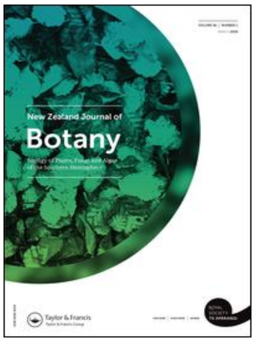

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Late Holocene forest disturbance in Gisborne, New Zealand: a comparison of terrestrial and marine pollen records

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Abstract A late Holocene (from c. 5500 yr B.P.) record of vegetation change is presented for the Gisborne region, based on pollen, charcoal, and tephra analyses of a terrestrial and a marine core. Up until the time of anthropogenic deforestation about 650 yr B.P., well drained lowland areas were covered with a *Prumnopitys taxifolia*, and *Dacrydium cupressinum*-dominated podocarp/hardwood forest. The poorly drained *Dacrycarpus dacrydioides*-dominated alluvial swamp forests were not as vulnerable to fire, and remained on the Gisborne Plains until European drainage and clearance began in the 19th century. In the last 5500 yr B.P., the lowland forests have been disturbed by at least five ashfalls originating from volcanic eruptions in the Central Volcanic Region. Where the terrestrial and marine cores overlap, comparisons of the pollen records show the vegetation changes and taxa present to be comparable. The fire record was not clear in the marine record, as the charcoal curve was diluted with high background levels of reworked charcoal. Sedimentation rates from the marine core indicate that erosion in the Waipaoa catchment has increased significantly since European clearance of soil-protecting remnant forest and fern/scrubland and its replacement with pasture.

Keywords charcoal; deforestation; disturbance; El Niño; fire; human impact; New Zealand; pollen; Poverty Bay; tephra; vegetation history; volcanism

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INTRODUCTION

Only the late Pleistocene vegetation history has so far been established for the Gisborne region in the eastern North Island of New Zealand (McGlone et al. 1984). This paper provides a late Holocene record of vegetation disturbance following volcanic eruptions, fire, and human settlement, based on pollen and sediment analyses of a terrestrial peat core from a sub-catchment of the Waipaoa River. These analyses were also repeated on a short marine core taken from the Poverty Bay continental shelf. The Waipaoa River catchment originates in the axial ranges of the eastern North Island and drains out to Poverty Bay via the coastal plains of Gisborne. Because of the large size of the Waipaoa River catchment (2205 km^2), and the fact that its geology is dominated by highly erodible soft Tertiary and Cretaceous rock, the suspended bedload of the Waipaoa River supplies the largest proportion of sediments to the Poverty Bay shelf (Foster & Carter 1997). Comparisons of the marine and terrestrial pollen records are made where they overlap.

Important regional vegetation and climate histories, some spanning several glacial-interglacial cycles, have been derived from long marine cores taken from the eastern coast of New Zealand (e.g., Stewart & Neall 1984; Heusser & Van de Geer 1994; Wright et al. 1995). These deep-sea cores are also composed mainly of terrestrially derived sediments. Given that there are 30–45 m of sediment on the open shelf of Poverty Bay that date from c. 18 000 yr B.P. (Foster & Carter 1997), long cores from this part of the Poverty Bay coastal shelf hold the potential to contain a detailed and accurate palaeoclimatic record for this period. Therefore, in the context of these long records, the work presented here not only provides a history of vegetation disturbance for the last 5500 years for Gisborne, but also establishes how accurately the marine record can represent certain aspects of the terrestrially derived environmental history for the eastern region of New Zealand.

STUDY AREA

Repongaere Swamp lies c. 15 km north-west of Gisborne (Fig. 1) at the northern end of a small shallow lake basin, which is surrounded by a steep hilly catchment (2.8 km^2) ranging in elevation from 20 to 223 m. Swampy lagoons used to be more extensive in the catchment before European drainage, covering the flat valley bottom up to 2 km north of the lake, in the direction of the lake drainage (Henderson & Ongley 1920). The catchment is almost entirely covered with pasture, with a narrow fringe of willow trees planted on the western shores of the lake. The swamps on the lake margin are dominated by *Typha orientalis** (raupo), and *Glyceria fluitans* (floating sweetgrass) dominates in the northern reaches of the swamp where the water table is lower. The Repongaere catchment and the lowland regions of the Waipaoa River catchment lost most of their original cover of native lowland podocarp/hardwood forest and swampland as a result of anthropogenic clearance and drainage, although a swamp forest persisted on the poorly drained flood plains up until the time of early European settlement.

The marine core used in this study was taken from the Poverty Bay continental shelf, which extends 22–26 km east of the coast (Foster & Carter 1997). The shelf-floor is mantled by sand and mud, most of which is derived from the Waipaoa River, and has a mean grain size decreasing gradually offshore, with little material contributed by coastal erosion.

The Repongaere catchment and the Gisborne Plains receive a mean annual rainfall of c. 1000 mm, but rainfall is much higher in the mountainous parts of the region (>3000 mm yr^{-1}), strongly reflecting the effect of topography on the principal rain-producing winds from the north and south-east (Hessell 1980). Gisborne has highly variable monthly and seasonal rainfall and is affected by periodic droughts and intense rainstorms. Modified storms of tropical or polar origin affect the east coast (Hessell 1980).

The study area lies about 120 km directly east of the Central Volcanic Region of New Zealand (Froggatt & Lowe 1990). Numerous eruptive episodes during the Holocene have deposited tephras on the Gisborne and Poverty Bay area. The most prominent of these tephras from the last 4000 years are from the Taupo Volcanic Centre, including the Taupo Tephra (1850 ± 10 yr B.P.; Froggatt & Lowe 1990) and the Waimihia Tephra (3280 ± 20 yr B.P.; Froggatt & Lowe 1990) which are widespread and 15–30 cm and 10–20 cm thick, respectively, on the Repongaere and Waipaoa catchments. Other, thinner, microscopic layers of tephra, including the Mapara (2160 ± 25 yr B.P.) and Whakaipo (2685 ± 20 yr B.P.), are also present on the Gisborne landscape, as is the Kaharoa Tephra (665 ± 15 yr B.P.; Lowe et al. 1998) from the Mount Tarawera complex in the southern part of the Okataina Volcanic Centre, which is found up to 3 cm thick in the area.

METHODS

Coring

Terrestrial core: Repongaere Swamp (38°35′36″S, 177°52′18″E)

A 5-m peat core was taken using a Hiller borer, from a small grass-covered area bordering the water-logged swamp (grid ref: NZMS 260 Y18/343787) at the northern end of Lake Repongaere (Fig. 1). The core was sub-sampled in the field at 5-cm intervals, with closer sampling intervals of 2 cm above visible tephra layers.

Marine core: Poverty Bay (38°39′54″S, 178°20′36″E)

A 2.5-m long mud core (core W396) was collected by the National Institute of Water and Atmosphere (see Foster & Carter 1997) from mud basins on the northern Poverty Bay continental shelf about 10 km due east of the coast (Fig. 1). The water depth at the coring site was 63 m. The core was sampled at 5-cm intervals for pollen analysis.

* Taxonomic nomenclature follows Allan (1961) and Moore & Edgar (1976), with the subsequent taxonomic revisions made by Brownsey et al. (1985), Connor & Edgar (1987), and Webb et al. (1988).

