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The effects of the Taupo Tephra eruption of *c.* 1718 BP on the vegetation of Mt Hauhungatahi, central North Island, New Zealand

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Abstract. An altitudinal series of eleven fine resolution pollen diagrams were used to examine the role of volcanism in forest dynamics on Mt Hauhungatahi. Partial pollen diagrams from four of these sites, chosen to illustrate the major effects of the 1718 BP Taupo eruption, are presented. Following the eruption *Libocedrus bidwillii* expanded in all sites. Open sites created by the eruption may have facilitated an expansion already underway as a result of more variable climatic conditions since *c.* 3000 BP. *Weinmannia racemosa* invaded upper montane forest *c.* 650 BP. The current altitudinal sequence of forest types, with *Libocedrus* dominating the subalpine and *Weinmannia* the upper montane forests, has thus been synthesized only within the last 1800 years. This is interpreted as a consequence of individualistic species' responses to major disturbance by the eruption. The results support nonequilibrium theories of community composition.

Key words. Palynology, fossil pollen, Holocene, volcanism, Taupo Tephra eruption, *Libocedrus bidwillii, Weinmannia racemosa,* New Zealand.

INTRODUCTION

During the last two decades the view that disturbances of various types, usually showing continuous gradients in magnitude, are a normal feature of most landscapes has gained wide acceptance (White, 1979). Successional patterns create a landscape mosaic of 'patch dynamics' (Pickett & Thompson, 1978), in which forest community structure and status varies locally (White & Pickett, 1985). Natural landscapes may thus be regarded as 'shifting mosaics' (Borman & Likens, 1979) of variously aged and sized patches.

In New Zealand forests there is strong evidence that localized and occasionally widespread forest destruction occurs on a time scale relevant to the demography of the canopy dominants (Ogden, 1985). Storm damage to forests has been commonly reported (e.g. Elder, 1965; Clayton-Green, 1977; Veblen & Stewart, 1982). Forest mortality as a result of drought has been discussed by Jane & Green (1983), Grant (1984), and Hosking & Hutcheson (1986); landslides by Mark *et al.* (1964); earthquakes by Robbins (1958); and avalanches by Wardle (1985). Damage from fire (e.g. Molloy *et al.*, 1963; Esler & Astridge, 1974; McGlone, 1983a, 1989) and insects (e.g. Dugdale, 1965; Milligan, 1974) has also been discussed. Grant (1983, 1989) suggested that extensive forest destruction periodically occurs over much of New Zealand as a result of increases in climatically driven rates of erosion.

Much of the central North Island of New Zealand has been affected by cataclysmic volcanic events during the Quaternary. The rhyolitic Taupo Tephra (Froggatt & Lowe, 1990) eruption (hereafter referred to as the 'Taupo eruption', recently calibration dated at 1718 ± 15 BP (Sparks *et al.*, 1995), was one of the most violent Holocene eruptions known. During this eruption, tephra erupted from a vent in north-east Lake Taupo, resulting in an overland pumice flow that covered an area ≈ 160 km across. Forests were flattened by the shock wave preceding the flow and completely buried under the flow as far away as 70 km (Clarkson *et al.*, 1992). The shock wave would have damaged forests beyond the limit of the flow (Wilson, 1981; Spicer, 1989). McGlone (1980) suggested that forests up to 150 km from the vent were damaged by air-fall tephra, causing widespread fires to occur for at least 150 years after the eruption.

Elder (1962) and McKelvey (1963, 1973) ascribed a major role to the Taupo eruption in explaining the Kaimanawa, West Taupo and Urewera forest patterns. McKelvey (1963) described a concentric successional pattern of forest types with supposedly seral podocarp stands close to the explosive centre, and more mature forest with more abundant hardwoods further away. He also suggested that *Nothofagus* had been largely eliminated from the central Volcanic Plateau as a consequence of the eruption.

Using the pollen record, several researchers have disputed some of these findings. McGlone & Topping (1977) suggested that *Nothofagus* was nearly eliminated from the Volcanic Plateau during the last glacial maximum and failed to re-establish during the early postglacial rather than after the Taupo eruption. Similarly, McGlone (1983b) and

Clarkson *et al.* (1986) found that *Nothofagus* has not been widespread on the Plateau since at least 4000 BP. In addition, they showed that forest recovered much of its former composition much more rapidly after the eruption than McKelvey (1963, 1973) suggested. Furthermore, Steel (1989) demonstrated that *Nothofagus* can compete successfully with podocarp/hardwood associations following volcanic disturbance. She suggested that although much of the West Ruapehu *Nothofagus* forest was destroyed by the eruption, most of it quickly recovered its former composition.

