanded into surrounding districts. This interpretation is supported by the earlier dominance of podocarp forest at the Warea River site (12 550 yr B.P. versus c. 12 000 yr B.P.), where greater rainfall, more shelter, and the coastal location moderated the local climate. Significant differences in vegetation between the two sites have persisted through to the present.

The earliest late-glacial forests of the Taranaki region were different from those of the area at present, and showed a strong resemblance to the present *Prumnopitys taxifolia*-dominant forest of the eastern side of the southern North Island and South Island. *Streblus*, *Plagianthus*, and *Pittosporum* were among the most common angiosperm genera in the early Taranaki forests, and these are abundant in the present-day east coast forests, especially on alluvial sites. Present eastern forests grow under a more climatically stressed regime than those in the west, as the summers tend to be drier and warmer, and the winters colder and frostier. The probable presence of *Nothofagus menziesii* and *Libocedrus bidwillii* in the late-glacial forests also indicates a somewhat cooler climate. *L. bidwillii* trees are now common in the forest canopy only at altitudes >875–900 m on Mt Taranaki, and in the central North Island *N. menziesii* is mostly restricted to altitudes of 600 m or higher (Wardle 1967). McGlone & Topping (1977) and Newnham et al. (1989) have suggested that late-glacial annual temperatures may have been 2–3°C lower than those of the present in central and northern North Island, and this estimate is consistent with the Taranaki evidence. They also suggested that the climate was drier.

Prumnopitys taxifolia dominant forest, with *Dacrydium cupressinum* uncommon or absent, tends to be restricted to areas with an annual rainfall <1000 mm, although this general pattern is modified in high rainfall areas by well-drained fertile soils, which may have stands dominated by *P. taxifolia.* Of the major tree podocarps, *Prumnopitys taxifolia* is the least competitive in the presence of vigorous mesophytic broad-leaved vegetation, and has a slower growth rate than *D. cupressinum* on all but the most favourable sites (Beveridge 1983). Fresh alluvial soils tend to favour *P. taxifolia*, and the soils of the Eltham Basin and Warea sites are likely to have been fresh and therefore of high potential fertility. If the late-glacial climate was drier, droughtier, and more frost-prone than that of the Holocene, the faster growing, more competitive, but less stress tolerant *D. cupressinum* would have been at a disadvantage against *P. taxifolia.* As in the Waikato Basin (Newnham et al. 1989), both climatic and edaphic factors may have played a role in the early prominence of *P. taxifolia* in Taranaki.

Dacrycarpus dacrydioides, which, like *P. taxifolia*, favours fertile soils (Beveridge 1983) but has a lower altitudinal limit and a stronger preference for wet climates and sites (Hinds & Reid 1957), was even more restricted than *D. cupressinum* in the late-glacial. If fertile soils were the only factor favouring the dominance of *Prumnopitys taxifolia*, *Dacrycarpus dacrydioides* should have also been favoured. *D. dacrydioides* and *P. taxifolia* pioneered simultaneously on fresh alluvial soils in Southland at the beginning of the Holocene (McGlone & Bathgate 1983), which suggests that, under dry but otherwise equable climates, these trees together will dominate to the near-exclusion of *D. cupressinum*. Tree ferns, which are common only on moist sites, are initially scarce in the late-glacial Taranaki forests, becoming abundant only after a significant lag, which suggests that frosty conditions and a low rainfall restrained them. The initial mire vegetation at Eltham is also consistent with that growing in drier regions, with *Phormium* and sedges prominent, and an oligotrophic bog typical of regions with consistently high rainfall developed only later in the sequence.

Comparisons with extant forests, known ecological relationships, and competitive interactions among the major tall-tree species, therefore tend to point towards a drier, frostier, late-glacial in Taranaki, regardless of any influence from edaphic conditions. If late-glacial precipitation was the same as that of the present, lower annual temperatures and the resulting lower evapotranspiration would have led to much wetter soils. As the pollen evidence indicates drier soil conditions, late-glacial precipitation must have been substantially below that of the present. Eltham forests bear a strong resemblance to present-day lowland forests in Southland growing under a cooler, drier climatic regime (mean annual temperature 9–10°C; rainfall 1000–800 mm/yr) (McGlone & Bathgate 1983). Annual rainfall during the latter half of the late-glacial in inland Taranaki may therefore have been c. 1000 mm/yr, or some 30–20% lower than at present.