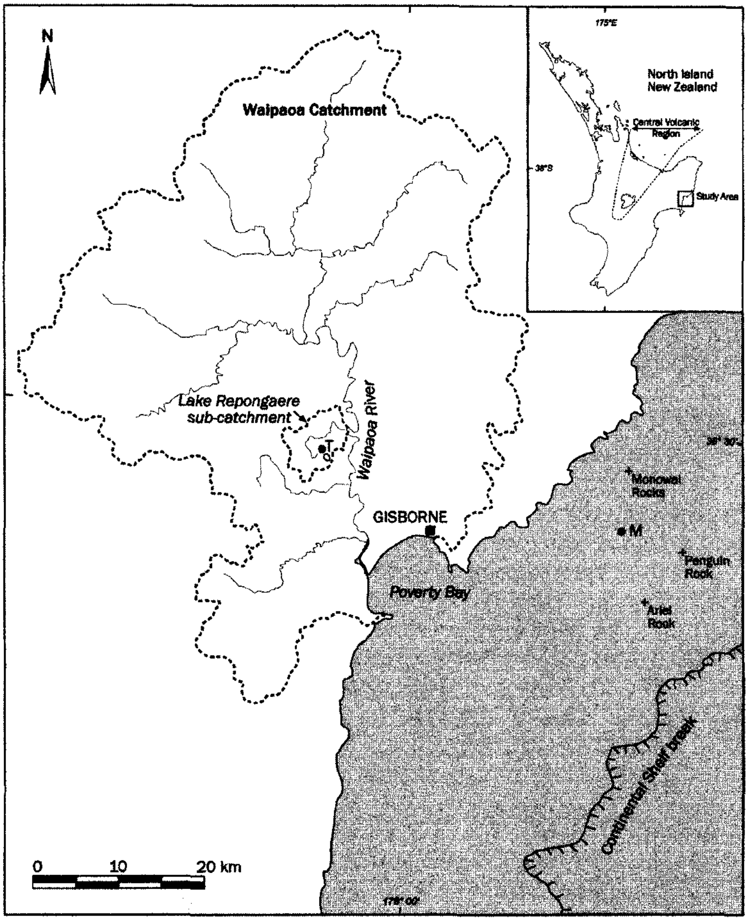

Fig. 1 Location map of terrestrial core site (● T) at Repongaere Swamp, and marine coring site (● M) on the Poverty Bay continental shelf. Positions of the Central Volcanic Region and continental shelf break (from Foster & Carter 1997) are also marked.

Table 1 Radiocarbon ages from Repongaere Swamp, *calibrations made using the program INSCAL 4.0 (R. Sparks pers comm.).

Sample depth (cm)	NZA number	^{14}C yrs B.P.	Submitted material	*Calibrated age 68% confidence interval
53	6404	1845 ± 83	Bulk peat	AD 81 to 256 AD 298 to 318
60	8286	958 ± 76	Selected wood fragments	AD 1013 to 1173
320	8287	3575 ± 69	*Prumnopitys taxifolia* seed	2015 to 2005 BC 1978 to 1870 BC 1841 to 1778 BC

Pollen analysis

Pollen was concentrated from the sediments using standard pollen preparation techniques (Moore et al. 1991). A pollen sum consisting of 250–300 terrestrial pollen and *Pteridium esculentum* (bracken) spores was counted at each depth. Pollen from local swamp-forming vegetation was excluded from the sum. After each count, slides were scanned for taxa not included in the count. The proportion of bracken spores with pitted exines was counted to differentiate reworked spores from contemporaneously deposited spores (Wilmshurst 1995). Microscopic charcoal fragments were also recorded during pollen counting, using the point-count technique of Clark (1982).

Loss on ignition

Loss on ignition was measured for the Repongaere Swamp samples to highlight changing rates of inwash into the swamp. Dried samples of known weight were combusted in a muffle furnace at 550°C for 2 hours, cooled, and reweighed, and the weight of ash residue expressed as a percentage of the dry weight (Bengtsson & Enell 1986).

Core chronology and tephra identification

Core chronology was provided by the presence of well known tephras, and supplemented in the Repongaere Swamp core with three accelerator mass spectrometry (AMS) measurements on samples that were pre-treated consecutively with hot solutions of acid, alkali, and acid and analysed by the Rafter Radiocarbon Laboratory, Lower Hutt, New Zealand (Table 1). All radiocarbon ages reported here are stated as radiocarbon years before present (i.e., AD 1950) unless otherwise stated. Eight distinct tephras were visible in the Repongaere Swamp core. Volcanic glass was separated from each of these layers and the glass chemistry of individual shards determined by electron microprobe analysis (Froggatt 1983). The tephra layers were identified using a combination of stratigraphy, glass chemistry, and ferromagnesian mineralogy (where possible). The distribution of glass in the marine core was determined at 5-cm intervals between 60 and 155 cm by counting glass shards using a polarising microscope. The glass chemistry of individual shards from 110 cm and 150 cm was determined by electron microprobe analysis.

RESULTS

Tephras

Repongaere Swamp core

The two prominent tephra layers at 117–135 cm and 284–300 cm were identified as Taupo (1850 yr B.P.) and Waimihia (3280 yr B.P.) Tephras, respectively, on the basis of their appearance, stratigraphic position, and known distribution and thickness on the east coast of the North Island (Pullar 1972; Eden et al. 1993). The electron microprobe data on Waimihia Tephra (Table 2) confirms this identification. The

Table 2 Electron microprobe results of major element composition of glass from tephra samples in Repongaere Swamp core, normalised to 100% volatile-free. All Fe as FeO; water by difference; mean and 1F (in brackets) based on *n* analyses.

	Kaharoa 52–54 cm	Mapara 205 cm	Whakaipo 211 cm	Waimihia 1 284–294 cm	Waimihia 2 294–300 cm	Hinemaiaia 311–316 cm	Moutere 480 cm	Moutere 481.5 cm
SiO_2	77.44 (0.24)	75.30 (0.79)	76.62 (0.36)	75.81 (0.23)	75.94 (0.45)	75.91 (0.23)	75.65 (0.28)	75.97 (0.21)
Al_2O_3	12.83 (0.16)	13.49 (0.40)	12.83 (0.22)	13.24 (0.15)	13.16 (0.17)	13.21 (0.11)	13.29 (0.24)	13.09 (0.18)
TiO_2	0.12 (0.05)	0.31 (0.05)	0.20 (0.04)	0.25 (0.07)	0.24 (0.04)	0.24 (0.06)	0.24 (0.07)	0.23 (0.04)
FeO	0.88 (0.09)	2.01 (0.17)	1.73 (0.13)	1.93 (0.12)	1.96 (0.12)	1.93 (0.12)	1.90 (0.13)	1.97 (0.13)
MgO	0.10 (0.02)	0.28 (0.05)	0.17 (0.05)	0.21 (0.05)	0.20 (0.05)	0.19 (0.03)	0.24 (0.04)	0.20 (0.04)
CaO	0.52 (0.06)	1.50 (0.25)	1.07 (0.05)	1.37 (0.11)	1.34 (0.12)	1.35 (0.08)	1.35 (0.07)	1.32 (0.08)
Na_2O	3.77 (0.07)	4.05 (0.34)	4.09 (0.14)	4.11 (0.30)	4.12 (0.19)	4.13 (0.17)	4.20 (0.14)	4.03 (0.12)
K_2O	4.14 (0.06)	2.88 (0.21)	3.11 (0.14)	2.90 (0.10)	2.84 (0.17)	2.86 (0.09)	2.91 (0.07)	3.00 (0.15)
Cl	0.19 (0.04)	0.19 (0.03)	0.16 (0.04)	0.18 (0.03)	0.20 (0.04)	0.19 (0.05)	0.22 (0.14)	0.20 (0.06)
Water	1.88 (1.77)	1.87 (1.98)	3.38 (1.38)	1.86 (1.34)	1.93 (1.89)	2.00 (1.84)	5.47 (7.05)	5.48 (4.24)
n	8	14	15	15	13	8	10	13