More recently, work by Clarkson *et al.* (1992) and Leathwick & Mitchell (1992) has also cast doubts on McKelvey's (1963, 1973) succession hypothesis. Clarkson *et al.*'s (1992) analysis of plant macrofossils buried under Taupo tephra showed that hardwood forest is not necessarily the endpoint of forest succession; the local pre-Taupo forests were podocarp-dominated. Leathwick & Mitchell (1992) found that present day temperature, solar radiation, and topography showed higher correlations with species distributions than distance from the eruption centre. Thus, the relative influence of volcanic and climatic factors on forest development in the central North Island is controversial.

Differentiating the roles of past disturbances and current climate factors as determinants of the 'present' distribution patterns of species requires detailed knowledge of preclearance forest patterns and information about the eco-physiology of the species. However, if species distributions in space can be related to the pattern of tephra fall-out, and distributions in time show changes in population levels coincident with the eruption, then the importance of this event is demonstrated.

The primary aim of the paper was to describe the effects of the 1718 BP Taupo eruption on vegetation using fine resolution pollen analysis. Mt Hauhungatahi is suitable for this because pollen is well preserved on many parts of the mountain and the Taupo Tephra forms a clear stratigraphic marker of pumice granules. The modern vegetation and pollen rain has been described (Stevenson, 1975; Atkinson, 1981; Druitt *et al.*, 1990; Horrocks & Ogden, 1994). Gibson's Swamp (Fig. 1), 15 km south of Hauhungatahi in the Horopito-Ohakune area, was included to provide a comparison from an area further away from, and presumably less affected by, the eruption.

THE STUDY AREA

Location, climate and geology

Mt Hauhungatahi is situated near the western boundary of Tongariro National Park in central North Island (lat. 39° 14′S, long. 175° 26′E) (Fig. 1). It rises to 1521 m from a plateau at about 700 m. The lower slopes are steep while the upper slopes form a broad, gently sloping wetland. Gibson's Swamp (810 m) lies 15 km south of Hauhungatahi, just outside the Park boundary on a plateau (lat. 39° 22′S, long. 175° 25′E).

The climate of the Tongariro region is cool-temperate. The two nearest weather stations to Mt Hauhungatahi are 8 km east at the Chateau (1120 m), and 20 km to the south at Ohakune (629 m). The two nearest weather stations to Gibson's Swamp are 5 km south at Ohakune and 4 km to the north-east at Horopito (725 m). At the Chateau, mean annual temperature is 7.1 °C and mean annual rainfall is 2914 mm (Atkinson, 1981). Ground frosts average 141 per annum and snow falls on 16 days. For Ohakune, mean annual temperature is 10.1 °C and mean annual rainfall is 1509 mm. Ground frosts average 97 per annum and snowfalls occur on 6 days. At Horopito, mean annual rainfall is 1839 mm. Rainfall in the region is distributed throughout the year with a winter maximum. Droughts are rare in the region but summer water deficits do occur.

Mt Hauhungatahi is an extinct, eroded andesitic volcano which originated in the mid to late Pleistocene. Several tephra deposits have been laid down on Hauhungatahi during the Holocene. There are marked differences in texture between some of these. For example, the uppermost formation, a series of andesitic layers from the Tongariro volcanoes referred to as the Ngauruhoe Tephra (Topping, 1973), overlies the much coarser rhyolitic Taupo Pumice. These sudden changes in texture have resulted in soils with poor drainage, especially on the gentler upper slopes.

Gibson's Swamp is situated on late Pleistocene Waimarino lahars originating from Mt Ruapehu which have formed a plateau platform in the south-west extension of Tongariro National Park (Lusk, 1989). These in turn are overlain by Holocene tephras.

