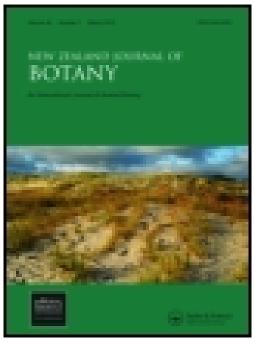

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A 6000-year palaeoenvironmental record from Harataonga, Great Barrier Island, New Zealand

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Abstract A pollen, sediment, and tephra record from a drained swamp at Harataonga contains a history of the local coastal environment from the Mid Holocene. This commences c. 6000 cal yr BP in a freshwater environment with swamp forest composed mainly of *Laurelia*, *Leptospermum*, *Ascarina*, and *Cyathea* spp. *Dodonaea* and Cyperaceae grew on margins of this forest. Forest on the hills surrounding the wetland comprised mainly *Metrosideros*, with emergent *Dacrydium* and *Libocedrus*. *Ascarina*, *Rhopalostylis*, and *Cyathea dealbata* type were a significant part of the understorey of the hillside forest. Around the time of deposition of the 5550 cal yr BP Whakatane tephra, a freshwater lake developed at the site. Extensive Cyperaceae swamp developed on the fringes of the lake. Shortly after c. 2900 cal yr BP, *Dacrycarpus* briefly invaded swamp forest, possibly as a result of storm disturbance, and the site made the final transition to swamp. *Myrsine* and then *Hebe* shrubs invaded fringes of the swamp as the water table fell, possibly as a result of a change to drier conditions in the Late Holocene. Polynesian deforestation, as indicated by the presence of abundant charcoal and *Pteridium* spores, is recorded in this core as occurring shortly after deposition of the c. 600 cal yr BP Kaharoa tephra.

Keywords palynology; Holocene; anthropogenic disturbance; Whakatane tephra; Kaharoa tephra; Great Barrier Island

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INTRODUCTION

A recent series of pollen studies from Great Barrier Island, Hauraki Gulf, has provided information relating to Holocene vegetation and environmental change (Horrocks et al. 1999, 2000a,b,c, 2001). Using pollen sequences from seven sites spanning 6.5 km across two large, directly adjacent catchments on the central eastern coast of Great Barrier, Awana and Kaitoke (Fig. 1B), Horrocks et al. (1999, 2000a,b,c) described records covering the last c. 7500 cal yr. These records show successional transitions from *Avicennia* and/or Restionaceae communities in the estuaries to Cyperaceae/*Gleichenia*/*Leptospermum*-dominated freshwater swamps, possibly as a result of regional sea level recession. After c. 3000 cal yr BP, these swamps underwent significant lowering of their water tables, and some sites were consequently invaded by swamp forest suggesting climatic change to drier and stormier conditions. This was followed by recent human disturbance by fire.

The presence of the 600 cal yr BP Kaharoa tephra on Great Barrier Island provides a stratigraphic marker allowing linkage of the studies described above. An overview of this aspect of the history of the Awana and Kaitoke catchments is given in Horrocks et al. (2001). Using the seven sites previously mentioned plus two others, it was found that deforestation by fire in Polynesian times was patchy, occurring at different times in different places. As

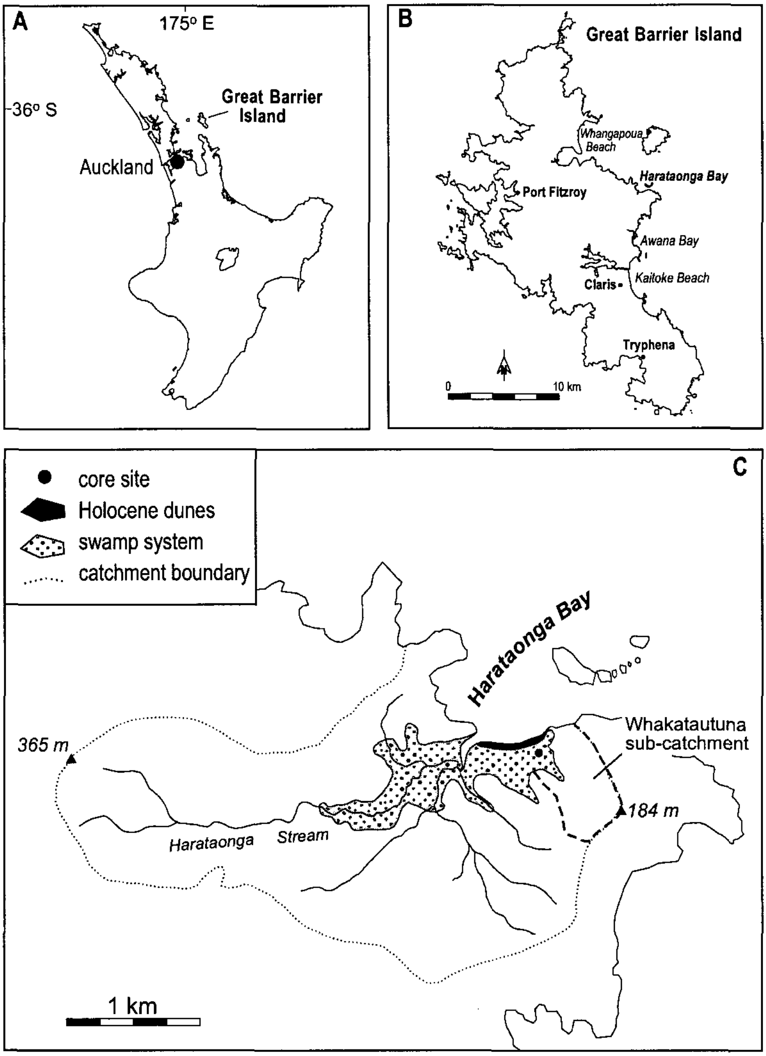

Fig. 1 **A**, North Island of New Zealand showing location of Great Barrier Island; **B**, Great Barrier Island showing location of Harataonga Bay; **C**, Harataonga showing location of core site.

well as the Kaharoa, another tephra was reported, the c. 55 ka Rotoehu. This tephra was observed on a surface that was apparently exhumed and subsequently reburied in pre-Holocene times, and in another two profiles as deposits reworked into the Holocene sediments.