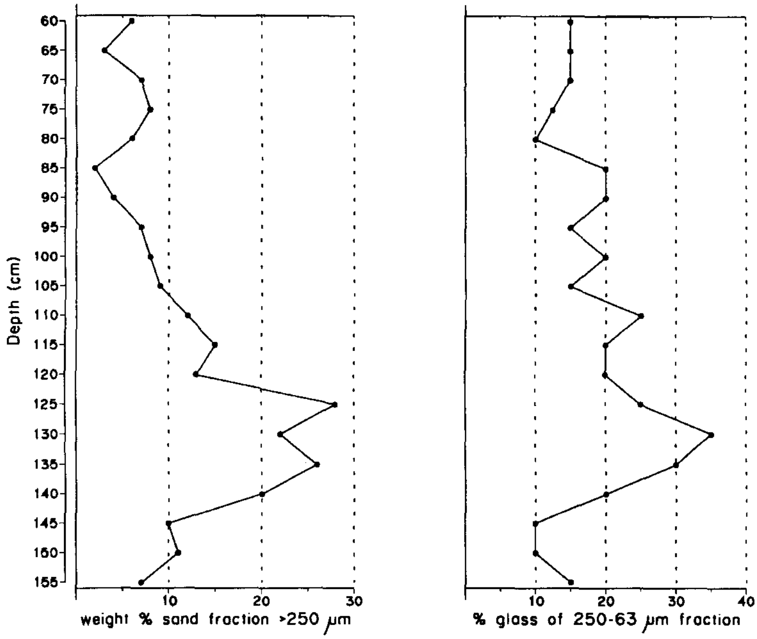

Fig. 2 Distribution of volcanic glass (250–63 μm) and weight % particles >250 μm from 60–155 cm depth in Poverty Bay core W396.

tephra layer at 52–54 cm is the Kaharoa Tephra (665 yr B.P.; Lowe et al. 1998), which is confirmed by the glass chemistry (Table 2). The two tephra layers at 205 cm and 211 cm are most likely to be Mapara (2160 yr B.P.) and Whakaipo (2685 yr B.P.), based on their stratigraphic position between the Taupo and Waimihia Tephras, and their Taupo Volcanic Centre glass chemistry. The tephra layer at 311–316 cm is probably Hinemaiaia Tephra (4510 ± 20 yr B.P.), and the pair at 480 cm and 481.5 cm probably represent Moutere Tephra (5430 ± 60 yr B.P.). These layers are equivalent to three of units R, Q, N, and K (Wilson 1993) which erupted c. 3950–4600 yr B.P. and have been recorded in Hawke's Bay deposits (Eden & Froggatt 1996).

Poverty Bay core

Initial observations of the Poverty Bay core indicated that tephra was present at 152 cm continuing in pulses up to 100 cm. The fine sand fraction (250–63 μm) was examined for glass content at 5-cm intervals between 60 and 155 cm (Fig. 2), and samples of the tephra at 110 cm and 150 cm were analysed by electron microprobe (Table 3) to establish if more than one tephra was present. Results showed a broad peak of glass between 125–135 cm, and the electron microprobe analysis of shards from the two depths indicated almost identical chemistry, closely resembling Taupo Tephra. Although the chemistry is also similar to Waimihia Tephra, it is unlikely to be this tephra on the basis of both glass distribution through the core and stratigraphic position. A large amount of Taupo Tephra was incorporated into sediment transported to the Poverty Bay and would be expected to be distributed over a considerable thickness of the core.

Table 3 Electron microprobe results of major element composition of glass from two tephra samples in Poverty Bay core W396, normalised to 100% volatile-free. All Fe as FeO; water by difference; mean and 1σ (in brackets) based on *n* analyses.

	Taupo 1 (110 cm)	Taupo 2 (150 cm)
SiO_2	76.38 (1.28)	76.64 (1.18)
Al_2O_3	13.04 (0.46)	13.03 (0.47)
TiO_2	0.25 (0.09)	0.22 (0.07)
FeO	1.75 (0.33)	1.74 (0.39)
MgO	0.29 (0.16)	0.26 (0.11)
CaO	1.29 (0.34)	1.22 (0.36)
Na_2O	3.84 (0.29)	3.68 (0.29)
K_2O	2.98 (0.28)	3.04 (0.33)
Cl	0.18 (0.03)	0.17 (0.04)
Water	1.75 (1.52)	2.41 (1.76)
n	11	10

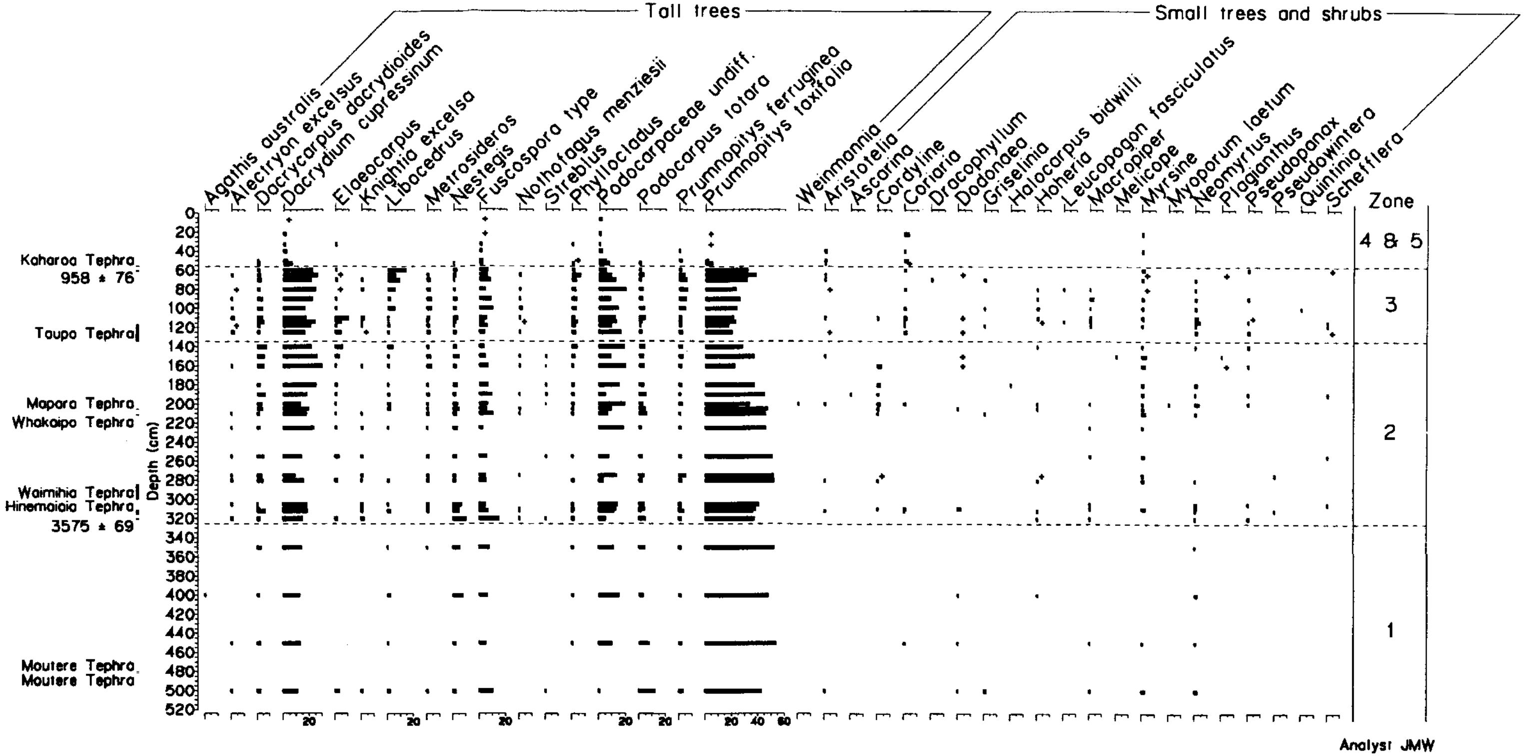

Fig. 3 Percentage pollen diagram, Repongaere Swamp, Gisborne. "+" represents taxa scanned after counting.