Present vegetation of Hauhungatahi

Forest commences at an anthropogenic lower boundary at 750 m. Conifers generally dominate with older individuals often emerging through a hardwood canopy. At lower altitudes, *Dacrydium cupressinum, Prumnopitys ferruginea, P. taxifolia, Weinmannia racemosa* and *Nestegis cunninghamii* form most of the canopy. Common subcanopy species include *Weinmannia racemosa, Nestegis cunninghamii, Melicytus ramiflorus, Coprosma tenuifolia, Cyathea smithii* and *Dicksonia squarrosa.* At 850–950 m, *Podocarpus hallii* and *Libocedrus bidwillii* become the dominant conifers. In the subcanopy, *Griselinia littoralis*, *Coprosma australis* and *C. foetidissima* become prominent. Over 1000–1150 m, *Podocarpus hallii* is replaced by *Phyllocladus aspleniifolius* var. *alpinus* and *Halocarpus biformis* which, together with *Libocedrus bidwillii,* form mosaic patterns in which *H. biformis* is associated with the wettest areas. *L. bidwillii* is the dominant emergent at these altitudes.

The tree-line is highly irregular, fluctuating between 1100 and 1200 m with a few narrow fingers of forest extending beyond this to 1250 (Fig. 1). These fingers appear to be associated with drier ridges. Landslips are evident in forest at these higher altitudes, and Atkinson (1981) and Ogden *et al.* (1991) noted extensive windthrow.

At tree-line, forest gives way either to fernland, or to a band of patchy, dense *Phyllocladus aspleniifolius* var. *alpinus*/*Halocarpus bidwillii* scrub. *Dracophyllum longifolium*/*Gleichenia circinnata* fernland extends up to 1250–1300 m and is associated with very poorly drained soils (Atkinson, 1981). Scattered shrubs of *Halocarpus bidwillii, Podocarpus*