As the climate ameliorated towards the end of the late-glacial, the forests changed slowly. *Dacrydium cupressinum* soon achieved dominance under the wetter, more maritime climate of the Warea site but, although it became a substantial element at the Eltham site, it remained secondary to *Prumnopitys taxifolia*. *Libocedrus bidwillii* and *Nothofagus menziesii* vanished from the local forests, and elements typical of milder climates, such as *Alectyron excelsus*, *Ascarina lucida*, and *Cyathea dealbata*, made an appearance after 11 000 yr B.P.

The Holocene (10 000 yr B.P. to the present)

Shortly after 10 000 yr B.P., the Eltham forests achieved a composition close to that of the present. A steep decrease in *Prumnopitys taxifolia* and a less marked increase in *Dacrydium cupressinum* reversed the relative dominance of these two, tall-podocarp trees. The most dramatic transformation of the vegetation occurred on the Eltham mire surface. The *Leptospermum*-oligotrophic mire vegetation was invaded first by *Metrosideros* spp. (including *M.* cf. *robusta* as well as *Metrosideros* vines), then by *Syzygium maire* swamp forest, and then by *Dacrycarpus dacrydioides*. Swamp forests generally do not grow on deep peat, and are more typical of gleyed or shallow organic soils. Pollen and spores are badly corroded at the Eltham site, which suggests that the water table may not have been permanently at the surface, thus permitting more aerobic activity and decomposition than would be normal in a typical wetland. The Eltham profile contained much sandy peat and abundant layers of volcanic lapilli, which may have provided sufficient nutrients to support a dense forest cover. The Eltham Basin sediments were therefore formed by a succession of wet forest soils.

The abrupt increase of *Metrosideros* spp. occurred after the close-spaced deposition of a succession of thick lapilli layers and was probably a consequence of rising annual temperatures and rainfall, combined with deposition of a nutrient-rich tephra substrate that improved fertility and drainage. Herbaceous swamp plants were rare, and there was a constant representation of forest vines and epiphytes from the point at which *Metrosideros* became abundant, which suggests a nearly closed forest canopy at the site. The initially dense *Metrosideros* forest was soon modified by the spread of first *Syzygium maire*, and then *Dacrycarpus dacrydioides* and probably *Dacrydium cupressinum*, onto the mire surface as drainage deteriorated again. For the rest of the Holocene, a complex swamp forest dominated by these elements must have extended over most of the Eltham wetland.

The Holocene vegetation transformation was most likely a consequence of wetter and warmer conditions. The spread of tall forest onto poorly drained soils suggests warmer, more equable conditions, as tall swamp forest tends to be restricted to lowland areas. Likewise, *Dacrydium cupressinum* is not a dominant in areas where drought or low rainfall prevails (Franklin 1968; Norton et al. 1988). A suite of taxa (such as *Passiflora tetrandra*, *Freycinetia*, *Dodonaea viscosa*, and *Ascarina lucida*) characteristic of warm equable conditions, either absent or present in low frequencies during the late-glacial, is consistently recorded during the Holocene. Nothing in the Eltham profile, however, demands climatic conditions significantly different from those of the present. Remnants of swamp forest in the district have floras essentially identical to those indicated by the pollen profile. However, Warea River, Waiweranui Stream, and Middletons Bay sites were distinguished from all present-day Taranaki locations by high amounts of *Ascarina lucida*. A mid-Holocene coastal site 50 km to the south had similar high levels of *Ascarina* and *Dodonaea viscosa* (Bussell 1988b). Only six individuals of *A. lucida* are now known in Taranaki, all on or near the Pouakai Range (McGlone et al. 1988), and its pollen is uncommon in present-day spectra (McGlone 1982; Bussell 1988a). Pollen percentages of 15–40% are rare even in areas where *A. lucida* is presently a dominant (McGlone & Moar 1977; Pocknall 1978, 1980). We conclude that not only was *A. lucida* present in mid-Holocene coastal Taranaki, but it also equalled the peak abundances now found only in lowland conifer/broad-leaved forests of the South Island West Coast, where this species is a dominant understorey plant.

Not much is known about the ecology of *Ascarina lucida*. It is a shrub or small tree, and is presently widespread as a subcanopy element in lowland conifer/broad-leaved forests of the West Coast of the South Island. Its present range shows an apparent preference for cool (c. 10°C annual temperature) but highly equable climates with a low incidence of drought and frost (McGlone & Moar 1977). However, until the recent European deforestation of lowland areas, it also occurred in the far north of the North Island. *Ascarina lucida* var. *lanceolata* is abundant on the warm (av. annual temperature 19°C), moist (av. annual rainfall 150 mm), temperate northern Kermadec Islands, where it is mainly confined to montane (above 245 m), moist cloud forests (Sykes 1977). *Ascarina lucida* therefore indicates highly oceanic equable climates, but will thrive over a wide range of annual temperatures. Its dominance in the forest understorey along the Taranaki and Wanganui coastlines during the early–mid Holocene is a clear indication that the climate was even less prone to the drought and frost than it is at present.