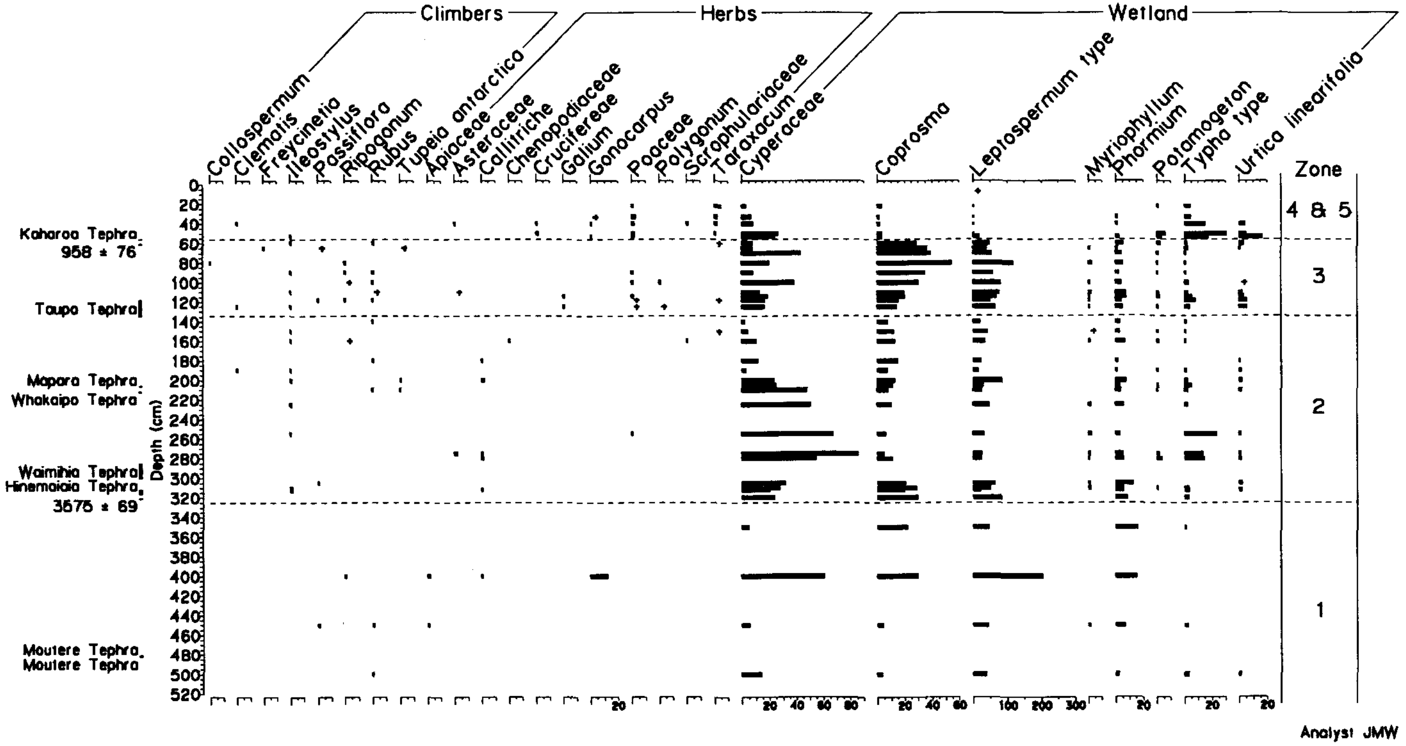
Climbers
Herbs
Wetland
Collospermum
Clematis
Freycinetia
Ileostylus
Passiflora
Ripogonum
Rubus
Tupeia antarctica
Apiaceae
Asteraceae
Callitriche
Chenopodiaceae
Cruciferae
Galium
Gonocarpus
Poaceae
Polygonum
Scrophulariaceae
Taraxacum
Cyperaceae
Coprosma
Leptospermum type
Myriophyllum
Phormium
Potamogeton
Typha type
Urtica linearifolia
Zone
4 & 5
3
2
1
Kaharoa Tephra
958 ± 76
Taupo Tephra
Mapara Tephra
Whakaipo Tephra
Waimihia Tephra
Hinemaiaia Tephra
3575 ± 69
Moutere Tephra
Moutere Tephra
Depth (cm)
Analyst JMW

Fig. 3 (cont'd)

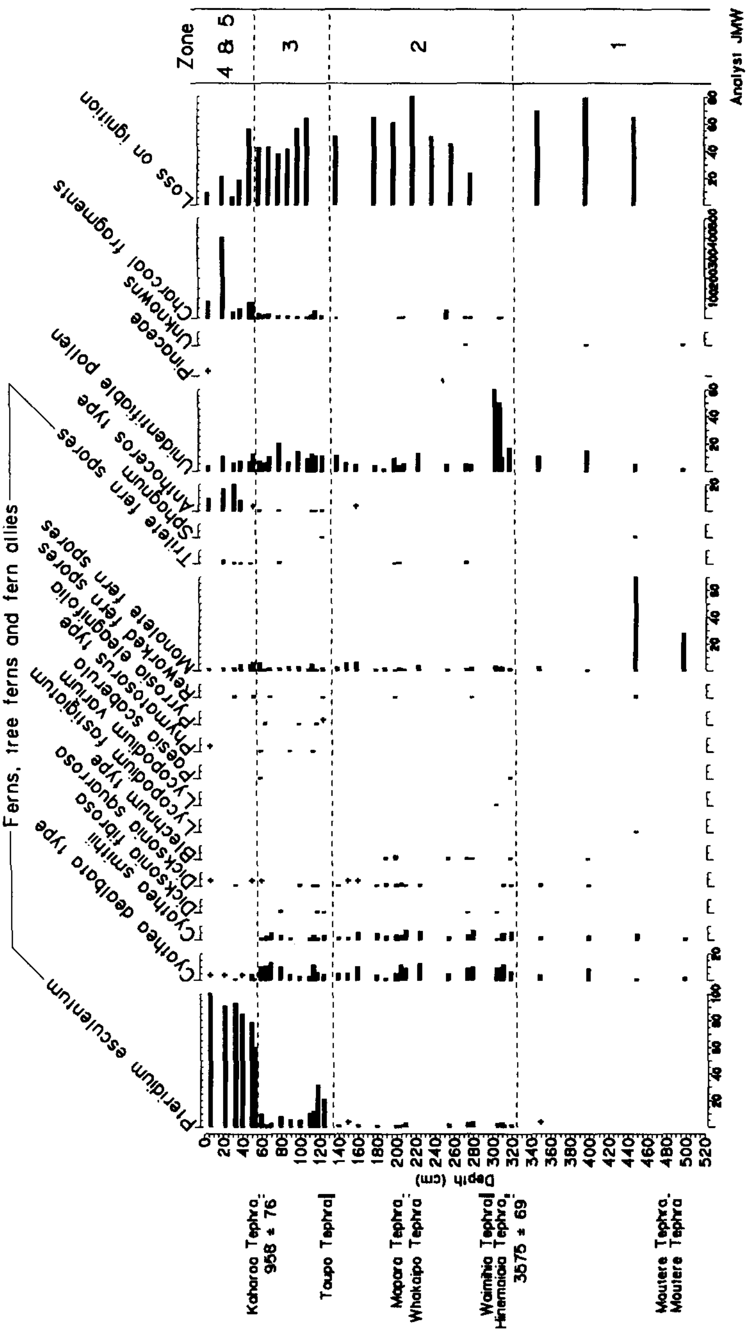

Fig. 3 (cont'd)

Pollen results

The Repongaere Swamp pollen diagram (Fig. 3) has been divided into five zones (from Zone 1 up to Zone 5) based on changes in the main dryland pollen percentages. The four uppermost zones (Zones 2–5) are also represented in the Poverty Bay pollen diagram (Fig. 4) and show marked similarities. The pollen zones, their depth boundaries, and characteristic vegetation types are described in Table 4.