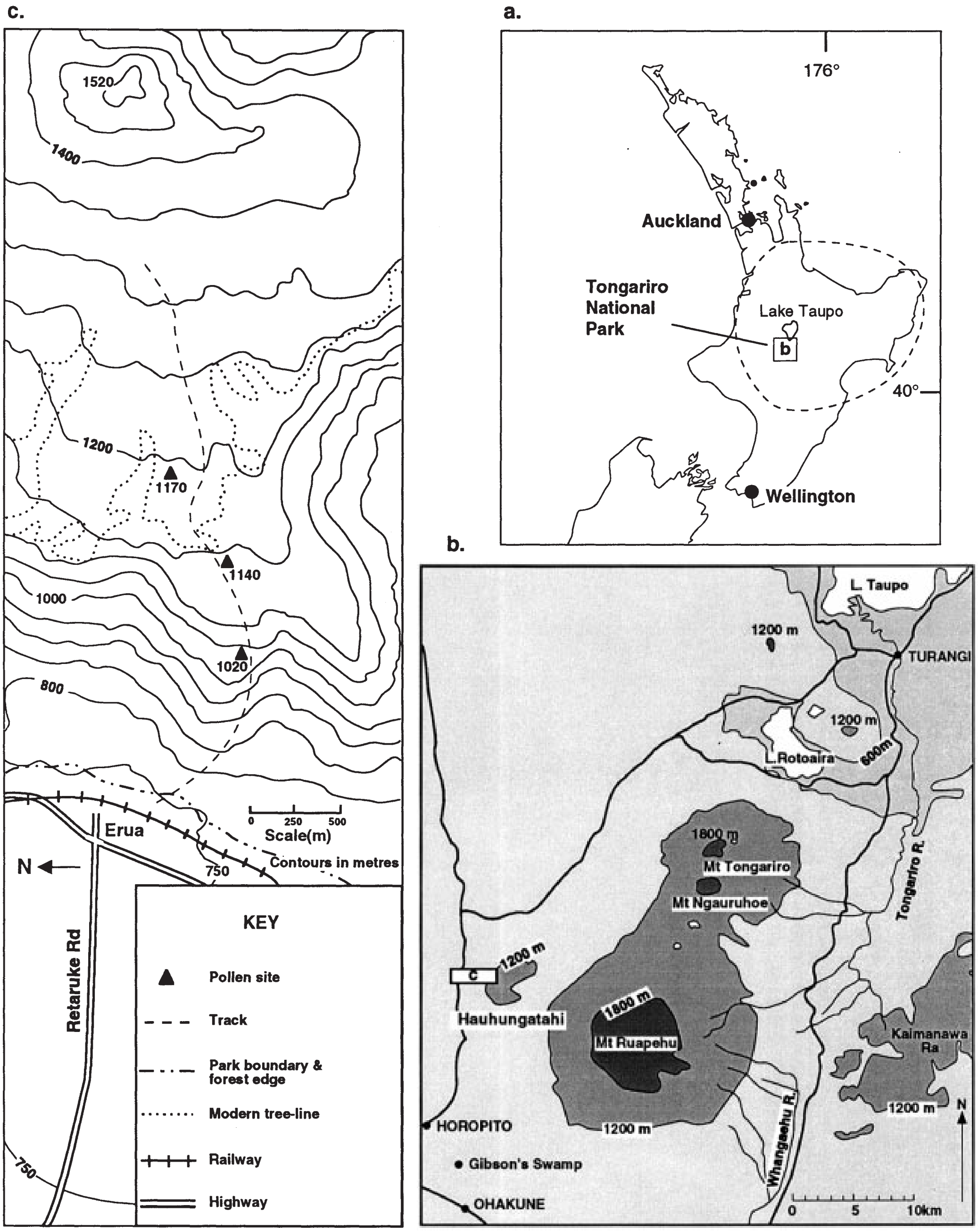

FIG. 1. (a) Location of Tongariro National Park and Lake Taupo (source volcano of Taupo Tephra), and distribution of Taupo Tephra (dashed line = 5 cm isopach) (Pullar *et al.*, 1977). (b) Tongariro region showing location of Hauhungatahi and Gibson's Swamp. (c) Location of pollen sites at Hauhungatahi.

nivalis, and a few other species occur. Fernland grades into tussockland, which is associated with slightly better-drained soils and extends to the summit. *Chionochloa rubra* and *Empodisma minus* dominate tussockland.

Present vegetation of Gibson's Swamp

Gibson's swamp is a forest swamp < 1 ha in area and lies on the fringe of better drained vegetation described by Atkinson (1981) as predominantly *Weinmannia racemosa* forest that has regenerated after milling of a previous conifer-dominated forest now represented by isolated trees. The canopy of this forest type is extremely variable in composition. As well as *W. racemosa* it is also comprised of young *Nestegis cunninghamii, Carpodetus serratus, Podocarpus hallii,* and *Prumnopitys ferruginea.* Isolated trees, including *Libocedrus bidwillii, Prumnopitys taxifolia, Dacrycarpus dacrydioides* and *Nestegis cunninghamii* are common on farmland bordering the swamp, which is currently grazed by stock.

TABLE 1. Radiocarbon dates from sites at Hauhungatahi and Gibson's Swamp. (1) Libby date based on 5568 years half-life of ^{14}C. BP refers to Before Present, where, by convention, AD 1950 is taken as 'Present'. (2) Based on 5730 years half-life. (3) Range within which dates calibrated by reference to tree-ring curve lie (Stuiver & Reimer, 1993), allowing also 40 years offset for the Southern Hemisphere. (4) The probability of the true date falling within the calibrated range.

Laboratory sample no.	Site	Sample type	Depth (cm)	Conventional date BP (1)	New date BP (2)	Calib. range based on 1 SD (3)	Prob. of falling in calib. range (4)
NZA 4187	Gibson's Swamp	Sandy silt	42.5	3890 ± 80	3400 ± 80	4412–4225	0.89
NZA 3423	1170	Fibrous peat	20.5	390 ± 60	400 ± 60	466–316	1
Wk-3193	1170	Wood	65–75	3040 ± 50	3130 ± 50	3213–3155	0.93
Wk-3192	1170	Sandy silt	95	4160 ± 240	4280 ± 250	4878–4252	0.97

METHODS

A total of eleven sites on Mt Hauhungatahi were examined for stratigraphy and pollen profiles (Horrocks, 1994). Three of these, which clearly illustrate the compositional changes occurring in the vegetation close to the present tree-line, are presented here along with the profile from Gibson's Swamp. These are named according to their respective altitudes a.s.l. Site locations are shown in Fig. 1.

Cores were taken with a 50 cm D-section corer. Although one core only from each site was analysed in detail, additional cores were taken and examined for charcoal layers and other stratigraphic markers. Fine resolution sampling of cores was carried out with samples taken at intervals from 0.5 to 5.0 cm. Samples were prepared for pollen analysis by the standard acetylation and hydrofluoric acid method (Faegri & Iversen, 1989). Bleaching was also carried out. A binocular microscope at 400 × magnification or higher was used to scan slides. The pollen sum (from which the percentages in the pollen diagrams are calculated) was at least 250 grains, excluding swamp plants and ferns (except *Pteridium)*. The software packages TILIA and TILIAGRAPH were used to construct the pollen diagrams.