We present here results of pollen analysis of a core from Harataonga, the catchment to the north of Awana-Kaitoke on the east coast of Great Barrier Island (Fig. 1B). Our primary aims are to provide a Holocene record of local vegetation, hydrology, and human effects in this small catchment, and to extend our knowledge of the spatial patterns of environmental change by comparing this record with those of the directly adjacent, much larger catchments of Awana and Kaitoke.

THE STUDY AREA

Great Barrier Island, in the outer Hauraki Gulf, Auckland, comprises an area of approximately 28 500 ha (Fig. 1). The island's interior is steeply dissected with several volcanic peaks up to 620 m altitude. The base rocks of most of the island, including Harataonga, are predominantly Miocene volcanics (Kermode 1992). On the more exposed eastern side of the island, a series of swamp systems, impounded by coastal dunes, are oriented either parallel to the shoreline or extend inland into valleys formerly occupied by estuaries.

The study area is located at Harataonga, a small bay on the central eastern coast of Great Barrier (36°10′S, 175°30′E) (Fig. 1C). Harataonga Beach is approximately 500 m from headland to headland and has a northerly aspect. The local watershed drains an area of 5.5 km^2 and comprises a single main watercourse that enters the sea at the western end of the beach. The sand dunes of the Harataonga shoreline rise to approximately 15 m above sea level and form an almost unbroken line along the length of the beach. The swamp system that formed behind these dunes is about 2 km long in a more or less west-east direction, extending inland more than 1 km at the western end. Most of the swamp system has been drained since European settlement and at present is mainly pasture with abundant Cyperaceae.

The nearest weather station to Harataonga is 11 km west at Port Fitzroy. Mean annual rainfall over the period 1961–1997 was 1839 mm (NIWA 1997). Rainfall occurs throughout the year, with maxima in March, June, and August and minima in October and December. Precipitation always exceeds evaporation. The mean annual daily maximum air temperature is 19.4°C and the minimum 11.8°C.

Existing vegetation cover on Great Barrier Island reflects a history of intense and widespread modification by people. The predominant vegetation over most of the island, including the hills of the Harataonga catchment, is regenerating forest of/under *Kunzea ericoides* and/or *Leptospermum scoparium*, with *Cyathea dealbata* frequent in the sub-canopy (Anon. 1996). Remnants of podocarp-hardwood forest occur in the far south and far north of the island. The main canopy species in these forests are *Beilschmiedia taraire*, *B. tawa*, and *Dysoxylum spectabile* with occasional *Metrosideros robusta*, *Knightia excelsa*, *Vitex lucens*, and *Dacrydium cupressinum.* Some regenerating *Agathis australis* forest, with occasional very large emergent trees, survives in the central part of the island. *Dacrydium cupressinum*, *Phyllocladus trichomanoides*, and hardwood species also form part of the canopy there. One of the few small patches of coastal forest remaining on Great Barrier occurs on the hills at the far eastern end of the Harataonga catchment. The canopy of these patches of coastal forest is dominated by *Metrosideros excelsa*, *Beilschmiedia taraire*, *B. tawa*, and *Dysoxylum spectabile*, and some less common *Knightia excelsa*, *Vitex lucens*, *Corynocarpus laevigatus*, *Nestegis apetala*, and *Planchonella novo-zelandica.* Mobile foredunes on the east coast of the island are stabilised by *Desmoschoenus spiralis* and *Spinifex hirsutus.* The vegetated dunes further inland are covered by *Muehlenbeckia complexa* mats, *Pomaderris phylicifolia*, and *Ozothamnus leptophyllus* with some exotic *Lupinus arboreus* (Anon. 1966).

Freshwater swamp associations on Great Barrier include *Typha orientalis*, *Cyperus ustulatus*, *Leptospermum scoparium*, *Baumea* spp., and *Gleichenia dicarpa* (Anon. 1996; Rutherford 1998). Estuarine wetland associations are dominated by *Avicennia marina* with *Zostera muelleri*, *Juncus maritimus*, *Leptocarpus similis*, and *Plagianthus divaricatus.* Saltmarsh is dominated by *Salicornia australis*, *Baumea juncea*, and *Leptocarpus simili* (Anon. 1996; Rutherford 1998).

METHODS

A site in drained swamp approximately 40 m south of the dunes towards the eastern end of Harataonga Bay (Fig. 1C) was selected for analysis.

A 3.5 m continuous sediment core was collected in an aluminium tube using a vibracoring system. The core was split lengthwise and the sediment facies were described. Tephra were sub-sampled for geochemical characterisation and correlation studies, and glass shards analysed by electron microprobe. The analyses were recalculated to 100% on a volatile free basis, and are presented as a mean and standard deviation of *n* shard compositions (Table 1). Total Fe is expressed as FeO and water is estimated by difference from 100%. The latter also includes other volatiles and minor elements not analysed.

Samples were prepared for pollen analysis by the standard acetylation and hydrofluoric acid method (Moore et al. 1991). The pollen sum for each sample was at least 250 grains, excluding swamp plants and ferns (except *Pteridium*, which can form a dominant vegetation cover (McGlone 1982, 1983, 1989)). *Leptospermum* type was also excluded from the pollen sum since in this case it had probably grown primarily on or directly adjacent to the core site. The software packages TILIA.2 and TILIAGRAPH.2 were used to construct the pollen diagram (E. Grimm, Illinois State Museum, Springfield, Illinois). Zonation of the pollen diagram was facilitated by a stratigraphically constrained classification of pollen spectra using CONISS, which is included in the TILIA.2 software package.

The AMS radiocarbon age determination (2731 ± 75 ^{14}C yr BP, $\delta^{13}C = 23.7$) was carried out on two non-aquatic seeds/fruits by the Rafter Radiocarbon Laboratory, Institute of Geological and Nuclear Sciences, Wellington (NZA-12125). The calibrated range (95% highest posterior density) is 2997–2714 cal yr BP (INTCAL98; Stuiver et al. 1998).

Table 1 Composition of glass shards in Harataonga core tephra and other selected late Quaternary units. Ka = Kaharoa tephra, Crater Road, Tarawera; Wk = Whakatane tephra, Lake Poukawa, Hawke's Bay; Rm = Rotoma tephra, Mt St John, Auckland; Wh = Waiohau tephra, Te Ngae, Rotorua.