DISCUSSION

Pre-deforestation vegetation in Gisborne

For at least 4800 years before Maori and European deforestation, the Repongaere catchment and adjacent lowland areas were covered in a dense lowland podocarp/hardwood forest. *Prumnopitys taxifolia*, *Dacrydium cupressinum*, and *Podocarpus totara* were the dominant emergents over a canopy of a wide range of hardwood trees and shrubs (e.g., *Alectryon excelsus*, *Elaeocarpus*, *Metrosideros*, *Nestegis*, *Myrsine*, *Pseudopanax*, and *Neomyrtus*), parasitic shrubs and climbers (e.g., *Ileostylus*, *Clematis*, and *Rubus*), and tree ferns (particularly *Cyathea dealbata/medullaris* and *C. smithii*). *Beilschmiedia tawa* pollen is absent from the pollen record but is normally severely under-represented in the pollen rain (Macphail 1980), and would have formed a major component of the canopy. Many other insect- and bird-pollinated hardwood trees would also have been present but are either not recorded (e.g., *Dysoxylum spectabile*, *Sophora* spp., and *Vitex lucens*) or are present as trace amounts in the pollen record (e.g., *Myoporum laetum* and *Schefflera digitata*). *Nothofagus* subgenus *Fuscospora* type pollen (probably *N. solandri* and *N. fusca*) is well represented throughout and *N. menziesii* occurs at low percentages, and both most likely represent long-distance dispersed pollen from mixed beech forests on the North Island axial ranges.

Leptospermum and *Coprosma* were prominent on swamp margins, whereas Cyperaceae, *Typha orientalis*, and *Phormium tenax* dominated the fertile, wetter parts and along lake margins. Alluvial swamps on the Gisborne Plains were dominated by *Dacrycarpus dacrydioides*. Although *Laurelia novae-zelandiae* would also have been present on poorly drained soils, this pollen type is not recorded.

The forest and wetland vegetation described here is similar to the pollen record from peat and silt deposits near Gisborne which date from c. 45 000 to 28 000 yrs B.P., an interstadial described as having cool and fluctuating climates (McGlone et al. 1984).

Comparisons of pollen representation in the marine and terrestrial cores

Mean pollen percentages of the main taxa from the terrestrial and marine cores are compared in an equivalent section of the profiles where there is little disturbance, i.e., from above the Waimihia Tephra to the Taupo Tephra (Table 5). Of the main forest types, *Prumnopitys taxifolia* is recorded at lower percentages in the marine core compared with the terrestrial core, reflecting the local dominance of this tree at Repongaere (supported by the presence of *P. taxifolia* endocarps in the peat). The undifferentiated Podocarpaceae group is also recorded at lower percentages in the marine core. This pollen type contains mainly *Prumnopitys taxifolia* and *Podocarpus totara* grains which were unidentifiable at the species level because of poor preservation. The lower percentages of undifferentiated Podocarpaceae pollen in the marine core may be a reflection of better pollen preservation, which is supported by the generally lower levels of unidentifiable pollen. The main wetland taxa at Repongaere (including *Leptospermum*, Cyperaceae, *Coprosma*, *Phormium tenax*, and *Typha orientalis*) are present in the marine core

Table 4 Pollen zone descriptions and depth boundaries in Repongaere Swamp and Poverty Bay pollen profiles.

Zone	Zone description	Zone boundary (cm) Repongaere Swamp	Poverty Bay
5	Pasture	0–53 (boundary between zones 5/4 difficult to pinpoint)	0–55
4	Bracken/ scrubland		55–75
3	Post-Taupo eruption followed by patchy disturbance in lowland podocarp/ hardwood forest	53–134	75–155
2	Post-Waimihia, Mapara, and Whakaipo eruption disturbance in lowland podocarp/hardwood forest	134–320	155–250 (only the top of the zone is present)
1	Intact lowland podocarp/hardwood forest	320–500	not present

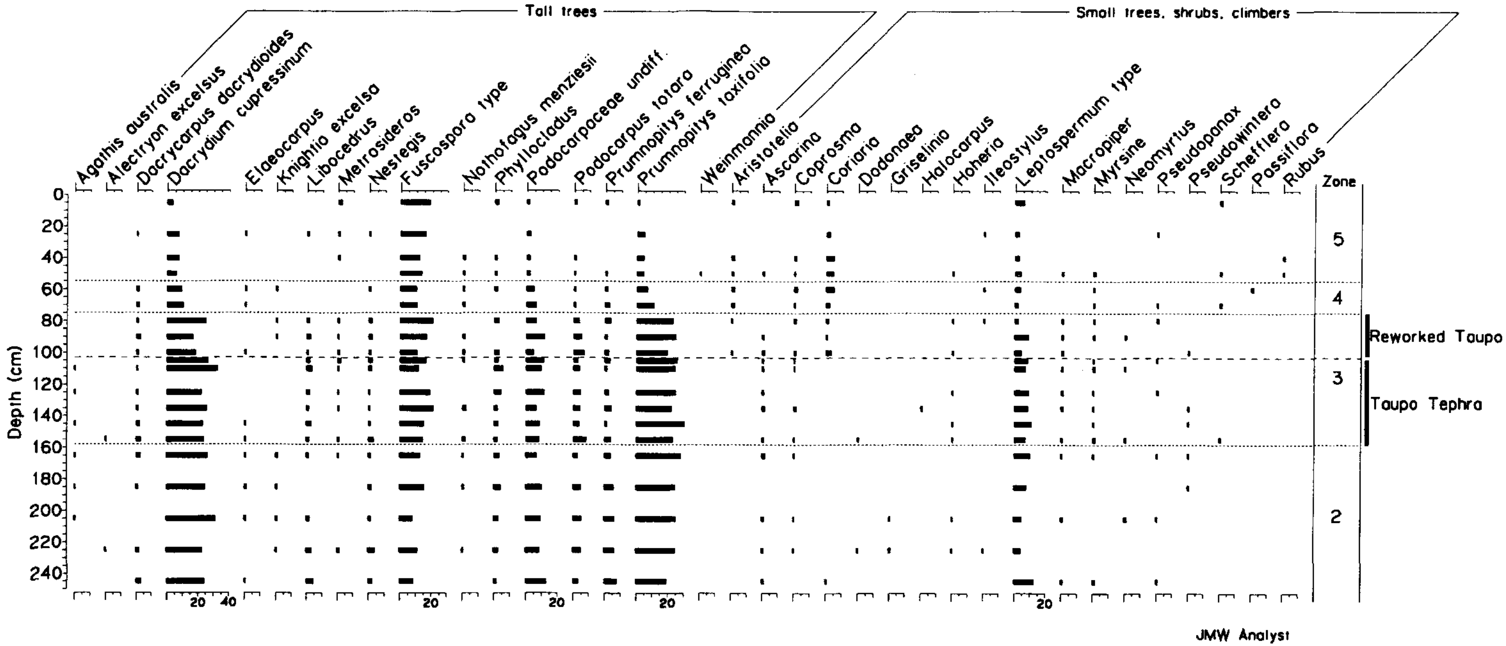

Fig. 4 Percentage pollen diagram, Poverty Bay W396.