Radiocarbon dating was carried out by the Institute of Geological and Nuclear Sciences, Lower Hutt (NZA) and the University of Waikato, Hamilton (Wk). Calibrated radiocarbon dates in the text are based on tree-ring calibration with a 40 years Southern Hemisphere off-set (Stuiver & Reimer, 1993). For ease of comparison with other published dates, conventional dates are given in Table 1. Dates of some samples were estimated by extrapolation from their stratigraphic position in relation to the surface, the Taupo Tephra horizon (*c.* 1718 BP) and radiocarbon dated samples.

RESULTS

Pollen analysis results are shown in four summarized pollen diagrams (Fig. 2a–d). The full diagrams each show up to sixty-five different pollen types and cover periods up to the late glacial (i.e. > 10,000 BP). In order to simplify the diagrams and emphasize the main local changes in vegetation composition resulting from an event < 2000 BP, pollen types considered of little importance (e.g. rare types, those showing little change or those mainly from elsewhere) are excluded, as are samples in the profiles that cover the period before *c.* 6000 BP. The full diagrams, including all identified pollen taxa and more information on stratigraphy, are given in Horrocks (1994).

Site 1020 (Fig. 2a)

The site is located within the transition zone of steep montane/subalpine forest on a flat area < 20 m^2 and ≈ 5 m north of the track (Fig. 1). The substrate is wet, organic forest soil. Dominant canopy species in surrounding forest are *Podocarpus hallii, Libocedrus bidwillii, Phyllocladus aspleniifolius* var. *alpinus* and *Halocarpus bidwillii.* The nearest scrub or open area is ≈ 450 m east.

Pre-Taupo, 29–16 cm, c. 2500 BP–c. 1718 BP

Dacrydium and *Libocedrus* are the main local contributors to the pollen sum during this period. Pollen values strongly suggest that pre-Taupo cover was mixed-podocarp forest, probably with *Dacrydium cupressinum* and *Libocedrus bidwillii* the main emergents. *Phyllocladus aspleniifolius* var. *alpinus* most likely formed a large part of the canopy and under-story.

The Taupo Tephra, at the upper part of this zone, is ≈ 6 cm thick. The pumice granules are diffusely scattered through the sandy silt sediments, suggesting that some secondary reworking of the tephra has occurred.

Post-Taupo, 15–0 cm, c. 1718 BP–present

Libocedrus shows a dramatic increase (up to 45%) immediately after the Taupo Tephra while *Dacrydium* declines. *Libocedrus bidwillii* probably replaced *Dacrydium cupressinum* as the dominant post-Taupo emergent. At 7 cm (≈ 650 BP), *Weinmannia* pollen appears significantly for the first time although levels remain low (< 10%).

Site 1140 (Fig. 2b)

The site is located in forest ≈ 5 m from the subalpine forest/scrub boundary on a flat area ≈ 50 m south of the track, at the foot of the broad, gently sloping upper western flank of the mountain (Fig. 1). The substrate is wet, organic forest soil. Dominant canopy species in surrounding forest are *Libocedrus bidwillii, Phyllocladus aspleniifolius* var. *alpinus* and *Halocarpus bidwillii.* The site is ≈ 40 m above the present upper altitudinal limit for *Weinmannia* (Druitt *et al*., 1990).

Pre-Taupo, 34–23 cm, c. 2500–c. 1718 BP

Distant dispersers, e.g. *Dacrydium,* increase at the expense of *Phyllocladus* (50%) during this period. This suggests a degeneration of *Phyllocladus*-dominated low forest at the site into open subalpine scrub (Horrocks & Ogden, 1994).

The Taupo Tephra, forming the upper boundary of this zone, is ≈1 cm thick. The pumice granules are diffusely scattered through the sandy silt sediments, suggesting that some secondary reworking of the tephra has occurred.

Post-Taupo, 22–0 cm, c. 1718 BP*–present*

The forest taxon *Libocedrus* (up to 10%) appears significantly for the first time and *Phyllocladus* increases to former levels. This indicates a post-Taupo recovery of subalpine forest at the site but of a different composition to pre-Taupo forest.

Later during this zone, *Weinmannia* (up to 11%) also appears significantly for the first time, remains at steady levels, then declines sharply at the surface, indicating a recent expansion of this species at the site then a sudden decline. Ericales record a significant value at the surface (8%), coinciding with the *Weinmannia* decrease, suggesting that *Weinmannia* was replaced largely by *Dracophyllum longifolium* (Ericales) which is presently abundant at the site. The pollen profile from a tree-line site at the same altitude 200 m to the north (Horrocks, 1994), shows more pronounced *Weinmannia* (up to 38%) and *Ericales* (16%) curves (included in Fig. 2b).