Dodonaea viscosa was also abundant in coastal south-western North Island sites during the mid Holocene (Bussell 1988b). *D. viscosa* is characteristic of warm, sunny, coastal sites and favours well-drained, often dry sites, and is usually marginal to forest. *D. viscosa* and *Ascarina lucida* do not normally occupy the same sites in the present-day vegetation. Their apparently close association in coastal sites in the early and mid Holocene further suggests a highly equable, drought-free climate, but one with a lower annual rainfall than now.

The Eltham record shows no clear indication of a change in the dominant tall-forest trees in the late Holocene. A pollen profile in the Ngaere Swamp 2 km from the Eltham site (Lees 1987: core 82/1) spans the last 4000 years of the Holocene and indicates that forest similar to that in the uppermost levels of the Eltham core persisted without change until cleared by European settlers. Pollen diagrams from the upper slopes of Mt Taranaki about 30 km away also show relatively unchanging lowland tree-pollen spectra dominated by *Dacrydium cupressinum* over the last 3500 years (McGlone et al. 1988).

Some small or subdominant trees and shrubs do alter in abundance in the late Holocene. *Ascarina lucida* and *Dodonaea viscosa* become less abundant after c. 4000 yr B.P. in the Eltham diagram, although this change is not strongly registered. However, Bussell (1988b) showed that both *Ascarina lucida* and *Dodonaea viscosa* had reduced abundances by 5700 yr B.P. and were essentially at present-day levels by 3000 yr B.P. The Mt Taranaki diagrams show that both were rare by 3500 yr B.P. and at present-day abundances by 1400 yr B.P. Their late Holocene reduction shows that both drought and frost increased towards the present.

The expansion of *Knightia excelsa* just before the deposition of the Korito Tephra (4000–5000 yr B.P.) may be the local expression of a North Island-wide event. *Knightia* became common at 7000 yr B.P. in the Waikato Basin (McGlone 1988; Newnham et al. 1989); at c. 5000 yr B.P. on the Volcanic Plateau (McGlone & Topping 1977); by 3000 yr B.P. in the Wanganui district (Bussell 1988b); after 3000 yr B.P. in the northern Ruahine Range (Rogers & McGlone 1989); and c. 3400 yr B.P. at a site on the western side of the Wellington Peninsula, southern North Island (Mildenhall 1979). Isolated grains of *K. excelsa* are recorded in the late-glacial, not only at Eltham, but also in the Waikato Basin (Newnham et al. 1989) and on the Volcanic Plateau (McGlone & Topping 1977), and it is therefore likely to have been present, but uncommon, in North Island forests until the mid–late Holocene, when it began a North Island-wide expansion.

Knightia excelsa grows under a wide range of conditions in the North Island and northern South Island, but does best as a pioneering tree on sunny and often well-drained slopes (Hinds & Reid 1957). Within Egmont National Park it occurs in forest on well-drained slopes and ridge tops on the lower slopes of Kaitake, and as a canopy dominant in regenerating scrub in the same area (Clarkson 1986). Its expansion in the late Holocene may well have been a consequence of greater opportunities for a species favoured by disturbance and tolerant of edaphically dry sites. As climates became more variable and severe in the late Holocene, and the previous understorey and seral dominants became less prominent, *Knightia* may have begun to expand from its previously restricted role (Mildenhall 1979). The impact of more frequent and larger scale disturbances, such as cyclonic storms, as suggested by McGlone et al. (1984b), would have aided this process.