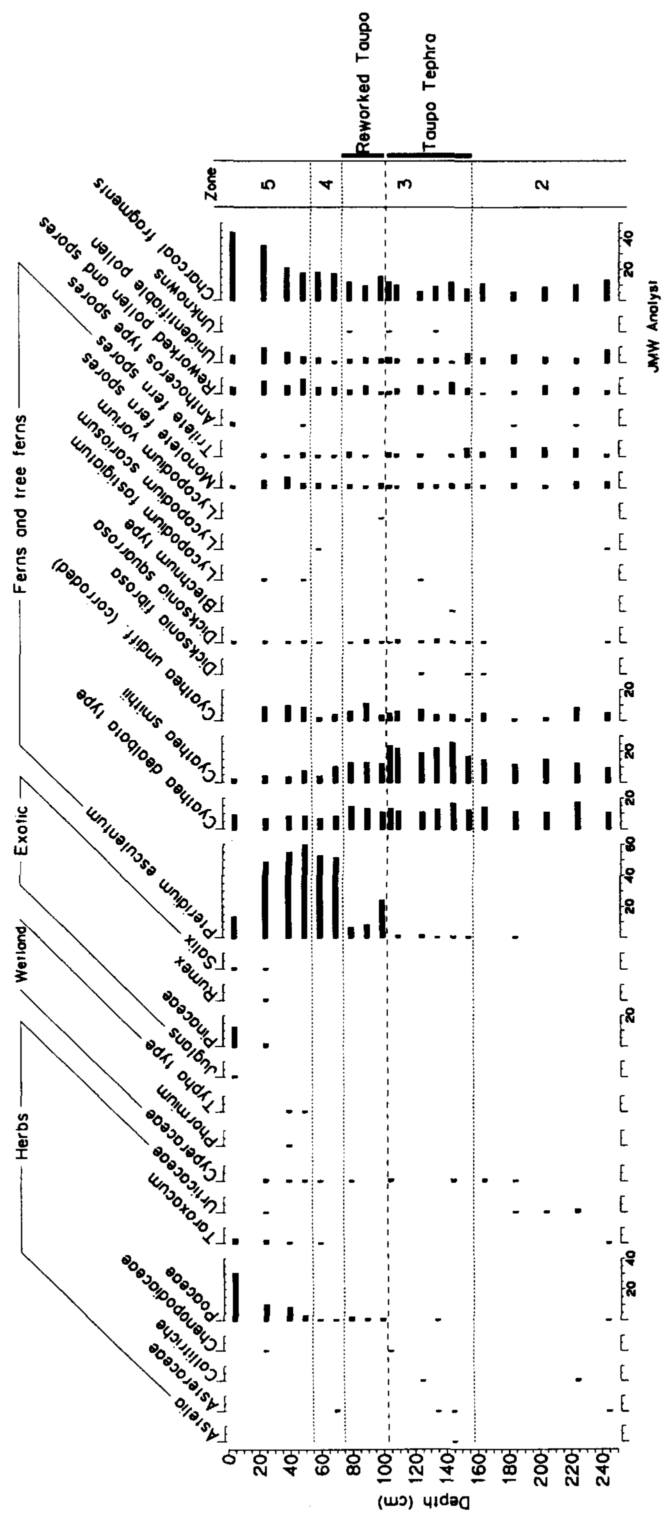
Herbs
Wetland
Exotic
Ferns and tree ferns
Astelia
Asteraceae
Callitriche
Chenopodiaceae
Poaceae
Taraxacum
Urticaceae
Cyperaceae
Phormium
Typha type
Juglans
Pinaceae
Rumex
Salix
Pteridium esculentum
Cyathea dealbata type
Cyathea smithii
Cyathea undiff. (corroded)
Dicksonia fibrosa
Dicksonia squarrosa
Blechnum type
Lycopodium fastigiatum
Lycopodium scariosum
Monolete fern spores
Trilete fern spores
Anthoceros type spores
Reworked pollen and spores
Unidentifiable pollen
Unknowns
Charcoal fragments
Zone
5
4
3
2
Reworked Taupo
Taupo Tephra
Depth (cm)
JMW Analyst

Fig. 4 (cont'd)

but are relatively poorly represented compared with the terrestrial record, again reflecting the local presence of these taxa and their locally abundant dispersal and deposition of pollen in the swamp.

Charcoal, *Nothofagus* subgenus *Fuscospora* type pollen, reworked Tertiary pollen and spores, and the tree fern spores *Cyathea dealbata* type (including both *C. dealbata* and *C. medullaris*) and *C. smithii* are all over-represented in the marine core compared with the swamp profile. Tree fern spores are among the most robust palynomorphs and are differentially preserved and severely over-represented in soil samples from the lower reaches of the Waipaoa catchment (J. M. Wilmshurst unpubl. data). Their over-representation in the marine core indicates that they are derived from eroded soils from the Waipaoa catchment. Unlike the terrestrial profile, the charcoal record in the marine core does not have any distinct peaks because there is a high background level of reworked charcoal, probably derived from Tertiary sediments. The continuous presence of reworked Tertiary pollen and spores in the profile (mostly *Nothofagus* subgenus *Brassospora* type, Myrtaceae, *Casuarina*, *Phyllocladus*, and trilete fern spores) supports this as a possible source. As Tertiary sediments can contain both *Fuscospora* and *Brassospora* type pollen (McGlone et al. 1996), the presence of both types in the marine core may exaggerate the *Fuscospora* type curve.

Vegetation disturbance from volcanism

The Repongaere Swamp pollen profile shows that forests were disturbed after the fall of the Hinemaiaia, Waimihia, Whakaipo, Mapara, and Taupo tephras; the marine profile shows only the effects of the Taupo Tephra. Any potential volcanic disturbance caused by the Kaharoa Tephra is masked by the impact of deforestation which occurred at about the same time as the eruption. However, the other tephras mentioned caused patchy forest disturbance from the direct effects of ashfall and fires and, subsequently, the proliferation of seral taxa in gaps and small clearings. A distinctive suite of taxa is recorded above each tephra, which includes tall trees (*Knightia excelsa*, *Libocedrus* cf. *plumosa*, *Metrosideros*, *Prumnopitys ferruginea*, *Weinmannia racemosa*), small trees and shrubs (*Aristotelia*, *Cordyline*, *Coriaria*, *Dodonaea viscosa*, *Hoheria*, *Macropiper excelsum*, *Myrsine*, *Neomyrtus*, *Schefflera digitata*), and ferns (*Pteridium esculentum*). Wetland taxa fluctuate above the thicker tephra deposits. Above the Waimihia and Taupo Tephra, for example, *Typha orientalis* and *Potamogeton* pollen increase, as does the swamp nettle *Urtica* cf. *linearifolia* (which grows among *Phormium tenax* and *Typha orientalis* in extant lowland swamps; Johnson & Brooke 1989). These were probably responding to impeded drainage on the swamp and elevated nutrient levels.

Table 5 Comparison of mean pollen percentages of main taxa in the terrestrial core (samples from140–190 cm and 225–255 cm, *n* = 7), and marine core (samples from 105–245 cm, *n* = 11).