Site 1170 (Fig. 2c)

The site is located in subalpine ombrogenous peat bog on a level area ≈75 m north of the track, in fernland on the broad, gently sloping upper western flank of the mountain (Fig. 1). Dominant fernland species are *Dracophyllum longifolium* and *Gleichenia circinnata.* The nearest forest is ≈100 m west.

Pre-Taupo, 95–54 cm, c. 4280 BP*–c. 1718* BP

Local vegetation during this period was most likely *Phyllocladus*-dominated low forest extending up from Site 1140. A distinct tephra layer at 86 cm coincides with a drop in *Phyllocladus.*

Phyllocladus recovers and *Libocedrus* increases (up to 25% of the pollen sum) in the later part of this period. A *Libocedrus* stump (3213 ± 3155 cal. BP, Wk-3193) with 204 annual rings was found at 65–75 cm in the profile. After this, *Libocedrus* and *Phyllocladus* suddenly decline in abundance, with vegetation opening out to allow the influx of regional pollen (e.g. *Dacrydium).* This decline coincides approximately with another distinct tephra layer at ≈70 cm. Unlike the other three sites where immediate pre-Taupo vegetation was forest, the pollen profile from this site thus indicates a change to subalpine scrub immediately prior to the eruption.

The Taupo Tephra, at the upper zone boundary, is ≈4.5 cm thick. Unlike the other three sites, the pumice granules form a distinct layer between sandy silt sediments, indicating that no secondary reworking of the tephra has occurred.

Post-Taupo, 52–0 cm, c. 1718 BP*–present*

The Taupo eruption appears to have dramatically affected the vegetation at this site. The remarkably high *Libocedrus* values (up to 80%) imply massive *Libocedrus* regeneration on or close to the site immediately after the eruption. The time lag between *Libocedrus* establishment and pollen production may be < 50 years (Clayton-Greene, 1977).

Libocedrus declined as rapidly as it arose, unlike Site 1020 and Gibson's Swamp where its increase was sustained. Increased representation of tall podocarps with well dispersed pollen indicates that the vegetation opened as *Libocedrus* became less abundant. Corresponding increases in smaller tree and shrub taxa, e.g. *Phyllocladus,* suggest that subalpine shrubland replaced the *Libocedrus* stand.

Major vegetation changes in the later part of this period coincide with a charcoal layer ≈0.75 cm thick, at a depth of 21 cm. A radiocarbon date (466 ± 316 cal. BP, NZA 3423) at 0.5 cm above the charcoal layer suggests that the fire occurred ≈450–400 BP. Pollen values indicate that shrubland disappeared quite suddenly. Layers of charcoal (rarely thicker than 0.1 cm) were found in six out of sixteen shallow cores from around this site. Charcoal is patchily distributed in a discontinuous layer between 6 and 21 cm depth over an altitudinal range of at least 1170–1240 m. A second charcoal peak at 11.5 cm in some cores suggests a second fire destroyed remaining clumps of shrubland, leaving the area much as it is at present, i.e. boggy fernland with tussock and sparsely scattered shrubs.

Gibson's Swamp (810 m) (Fig. 2d)

The site is located in flat swamp forest < 1 ha in area bordering farmland in the Horopito-Ohakune area, 15 km south of Mt Hauhungatahi (Fig. 1). The substrate is waterlogged, organic forest soil. Dominant canopy species in surrounding forest are *Weinmannia racemosa, Nestegis cunninghamii, Carpodetus serratus, Podocarpus hallii* and *Prumnopitys ferruginea. Libocedrus bidwillii* is also present at the site. The nearest open area is ≈20 m west.

Pre-Taupo, 56–29 cm, c. 6000–c. 1718 BP

During the early part of the pre-Taupo period (*c.* 6000 BP–*c.* 3400 BP) *Dacrydium* (up to 60%), although declining, dominates the pollen sum. *Nestegis* appears and *Libocedrus* maintains steady levels (along with *Elaeocarpus,* up to 18%). The site must have been conifer/hardwood forest, with abundant *Dacrydium* and some *Libocedrus* and *Prumnopitys taxifolia* emerging through a predominantly *Elaeocarpus* and *Nestegis* canopy. *Cyathea smithii* formed a subcanopy throughout most of this zone.