The vegetative cover of the mire complex at Eltham changed little during the late Holocene, except for the strong increase of *Lagarostrobos colensoi*, which had been present as a minor constituent of the mire vegetation from late-glacial times. However, it greatly expanded after 5500 yr B.P., which must reflect a more open forest structure on the mire, with a *Gleichenia*-dominated ground cover. The period of *Lagarostrobos colensoi* dominance was apparently brief, as it returned to low levels by 3000 yr B.P. and is not found in the Taranaki region today, although *Lagarostrobos colensoi* wood is found in the surface layers of many drained lowland peats in the general area of the Eltham Swamp. *Lagarostrobos colensoi* expanded elsewhere in the central North Island during the latter half of the Holocene. At Rotoaira (Volcanic Plateau, central North Island; McGlone & Topping 1977) *Lagarostrobos colensoi* was consistently present throughout the Holocene, increased strongly c. 5000 yr B.P., but returned to lower levels by 3500 yr B.P., and then underwent a second but less clearly defined oscillation just before 1800 yr B.P. A similar increase occurred at a site in Waikato (Rotokauri) c. 5500 yr B.P., but the species was also common during the late-glacial (Newnham et al. 1989), and McGlone et al. (1984b) recorded it in low but continuous amounts from 6000 to 2000 yr B.P. at Ohinewai. Wood of *Lagarostrobos colensoi* is abundant in the upper layers of some Waikato mires, although the tree is no longer found in the region (Gudex 1954).

The rise and decline of *Lagarostrobos colensoi* may be regionally synchronous and, if so, it is possibly climatically induced. *Lagarostrobos colensoi* is abundant at present only on the West Coast of the South Island and the Volcanic Plateau of the central North Island (Hinds & Reid 1957). It is a small tree that grows mainly on gley or mire soils. It is mainly confined at present to areas of high rainfall (>2000 mm) and cool average annual temperatures

Table 1 Summary of vegetation and climate history, 12 500–3000 yr B.P., lowland Taranaki.

Years B.P.	Vegetation	Inferred climate
3000–5000	Tall conifer/broad-leaved forest dominated by *Dacrydium*; *Knightia* prominent; *Ascarina lucida* and *Dodonaea* much reduced. *Lagarostrobos colensoi* common at times on mires.	Close to that of the present, drought/summer moisture deficit increasing.
9500–5000	Tall conifer/broad-leaved forest dominated by *Dacrydium*. *Ascarina lucida* and *Dodonaea* abundant in coastal regions. *Dacrycarpus dacrydioides* and *Syzygium* dominant in Eltham Basin.	Mild equable climate; rainfall probably lower than at present; summer moisture deficits rare or absent.
9500–11 000	Tall conifer/broad-leaved forest dominated by *Prumnopitys taxifolia*; *Libocedrus* and *Nothofagus menziesii* present in lowlands.	Temperatures cooler by as much as 1–2°C than those of the present, and precipitation possibly 30% lower.
11 000–12 500	Rapid transition from grassland-shrubland to tall podocarp dominant forest.	Rapid amelioration of climate; *Nothofagus* eliminated.
14 000?–12 500	Grassland-dominated landscape with low shrubs; forest highly restricted.	Perhaps 3°C cooler than now, with windier, drier, frostier conditions.

(11–10°C or less). However, *Lagarostrobos colensoi* has highly specific ecological requirements, as it often forms an intermediate zone of low forest between open mire shrub and herb vegetation and tall podocarp-dominated forest (Norton 1989). It can thus tolerate shallow peat soils and intermediate levels of soil saturation. Its restriction to cool, very wet areas may argue for its intolerance of drought or summer water deficits. If this is so, its strong upsurge in the late Holocene, but absence after c. 3000–2000 yr B.P. at many sites, could indicate some intermediate level of cool climatic conditions but tolerable summer moisture deficits.

In many locations in the North Island, especially in southern and upland regions, *Nothofagus* species increased strongly during the middle and late Holocene after having been restricted or uncommon in the early Holocene (McGlone 1988). There is no sign of such an increase in western Taranaki, where *Nothofagus* species are completely absent. However, *N. menziesii* was present in the late-glacial and vanished as a result of competition from other angiosperm trees and podocarps under an ameliorating climate. Its present-day absence, despite the cooler, more variable late Holocene climates, probably reflects the difficulty *Nothofagus* species have in invading well-established, tall podocarp/broad-leaved forest growing in mild moist conditions, especially on moderately fertile to fertile soils.

Of similar biogeographic importance is the absence of *Empodisma* and the highly localised occurrence of *Gleichenia dicarpa* in Taranaki, and the general low abundance of many oligotrophic or raised bog species (Bruce Clarkson pers. comm. 1992). This may be the result of the long Holocene dominance of swamp forest on poorly drained sites, made possible because of the mild climate and the continual fertilisation by frequent volcanic ashfall. Few wetland sites would have been sufficiently open to support low-growing oligotrophic vegetation.

In summary, we present our conclusions on the vegetation and climate of the last 14 000 years in the Taranaki lowlands in Table 1.

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