Taxa	Terrestrial core	Marine core
Dacrycarpus dacrydioides	4.4 ± 1.8	1.2 ± 1.0
Dacrydium cupressinum	22.0 ± 5.2	25.2 ± 3.4
Fuscospora type	5.1 ± 2.2	13.7 ± 4.0
Podocarpaceae undiff. type	12.7 ± 6.0	9.0 ± 1.9
Podocarpus totara type	3.0 ± 1.2	3.9 ± 1.6
Prumnopitys taxifolia	37.6 ± 10.1	24.3 ± 2.9
Coprosma	9.4 ± 3.2	0.3 ± 0.4
Leptospermum	27.9 ± 12.2	7.8 ± 2.4
Cyperaceae	20.6 ± 26.4	0.4 ± 0.6
Pteridium esculentum	0.7 ± 0.7	0.4 ± 0.5
Cyathea dealbata type	5.6 ± 3.7	12.7 ± 2.3
Cyathea smithii	3.1 ± 1.7	17.4 ± 5.3
Reworked pollen and spores	0	3.1 ± 2.1
Unidentifiable pollen	6.1 ± 4.0	3.5 ± 2.1
Charcoal	5.5 ± 14.3	9.3 ± 2.5

Post-Taupo forest disturbance

Both the terrestrial and marine pollen records show a marked disturbance response following the deposition of Taupo Tephra (the only volcanic ash in both cores), in which podocarp pollen declines and charcoal and the pollen of many seral taxa, e.g., *Elaeocarpus*, *Knightia*, *Macropiper*, *Aristotelia*, *Coriaria*, *Hoheria*, and Poaceae increases. The vegetation disturbance of the central and eastern regions of the North Island following the last Taupo eruption is discussed in detail by Wilmshurst & McGlone (1996), and for the central North Island by Horrocks & Ogden (1998a). In the terrestrial core, the post-Taupo disturbance recorded in the pollen profile is more severe than any disturbance recorded above the other tephras in the core, even the Waimihia Tephra which covered the Gisborne area with a similar thickness of ash. The impact of the Taupo eruption on the vegetation may have been exacerbated by droughts at the time of the eruption (Wilmshurst & McGlone 1996; Wilmshurst et al. 1997).

The total thickness of Taupo Tephra in the marine core, although dispersed rather than a distinct layer, is about 40 cm, compared with only 17 cm in the terrestrial core. The main peak of Taupo Tephra glass shards in the marine core is at 125–135 cm (Fig. 2). However, other than a trace of *Pteridium* spores, there is no change in the pollen record that coincides with this glass peak. It is not until 100 cm that seral taxa are recorded and *Pteridium* reaches the same distinctive peak as it does in the terrestrial core (i.e., 30%). The primary peak of Taupo Tephra shards was from direct airfall on Poverty Bay and, therefore, there is no corresponding pollen change associated with this because it was deposited very rapidly. However, after the eruption, when normal erosion and depositional processes resumed, the pollen record of volcanic impact is contained along with reworked Taupo Tephra above the primary airfall deposit.

Fire history

Charcoal is associated only with the presence of volcanic tephras in the Repongaere Swamp core before the Taupo Tephra, except for one localised fire episode at 255 cm. However, after the forest recovered from the effects of the Taupo eruption, charcoal and pollen of seral taxa recorded throughout Zone 3 suggest that small-scale forest disturbance continued up until the time of deforestation, most likely from lightning-strike fires associated with periods of drought. There are also substantial increases of *Libocedrus* cf. *plumosa* and *Prumnopitys ferruginea* pollen in Zone 3, indicating sub-dominant conifers were probably also exploiting gaps and small clearings in the forest. The presence of highly combustible bracken fern in the clearings supplied a potential fuel supply and may have encouraged cycles of fire disturbance, allowing small patches of seral communities to persist. However, traces of charcoal and increases of *Elaeocarpus*, *Metrosideros*, and *Phyllocladus* cf. *trichomanoides* pollen are recorded just before the Taupo Tephra and may signal the onset of fire disturbance, which merely continued through to the time of deforestation. The period of disturbance may have been associated with more frequent and intense El Niño/La Niña events which McGlone et al. (1992) suggested began in New Zealand after 3000 yr B.P. Pollen evidence from the neighbouring region of Hawke's Bay to the south also showed that lowland podocarp/hardwood forests, similar to those in Gisborne, were frequently disturbed by fires in the period between the Taupo Tephra and deforestation (Wilmshurst et al. 1997). Eden & Page (1998) indicated increased storminess in the same region c. 2090–1855 cal. yr B.P., based on erosion pulses in lake sediment cores. Horrocks & Ogden (1998b) also report palynological evidence from the central North Island for a more seasonal climate, intensifying at c. 3000–2000 yr B.P. Although it is difficult to detect evidence of other natural disturbances in peat core records, such as earthquakes, windthrow, insect attack, or storm damage, some may also have been active over this period and linked with climate-driven disturbance.

Polynesian deforestation

Deforestation depicted in the terrestrial and marine profiles

A rapid decline of the main forest taxa occurs in Zone 4 of the terrestrial and marine cores at the same time as an increase in charcoal and pollen and spores from seral taxa, particularly *Pteridium* but also *Coriaria*, *Aristotelia*, and Poaceae. This sudden demise of forest from the lowland hilly areas of Gisborne represents the most severe and prolonged case of disturbance in the last 5500 years, and was caused by fires lit by early Maori settlers (discussed in McGlone 1983a; McGlone et al. 1994). In the terrestrial core, local responses to disturbance are also recorded, such as the increase of *Typha orientalis* and *Urtica* which were probably responding to elevated levels of nutrients released after clearance. Although the marine pollen record does not show these localised wetland disturbances clearly, it does record some wider regional impacts of deforestation. For example, *Agathis australis* (kauri) pollen, a species absent from the east coast, is present, albeit sporadically and at low percentages, throughout Zones 2 and 3 of the marine pollen profile but is not recorded again after deforestation. As there is no Quaternary pollen evidence for *Agathis* in this region (Ogden et al. 1993), the pollen must have derived from northern sources and been dispersed to the shelf either by sea or air currents. The demise of kauri pollen in the marine core may reflect the destruction of forests further north (see also Wilmshurst 1997). The deforestation sequence recorded here is typical of that reported for deforestation by Maori fires in the neighbouring regions of Hawke's Bay to the south (e.g., McGlone 1978; Wilmshurst 1997) and the Bay of Plenty to the north (McGlone 1981; Newnham et al. 1998), all of which occur around the time of the Kaharoa eruption, about AD 1350 (Lowe et al. 1998). The nature and timing of deforestation in Gisborne is also consistent with the majority of palynological records throughout New Zealand (McGlone & Wilmshurst 1999).

Defining the age of deforestation at Repongaere

Initially, a bulk sediment sample from the Repongaere Swamp core at 53 cm was dated by AMS to provide an age for the start of Maori deforestation. Although the bulk sample contained Kaharoa Tephra (665 yr B.P.), the radiocarbon age for the sample was 1845 ± 83 yr B.P. (Table 1), but this was rejected for two reasons. Firstly, it is more than a thousand years older than both the Kaharoa Tephra which was present in the sample, and the time of deforestation recorded in closely neighbouring regions of the North Island (Wilmshurst 1997; Newnham at al. 1998). Secondly, the sample from 53 cm contained charcoal, possibly reworked from earlier fires and/or containing a built-in age. In fact, the radiocarbon age derived from the 53-cm bulk peat sample is statistically identical to the average of radiocarbon ages for the last Taupo eruption of 1850 ± 10 yr B.P. (Froggatt & Lowe 1990). We propose that deforestation in the Repongaere catchment eroded and transported catchment soils containing mixed-aged materials into the swamp, particularly charcoal dating to the time of the last Taupo eruption.

To test this hypothesis, only non-charcoalised woody fragments were selected for dating from the next available, sampled horizon at 60 cm—unfortunately there was not enough sample material from 53 cm to allow redating from the same horizon. This deeper material gave an age of 958 ± 76 yr B.P. (Table 1) which is 887 radiocarbon years younger than the bulk sediment age from 53 cm, and one we accept as being closer to the true age of this part of the core. In the absence of an accurate radiocarbon age from 53 cm, we can only estimate that the timing of deforestation at Repongaere began at c. 665 yr B.P., based on the relative position of the Kaharoa Tephra, and certainly after 958 ± 76 yr B.P.