	40 cm		278 cm			Ka	Wk	Rm	Wh
	a	b	a	b	c				
SiO_2	77.38 (0.09)	76.53	77.75 (0.15)	77.42 (0.21)	78.02	77.63 (0.19)	77.85 (0.17)	77.73 (0.13)	77.71 (0.10)
Al_2O_3	12.44 (0.08)	12.73	12.28 (0.09)	12.30 (0.22)	12.34	12.38 (0.10)	12.66 (0.08)	12.77 (0.08)	12.51 (0.05)
TiO_2	0.13 (0.06)	0.21	0.16 (0.06)	0.20 (0.02)	0.19	0.16 (0.07)	0.14 (0.05)	0.17 (0.04)	0.19 (0.04)
FeO	0.84 (0.08)	1.07	0.89 (0.06)	1.17 (0.02)	0.90	0.81 (0.07)	0.88 (0.07)	0.92 (0.06)	1.05 (0.06)
MnO	0.08 (0.06)	0.15	0.08 (0.04)	0.05 (0.05)	0.03	0.07 (0.04)	0.06 (0.03)	0.06 (0.03)	0.10 (0.05)
MgO	0.04 (0.03)	0.05	0.06 (0.05)	0.08 (0.14)	0.06	0.06 (0.05)	0.06 (0.05)	0.08 (0.06)	0.12 (0.06)
CaO	0.53 (0.06)	1.11	0.73 (0.06)	1.10 (0.08)	0.84	0.48 (0.03)	0.66 (0.03)	0.79 (0.03)	0.87 (0.03)
Na_2O	4.07 (0.07)	3.97	4.09 (0.14)	4.34 (0.18)	3.97	3.97 (0.09)	3.87 (0.08)	4.09 (0.16)	4.21 (0.04)
K_2O	4.32 (0.08)	4.06	3.83 (0.09)	3.20 (0.08)	3.48	4.29 (0.06)	3.85 (0.12)	3.42 (0.08)	3.34 (0.06)
Cl	0.17 (0.03)	0.11	0.15 (0.02)	0.15 (0.04)	0.16	0.15 (0.04)	0.21 (0.03)	0.18 (0.03)	0.18 (0.02)
H_2O	3.50 (0.87)	6.46	5.29 (1.44)	6.04 (3.43)	7.52	3.05 (0.57)	5.78 (0.88)	5.36 (1.21)	5.47 (1.56)
n	9	1	6	3	1	9	10	10	10

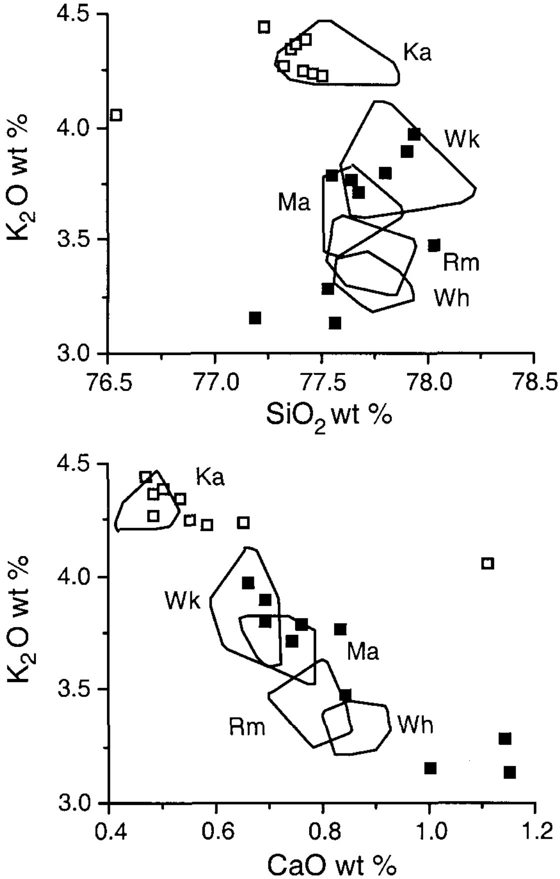

Fig. 2 Individual glass shards analyses of tephra from Harataonga core samples compared with those of other Holocene tephra from Okataina. □, Harataonga core H1 (40 cm); ■, Harataonga core H1 (278 cm); Ka, Kaharoa (665 ^{14}C yr); Wk, Whakatane (4.8 ka); Ma, Mamaku (7.2 ka); Rm, Rotoma (8.5 ka); Wh, Waiohau (11.8 ka) (P. A. Shane unpubl. data).

RESULTS

Tephrochronology

Whakatane tephra

Shards from a 1 cm thick bed containing abundant glass at a depth of 278 cm were selected for analysis. The shards represent at least three compositionally discrete populations (Table 1). Such populations can represent post-depositional mixing of products from different eruptions (e.g., Shane 2000). The largest population (six shards) is similar in composition to the 4.8 ka Whakatane tephra erupted from the Okataina Volcanic Centre (Fig. 2).

However, we note that the Whakatane tephra is similar in composition to the Okataina centre tephra beds, namely Mamaku (7.3 ka) and Rotoma (8.5 ka). These three tephra can be difficult to distinguish, especially Mamaku and Whakatane (Shane 2000). The shards in the Harataonga sample are more similar to Whakatane tephra in that they have relatively high K_2O contents (>c. 3.7 wt %). This distinguishes them from Rotoma tephra. The ferromagnesian mineral assemblage of the sample at 278 cm consists of abundant, rounded, and abraided orthopyroxene, clinopyroxene, and hornblende. We assume that most of these grains are derived from local Neogene rhyolites because a similar mineral assemblage is found in non-tephra samples. Trace amounts of cummingtonite occur in this sample, which is rare in New Zealand rhyolites, being known from only two Holocene tephra: Whakatane and Rotoma (Froggatt & Lowe 1990). The occurrence of cummingtonite further supports the correlation to the Whakatane tephra with an age of 4830 ± 20 ^{14}C yr BP (c. 5550 cal yr BP) (Lowe et al. 1999).

A second population of glass shards (Table 1, 278 cm b) has a high CaO composition that differs from Holocene tephra erupted from Okataina (Fig. 2), and is dissimilar to known tephra erupted from the central North Island in the last 22 ka (Shane 2000; P. A. Shane unpubl. data). These shards could be detrital contaminants derived from local Neogene rhyolites on Great Barrier Island. Such an origin would be consistent with the ferromagnesian detrital grains found abundant throughout the core. The third population (Table 1, 278 cm c) is represented by only one shard analysis. Its composition is similar to Okataina tephra. However, a single analysis does not allow any firm conclusions to be reached.

Kaharoa tephra

Pullar et al. (1977) reported the occurrence of Kaharoa tephra on Great Barrier Island. The Kaharoa tephra is the deposit from the youngest plinian rhyolitic eruption from the Okataina Volcanic Centre (Froggatt & Lowe 1990). It has been dated at 665 ± 15 ^{14}C yr BP, which equates to 650–560 cal yr BP (Lowe et al. 1998).

Glass from a tephra bed found occurring at a depth of 40 cm in the core was also analysed. The tephra is very similar in composition to fall deposits of Kaharoa tephra collected near source (Table 1). The tephra at 40 cm has a ferromagnesian mineralogy dominated by biotite. This further supports a correlation to the Kaharoa tephra because no other known Holocene tephra has such a mineralogy (Froggatt & Lowe 1990). The Kaharoa tephra can be chemically distinguished from other known Holocene Okataina-sourced tephra beds on the basis of glass chemistry (Fig. 2).

The analysis of the tephra at 40 cm includes a single glass shard that differs in composition from the other shards (Table 1, 40 cm b). It is considered to be a contaminant from an older event as discussed above for minor populations in the sample from 278 cm.

Sedimentology

The core has been divided into two sediment facies as shown on Fig. 3.

Facies A: 355–60 cm

This facies comprises silty, fine sand that includes six well-defined interbeds of poorly sorted, medium to coarse sand and gravel. The thickness of these interbeds ranges from 1 to 11 cm, with the thicker beds preserved in the upper metre of this facies. The interbed at 278 cm is diffuse and is identified as the 5550 cal yr BP Whakatane tephra (see above). The sandy interbeds buried at 70 cm and 106 cm include basal lag of rounded gravel resting upon an erosional surface that truncates the underlying silty sands. Between 278 cm and 134 cm this facies contains pronounced laminae of organic detritus.

Facies B: 60–0 cm

This facies comprises two 20–40 cm thick beds of fine to medium sand. The lower bed is in erosional contact with Facies A and includes coarse sand and rounded gravel clasts up to 5 mm long. Clasts of silty sand similar to those in Facies A lie within 2 cm of the erosion surface. The upper 2–3 cm of this sand-gravel bed contains the Kaharoa tephra (c. 600 cal yr BP). This in turn is overlain by a 40 cm thick bed that fines upward from a silty sand to sandy silt with *in situ* roots from plants growing on the surface.

Palynology

The pollen profile is divided into four zones (Fig. 3).

Zone 1: 355–285 cm, c. 6000–c. 5550 cal yr BP

The pollen sum throughout the zone is dominated by tall tree taxa, mainly *Metrosideros*, *Laurelia*, *Dacrydium*, and Cupressaceae. Shrub and small tree