European forest clearance and conversion to pasture

Although the onset of deforestation is clearly depicted in the Repongaere Swamp pollen record, it is difficult to pinpoint exactly where in the profile the effects of early European clearance for pasture began. The pollen record is dominated by bracken spores throughout Zones 4 and 5 and their severe over-representation occurs at the expense of many other taxa. The diversity of pollen and spore types recorded in a sample from Zones 4 and 5 is as low as 11 taxa, compared with 27–40 taxa in the zones below. Grass is also severely under-represented in the pollen record at the surface, although it is known to have dominated the catchment vegetation since the mid AD 1800s. The reasons for loss of pollen resolution in the surface of the core can be attributed to two factors. Firstly, Repongaere Swamp has been heavily trampled by grazing animals this century. Secondly, the top 50 cm of soily peat is severely disturbed, probably because the site was used for umu (earth ovens used by Maori for cooking), which is indicated by the presence of large charcoal fragments and oven stones at the core site at this depth. Stone chips exotic to the catchment, wooden posts, and shells of the marine bivalve *Paphies* sp. were also found at the site. There is considerable archaeological evidence in the Repongaere vicinity of storage pits, terraces, blackened charcoal soils, and oven stones suggesting occupation by extended Maori family units who were using the land for hamlet-style gardening (Jones 1988). In addition, there are many pa sites (Maori fortified constructions) one of which has a radiocarbon age of 460 ± 54 ^{14}C years, giving a minimum age (of c. AD 1450) for defensive construction at Repongaere (Jones 1988).

In contrast to the terrestrial core, the impact of European settlement in Gisborne is clearly recorded in Zone 5 of the marine core (Fig. 4). As charcoal increases, and pollen and spores from the *Pteridium*-scrubland (including *Pteridium*, *Myrsine*, *Leptospermum*, and *Coriaria*) decline as a result of European clearance, there is a corresponding steady increase of pollen from grasses and exotic species associated with pasture development (e.g., *Taraxacum* and *Rumex*) and European settlement, i.e., planted introduced trees including Pinaceae, *Juglans*, and *Salix*. Also notable in Zone 5 is the sudden decline of *Dacrycarpus dacrydioides* pollen, reflecting the drainage and clearance of extensive swamp forests from the Gisborne Plains by Europeans. By AD 1920 most of the swamp forests on the plains had been drained, felled, or burnt and converted to pasture (Pullar 1962). Accidental fires destroyed large expanses of these alluvial swamp forests in AD 1865 and AD 1878 (Pullar 1962), but it is apparent that these forests only became vulnerable to fire after extensive artificial drainage began.

Soil erosion

There are no discrete silt layers below the level of deforestation in the Repongaere Swamp profile. However, in Zones 4 and 5, above the deforestation event, the mineral content of the peat increases to the highest levels recorded in the core (Fig. 3). Some time after deforestation, the amount of soil eroded into the Repongaere swamp increased dramatically. Peat accumulation rates are variable in swamps because of frequent changes in surface drainage patterns and the often clumped distribution of peat-forming vegetation. As a result, sedimentation rates cannot be meaningfully compared between zones in the swamp core. However, in the marine core, where sediment sources to the Poverty Bay continental shelf are more consistent, the rates of sedimentation are comparable between zones. Sedimentation rates are 0.3 mm yr^{-1} in both the post-Taupo period (Zone 3) and the deforested fern/scrub period (Zone 4), compared with 3.7 mm yr^{-1} in the European period (Zone 5). Rates of erosion have increased dramatically, perhaps by more than an order of magnitude, since European conversion of soil-meshing fern/scrub and remaining forest to pasture. Reworked Tertiary pollen and spores derived from exposed and eroded regolith also increase in Zone 5 of the marine core. These increased rates of sedimentation are consistent with those recorded in the European pollen zones of cores from the eastern and central North Island (McGlone 1978; McGlone 1983b; Wilmshurst 1997; Horrocks & Ogden 1998c).

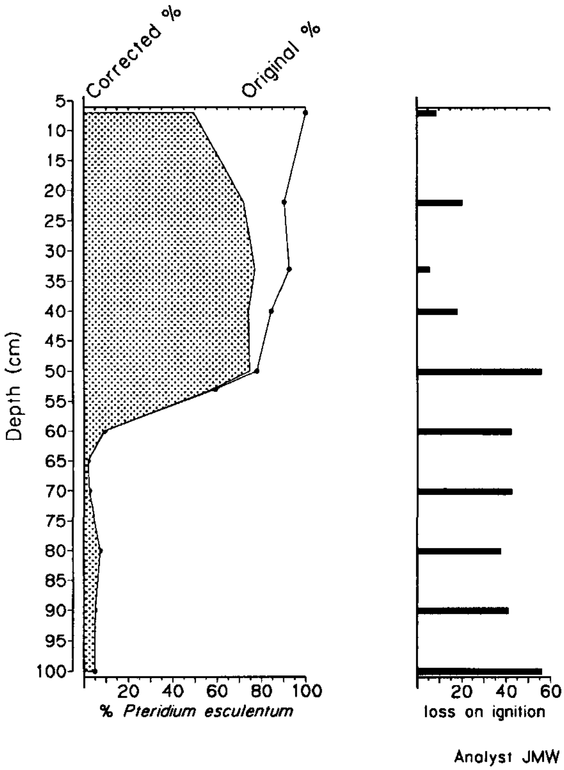

Fig. 5 Original (line) and corrected (shaded) *Pteridium esculentum* curves (see text) from the top 100 cm of Repongaere Swamp, as a percent of the dryland pollen sum, with loss on ignition (ash residue as a percent of dry weight) on the right.

Further evidence for soil erosion some time after deforestation in the Repongaere catchment is recorded by the bracken preservation curve (Fig. 5). In addition, the sudden increase of *Anthoceros* type (hornwort) spores in Zones 4 and 5 indicates soil erosion as they typically colonise freshly exposed soils.

An increasing proportion of the bracken spores recorded in Zones 4 and 5 have damaged exines, typical of those exposed to microbiological degradation in recent soil horizons (Wilmshurst 1995). Reworking of differentially preserved spores from soils to peat or lake sediments effectively distorts the representation of contemporaneous vegetation. In order to counter this distortion, the proportion of damaged bracken spores can be subtracted from the original bracken spore count and this new value recalculated as a percentage of the dryland pollen sum, providing a more realistic representation (Fig. 5). As a small proportion of undamaged bracken spores is also stored in the soils (Wilmshurst 1995), the estimated correction factor presented here is a minimum value only. The recalculated graph shows two important points: (1) before and immediately after deforestation up to 55 cm, all the bracken spores counted showed little or no sign of exine damage, and (2) after the initial episode of rapid deforestation, the corroded component of bracken spores increases from 12% to over 50% of the original count. Bracken spores increasingly include a reworked component derived from inwashed catchment soils towards the surface of the profile. These reworked spores are probably derived from soils dating from the time when a dense bracken scrubland covered the catchment after deforestation. Bracken spores dominate the pollen sum in the surface of the core, despite the absence of this fern in the catchment since it was cleared for pasture in the AD 1850s. This analysis was not done on the bracken spores in the marine core, as the causes of damaged pollen and spore exines are complex and largely a consequence of the longer transport pathways before incorporation into marine sediments.

CONCLUSIONS

The lowland hill country of the Gisborne region was covered with a podocarp/hardwood forest dominated by the emergents *Prumnopitys taxifolia* and *Dacrydium cupressinum* until much of it was cleared by early Maori fires about 650 years B.P.

A *Dacrycarpus dacrydioides*-dominated swamp forest persisted on the Gisborne Plains until European drainage and clearance.

The podocarp/hardwood forest was disturbed repeatedly over the last 5500 years by volcanic eruptions and associated fires.

Fire disturbance unrelated to volcanism only became common after the last Taupo eruption, possibly as a result of increased droughtiness associated with more frequent and intense El Niño/La Niña events.

The terrestrial and marine pollen profiles are similar and both record the effects of volcanism and human disturbance.

Rates of soil erosion increased dramatically in the European period, caused by the replacement of native soil-stabilising vegetation with pasture.

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