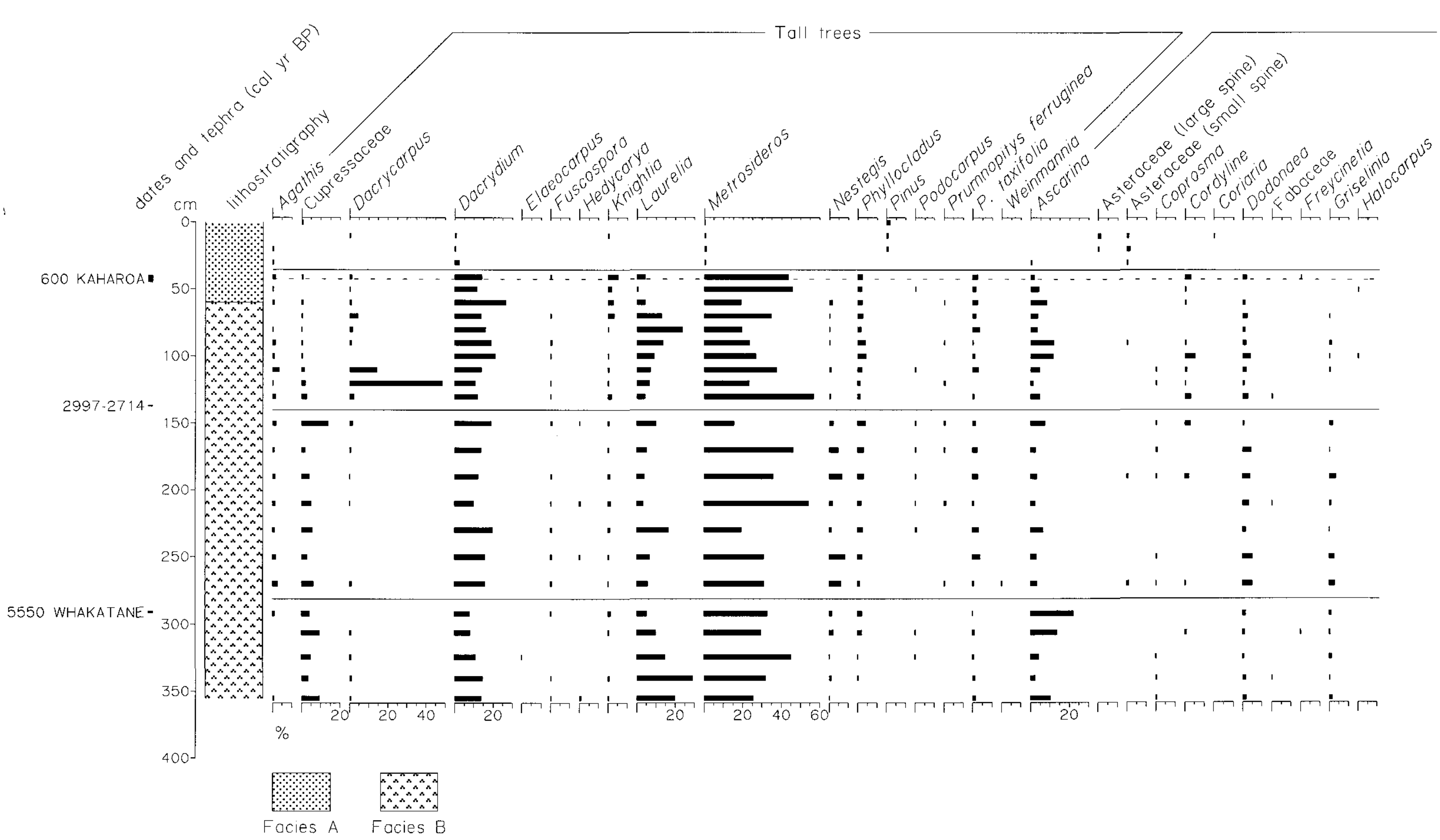

Fig. 3 Pollen diagram from Harataonga. Dotted line = Kaharoa tephra. (*continued over page*)

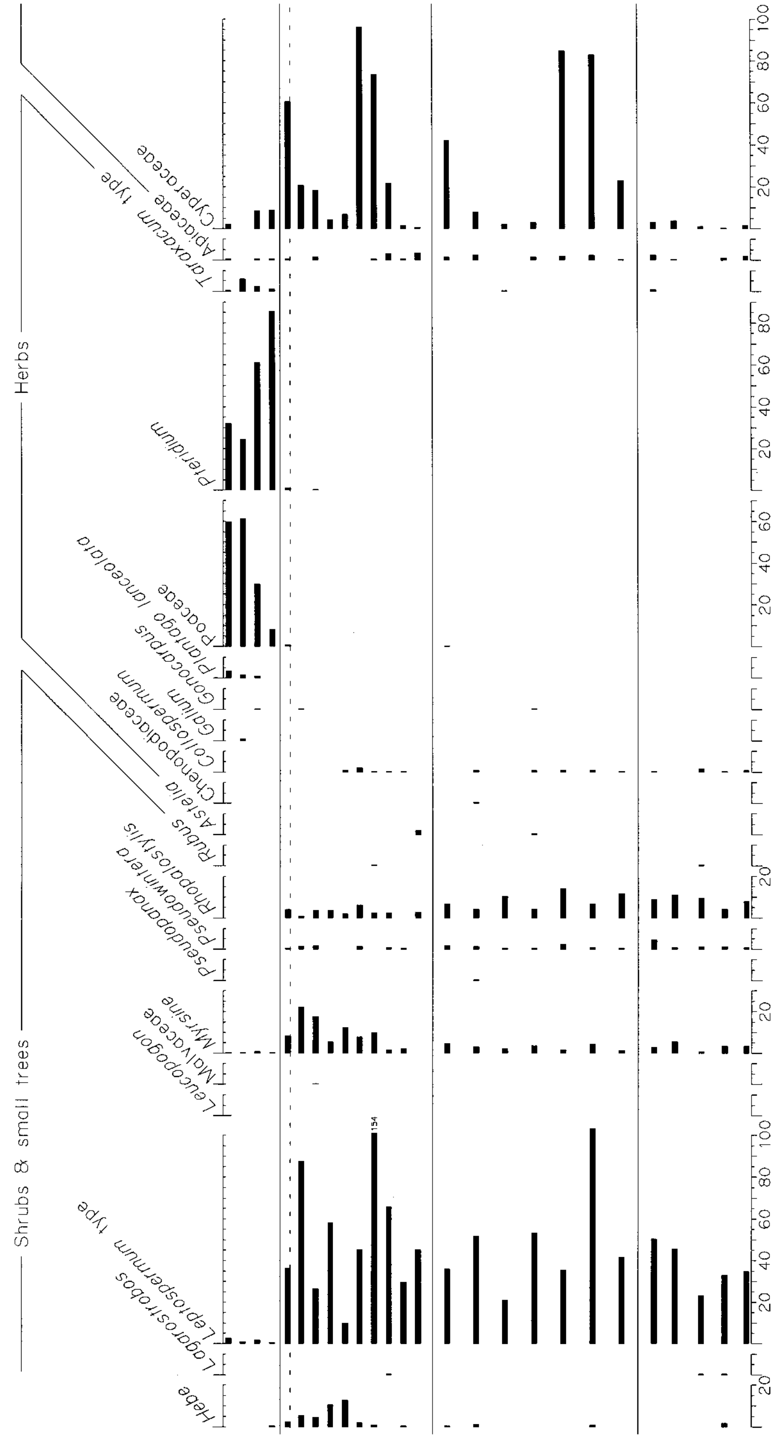

Fig. 3 *continued*

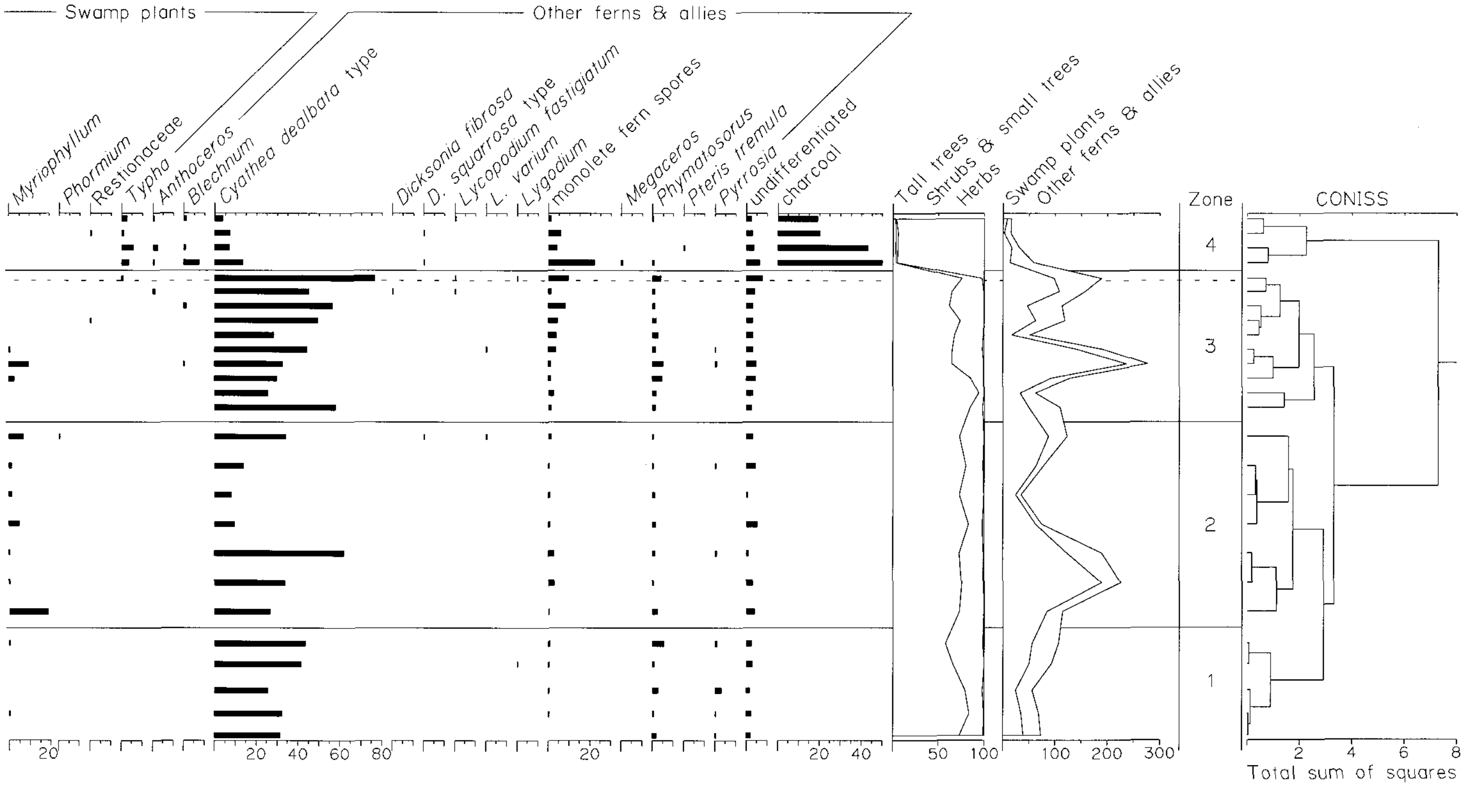

Fig. 3 *(continued)*

taxa are represented mainly by *Ascarina* and *Rhopalostylis* pollen. *Ascarina* pollen values peak towards the upper zone boundary. Swamp plants are dominated by *Leptospermum* type pollen, while Cyperaceae and *Myriophyllum* have low values. *Cyathea dealbata* type spores dominate the ferns. *Cordyline* pollen recorded a low but significant value in one sample in this zone (and was recorded significantly in the subsequent two zones). *Cordyline* has low pollen representation (Macphail & McQueen 1983). The 5550 cal yr BP Whakatane tephra marks the upper zone boundary.

Zone 2: 285–140 cm, c. 5550–c. 2900 cal yr BP

Tall tree taxa continue to dominate the pollen sum throughout this zone in proportions similar to those of the previous zone. The swamp taxa *Leptospermum* type and, especially, Cyperaceae increase and fluctuate dramatically during this zone, although high variability in pollen abundance, or over-representation, is not uncommon for taxa with local pollen dispersal such as *Leptospermum* type and Cyperaceae. A trace of *Phormium* pollen was found in the sample at 150 cm depth.

Zone 3: 140–35 cm, c. 2900–c. 600 cal yr BP

This zone is characterised by a dramatic peak in *Dacrycarpus* pollen, followed by an increase in the pollen of *Laurelia* and then of the shrub and small tree taxa *Hebe* and *Myrsine*. *Myriophyllum* pollen disappears toward the top of the zone. *Pteridium* and *Anthoceros* spores, and *Typha* pollen appear for the first time (in small amounts) in the upper part of the zone. Abundant fibres of *Phormium* leaves were found at 60 cm depth. The c. 600 cal yr BP Kaharoa tephra marks the upper zone boundary.

Zone 4: 35–0 cm, c. 600 cal yr BP–present

Zone 4 is characterised by a sharp and permanent decline in pollen of several forest taxa, *Dacrydium*, *Laurelia*, *Metrosideros*, *Phyllocladus*, *Prumnopitys taxifolia*, *Ascarina*, and *Rhopalostylis*, coinciding with the dramatic appearance of *Pteridium* spores and microscopic charcoal, and an increase in Poaceae and *Typha* pollen. *Dodonaea* and *Leptospermum* type pollen also decline. *Megaceros* spores appear for the first time in this zone, as a trace in one sample. Exotic *Pinus* pollen is present in the uppermost three samples. The uppermost two samples also have very high Poaceae values (approximately 60% of the pollen sum).

DISCUSSION AND CONCLUSIONS

The pre-Kaharoa environment (c. 6000–c. 600 cal yr BP)

The pollen, sediment, and tephra record from Harataonga contains a history of the local coastal environment from the Mid Holocene. This history commences with the development of a local wetland, probably as a result of sand dunes ponding drainage of the catchment into the sea. The presence of *Myriophyllum* (an aquatic) pollen (albeit in trace quantities) indicates that this wetland was freshwater and frequently inundated. The vegetation in the vicinity of the site was probably swamp forest, composed mainly of *Laurelia* trees, possibly with *Leptospermum* (most likely *L. scoparium*) and *Ascarina* small trees, and *Cyathea* spp. tree ferns. Small trees of *Dodonaea* would have grown on margins of this forest. Cyperaceae (most likely *Baumea* spp.) would also have grown on forest margins, although apparently not in abundance in the immediate vicinity of the core site. Interbeds of poorly sorted sands in the lower 50 cm of the core record are interpreted as hill slope material washed to the site during storms.

Forest on the hills surrounding the wetland at Harataonga during the period c. 6000–c. 600 cal yr BP comprised mainly *Metrosideros* trees with emergent *Dacrydium* and *Libocedrus*. *Ascarina*, *Rhopalostylis*, and *Cyathea* spp. would have been a significant part of the under-storey. This composition was similar to those of the Awana and Kaitoke catchments to the south (Horrocks et al. 1999, 2000a,b,c) (Fig. 1B). An exception to this is that *Metrosideros* appears to have been more abundant, and *Dacrydium* less so, at Harataonga. However, given that *Metrosideros* does not disperse pollen far from source (McGlone 1988), the plants may have been local to the core site.

Except for occasional, low values of Restionaceae pollen in the upper portion of the Harataonga core, absence of estuarine indicators, for example, marine shells, marine dinoflagellate cysts, and Restionaceae (salt tolerant spp.) pollen, suggests that the Haratoanga site has been freshwater for the last c. 6000 cal yr. However, we cannot rule out prior estuarine influence as is recorded in the much larger freshwater swamp systems at Awana and Kaitoke (Horrocks et al. 1999, 2000a,b,c). These estuarine indicators were found in the lower parts of most of the cores from the Awana and Kaitoke sites. Around 7500–7000 cal yr BP these sites were estuarine, but by c. 6000 cal yr BP the Awana sites had become freshwater. Kaitoke made the transition to freshwater later, at c. 4500 cal yr BP at its northern sites and c. 2550 cal yr BP at its southern sites.

The discovery of the 5550 cal yr BP Whakatane tephra in the Harataonga core is interesting in that it was not found in any of the sediment profiles from Awana or Kaitoke (Horrocks et al. 1999, 2000a,b). We propose that sediments in the Awana and Kaitoke profiles at this time, unlike those in the Harataonga profile, were deposited in generally higher energy environments where more reworking of sediments would have occurred. Thus, the Awana and Kaitoke sediments at this time were generally sandier than those at Harataonga, possibly obscuring this sandy tephra if it had been present. This also occurred with the Kaharoa tephra in two of the Kaitoke profiles where the tephra was not visible to the naked eye but was detected by microscopic examination (Horrocks et al. 2001).

Laminated organic-rich sediments (commencing at 278 cm) and higher values for *Myriophyllum* pollen indicate that a shallow lake had developed at the Harataonga site after c. 5550 cal yr BP, possibly flooding out *Laurelia*/*Ascarina* swamp forest. The absence of sand interbeds through this interval is supporting evidence for a standing water body. Extensive Cyperaceae swamp appears to have developed on the lake fringes, or at least became abundant in the vicinity of the core site. *Leptospermum* continued to be a prominent part of local vegetation, probably as dense stands and/or as part of *Laurelia* swamp forest also fringing the lake. Development of a freshwater lake at Harataonga is in sharp contrast to the Awana and Kaitoke sites (Horrocks et al. 1999, 2000a,b). None of the latter shows evidence of lake formation, although a brackish, then freshwater lagoon may have been present at one of the northern Kaitoke sites for some undetermined time period from c. 4500 cal yr BP (Horrocks et al. 2000b).

The dramatic *Dacrycarpus* pollen peak in the Harataonga profile a short time after c. 2900 cal yr BP suggests that *Dacrycarpus* (with low pollen dispersal (McGlone 1988)) trees invaded swamp forest surrounding the lake. This was possibly in part a result of the disturbance recorded in the sediments at 120–106 cm depth, as the layer containing rip-up clasts of gravel and clay. Some of the Awana and Kaitoke records also suggest local *Dacrycarpus* invasion of swamps after c. 3000 cal yr BP and also show an increased frequency of sediment disturbance after this time (Horrocks et al. 1999, 2000a,b). Newnham et al. (1995) also reported an invasion of the local swamp by *Dacrycarpus* at Waihi Beach, 120 km to the south of Great Barrier Island.

The apparent synchrony of tree invasion of swamps and increased frequency of sediment disturbance in different catchments suggests that these are not necessarily localised events (most notably hydroseral succession) and that climate change may be a cause. Horrocks et al. (1999, 2000a,b) suggested that various lines of paleoenvironmental evidence from many North Island sites concur in showing that a long-term Holocene trend towards a drier climate in the North Island intensified c. 3000–2000 ^{14}C yr BP. This would have had the effect of lowering the water table (see below) and allowing *Dacrycarpus* to invade lake fringes or swamps. McGlone et al. (1992) concluded that greater climatic variability associated with increased amplitude of the El Niño/Southern Oscillation (ENSO) commenced in the North Island between 5000 ^{14}C yr and 3000 ^{14}C yr BP.

The apparent brevity of the *Dacrycarpus* invasion at Harataonga suggests a single cohort that failed to regenerate. Similar fluctuations in the pollen curves of forest taxa are also apparent in the Awana and Kaitoke records at around the same time (Horrocks et al. 1999, 2000a,b,c, 2001). One explanation for this is that while the overall climate may have become drier, there was an increase in storm frequency. *Dacrycarpus* is known to colonise waterlogged sites following disturbance (e.g., Wardle 1974). The North Island has experienced, on average, one tropical cyclone per decade during the 20th century, as well as many other storms of extra-tropical origin (Shaw 1983). This would also explain the greater occurrence of sediment disturbance recorded in these three separate catchments on Great Barrier. In the central Bay of Islands, 150 km to the north of Great Barrier Island, Elliot et al. (1998) also reported fluctuations in the abundance of forest taxa during the late Holocene. They interpreted these as indicating repeated disturbance due to summer droughts and increased frequency of cyclonic winds.

This apparent correspondence of events on Great Barrier Island highlights the obvious advantage of analysing multiple sites within a region. Regional trends, such as climate change, can be more confidently differentiated from more local events.

The disappearance of *Myriophyllum* pollen (and of lamination in the core) shortly after c. 2900 cal yr BP marks the transition of the lake site at Harataonga to swamp. During the next two millennia, *Myrsine* and then *Hebe* shrubs invaded fringes of the swamp as the water table fell. The former is common in scrub in poorly drained sites, and the latter in seral scrub (Macphail & McQueen 1983). The presence of *Phormium* fibres in the profile towards the end of the c. 6000–c. 600 cal yr BP period indicates on-site presence of this taxon and fertile conditions in the swamp (Macphail & McQueen 1983). The corresponding lack of *Phormium* pollen (ornithophilous thus locally dispersed) in the profile at that time (the trace reported was found at 150 cm depth) is an example of the under-representation of this taxon in pollen spectra (Macphail & McQueen 1983). As one of the habitats of *Cordyline* is base-rich swamps (Macphail & McQueen 1983), the presence of pollen of this taxon in the Harataonga profile throughout most of the c. 6000–c. 600 cal yr BP period suggests that a base-rich wetland prevailed during most of this time. In contrast, much less *Cordyline* pollen was found at pollen sites at Awana and Kaitoke, suggesting generally more acid conditions in those wetlands (Horrocks et al. 1999, 2000 a,b,c).

Another difference between the freshwater wetland at Harataonga and those at Awana and Kaitoke (Horrocks et al. 2000a,b) is the apparent absence of *Gleichenia* from Harataonga for its entire c. 6000 cal yr history. The large difference in hydrology between the Harataonga site and those of the other two catchments (i.e., lake formation only at the former) may have somehow prevented the establishment of this taxon at Harataonga.

The Harataonga charcoal profile, showing absence of significant charcoal in pre-Kaharoa times, is similar to the Awana and Kaitoke profiles in this respect (Horrocks et al. 1999, 2000a,b). At the latter sites, pre-Kaharoa charcoal was not found in samples from four out of six cores covering up to the last 7300 cal yr. In the two remaining cores (from the southern part of Kaitoke), the earliest recorded charcoal occurred after c. 1700 cal yr BP. Horrocks et al. (2001) considered that this scarcity of charcoal appeared unusual when compared with profiles from elsewhere in the northern North Island. They noted that of the 14 other pollen profiles from northern North Island covering at least the last c. 3000 yr, 12 (86%) of these have microscopic charcoal present in most if not all pollen samples. Only two showed a scarcity of charcoal in pre-Kaharoa sediments similar to that found at Great Barrier. However, Horrocks et al. (2001) emphasised that they may have missed discrete charcoal layers present in their Great Barrier cores between samples. Nonetheless, Horrocks et al. (2001) concluded that Great Barrier Island may have had a lower frequency of natural fires during the pre-Kaharoa Holocene than other northern North Island areas, possibly due to being wetter. The Harataonga evidence supports this hypothesis.

The post-Kaharoa environment (c. 600 cal yr BP-present)

The pollen record from Harataonga shows that a period of vegetation disturbance on a catastrophic scale began very soon after deposition of the c. 600 cal yr BP Kaharoa tephra. The sharp increase of microscopic charcoal at the same time implies that large-scale Polynesian fires (McGlone 1983, 1989), rather than the eruption, were the primary cause. However, as Horrocks et al. (2001) pointed out, the possible presence of tephra-damaged trees after the eruption may have predisposed Great Barrier forest to burning for several centuries after the eruption by increasing the fuel load available for ignition (Wilmshurst & McGlone 1996). Nonetheless, the Harataonga profile and most of the Awana-Kaitoke profiles are typical of pollen profiles not recording the Kaharoa from elsewhere in New Zealand, which show that major Polynesian deforestation occurred 800–600 conventional yr BP (McGlone 1983, 1989).

The sharp increase in *Pteridium* and suddenly declining values for many taxa (notably *Dacrydium*, *Laurelia*, *Metrosideros*, *Phyllocladus*, *Prumnopitys taxifolia*, *Ascarina*, *Cordyline*, *Dodonaea*, *Leptospermum*, *Myrsine*, and *Rhopalostylis*) that occur along with the charcoal increase indicate destruction of local swamp vegetation and surrounding dryland forest. In addition, the deposition of coarse sand and gravel at this time is consistent with a disturbed environment. Specifically, disturbance of dune vegetation is considered to have led to mobilisation of soils into the sediments. This is supported by the appearance of *Anthoceros* and *Megaceros* spores around this time, also indicating a disturbed environment (Wilmshurst et al. 1999). These two genera are of the hornwort family, which typically colonises freshly exposed soils. The presence of traces of *Pteridium* and *Anthoceros* immediately below the Kaharoa tephra (where charcoal was not found) hints at possible small-scale human effects at Harataonga at some undetermined time shortly before deposition of the tephra.

As *Typha* is an indicator of swamp eutrophication, its appearance in the Harataonga record may also suggest large-scale effects by people in the catchment. Similar increases in *Typha* pollen occurred at around the same time in the pollen profiles from Awana and Kaitoke (Horrocks et al. 1999, 2000a,b).

The nature and timing of large-scale deforestation at Harataonga appears similar to that of the Awana and Kaitoke catchments. In the latter, Horrocks et al. (2001) found that large-scale burning had occurred, resulting in similar vegetation changes to those reported for Harataonga for the time of deposition of the Kaharoa tephra. However, the commencement of this burning at Awana and Kaitoke was patchy, occurring at different times. For instance, at one site at Awana, macroscopic charcoal was found in a bulk sample from 3 cm below the tephra, indicating a local fire (or fires) at some undetermined time shortly before deposition of the tephra. This fire was not recorded in a short profile from an adjacent site only 400 m distant. Here, neither macroscopic nor microscopic charcoal was found in any of the samples (taken every 2 cm) up to 9 cm below and up to 5 cm above the 2 cm thick layer of tephra. These apparent differences in timing of fires between the Great Barrier pollen sites have implications for inferring date of human presence in an extensive area, such as a catchment or region, from a single or small number of cores. With this in mind, we conclude that we can only be certain that anthropogenic burning at Harataonga commenced shortly after deposition of Kaharoa in the part of the catchment near the core site.

The presence of exotic, widely dispersed *Pinus*, *Plantago lanceolata*, and abundant Poaceae pollen in the uppermost three samples of the core (0–20 cm depth) reflects European influences in the Auckland region that began early in the 19th century. The very high values for Poaceae pollen reflect part of the present vegetation (pasture) at the site. Although large scale *Pinus* plantation forestry commenced in New Zealand only in the 20th century, *Pinus pinaster* was successfully growing wild in New Zealand by AD 1830 (Webb et al. 1988). However, possible mixing of surface sediments due to agriculture-related disturbance in European times may mean that these uppermost samples do not reflect the last 170 yr. The European period in New Zealand is also characterised in the pollen record by high values of grass pollen as forests not cleared by Maori were rapidly converted to pasture by European farmers in the latter half of the 19th century.

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