After *c.* 3400 BP, forest most likely still covered the site but its composition had apparently changed considerably. *Cyathea smithii*-type declined dramatically and never recovered to the same extent. *Libocedrus* became a dominant canopy emergent, partially replacing *Dacrydium cupressinum* and *Prumnopitys taxifolia.* (A pre-Taupo increase of *Libocedrus* is also seen at Site 1170.)

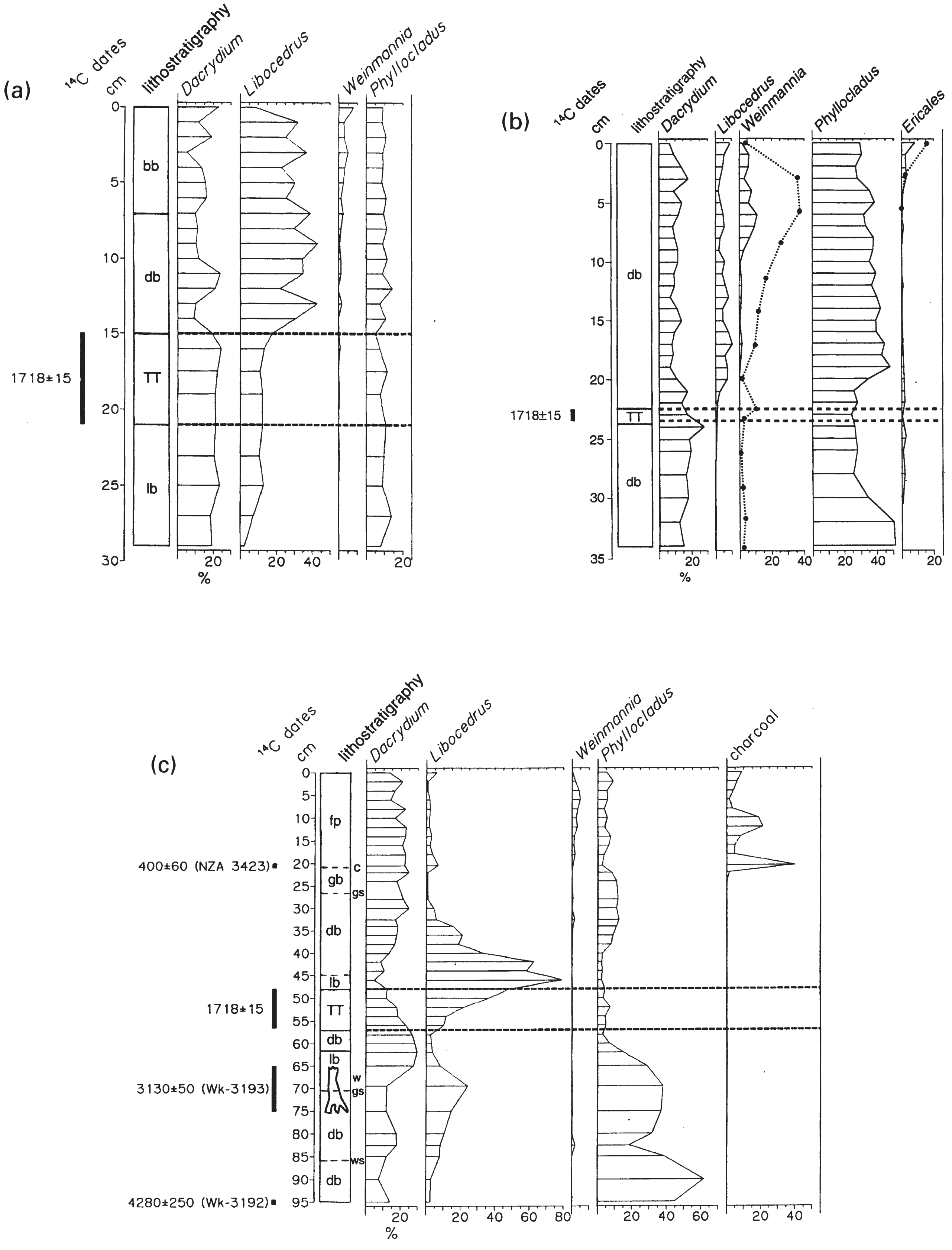

FIG. 2. *contd overleaf*

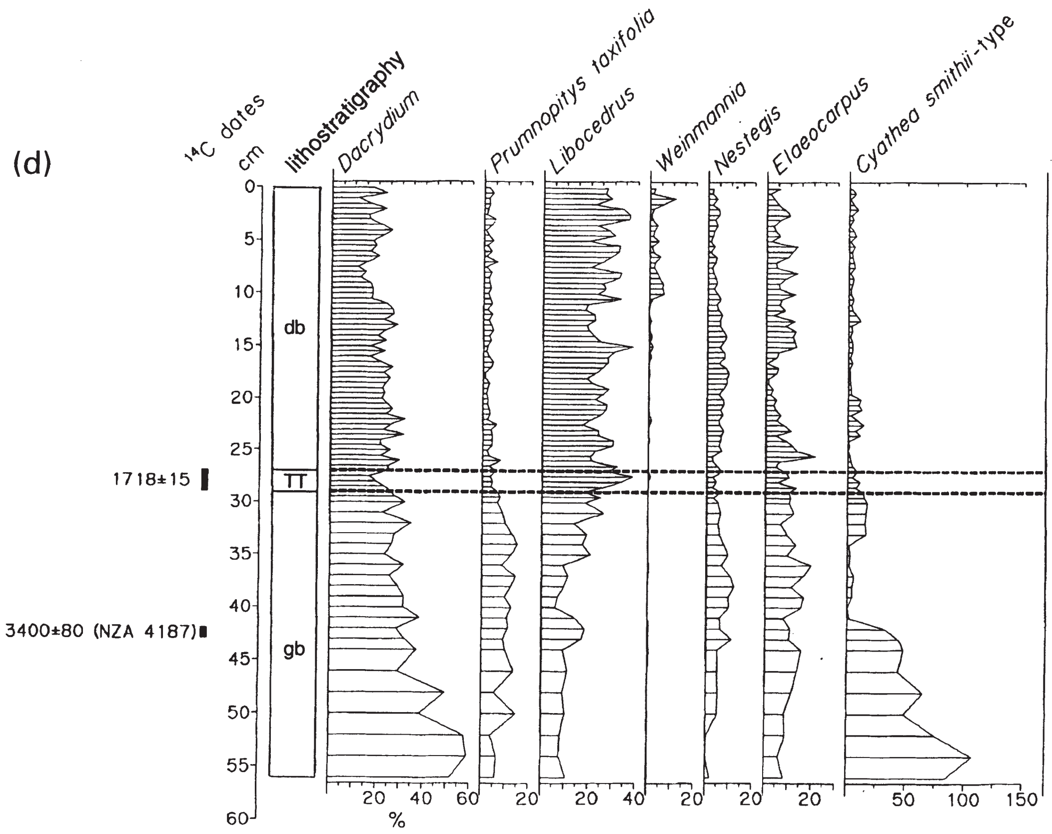

FIG. 2. Summarized pollen diagrams from Hauhungatahi (a) Site 1020, (b) Site 1140, (c) Site 1170 and (d) Gibson's Swamp (810 m). Fig. 2(b) includes scaled pollen curves (dotted lines, 2 cm sampling intervals) from a site nearby at the same altitude (Horrocks, 1994). Ericales and charcoal included only on diagrams where levels indicate dominance on site and fires on site, respectively. bb, brown black sandy silt; c, charcoal layer; db, dark brown sandy silt; fp, friable peat; gb, grey brown sandy silt; gs, grey sandy tephra; lb, light brown sandy silt; TT, Taupo Tephra; w, wood; ws, white sandy tephra.

The Taupo Tephra, forming the upper boundary of this zone, is ≈2 cm thick. The pumice granules are very diffusely scattered through the sandy silt sediments, suggesting that secondary reworking of the tephra has occurred.

Post-Taupo, 28.5–0 cm, c. 1718 BP–present

Libocedrus pollen peaks sharply immediately above the Taupo Pumice (up to 38% of the pollen sum), and maintains generally high levels (> 17%) throughout the period. This reflects the dominance of this species in the post-Taupo forest.

Weinmannia values increase at 12.5 cm, coinciding with a *Dacrydium* decrease. *Weinmannia* probably partially replaced *Nestegis* at this time. The depth of this change (i.e. almost half way to the Taupo Tephra) suggests that these changes occurred 600–1000 years ago. The presence of occasional pollen of the exotic taxa *Pinus* and *Taraxacum* in samples to the same depth (Horrocks, 1994), however, indicates that this development occurred only ≈150 years ago at the most. This 'stretching out' of the upper profile is most likely the result of surface mixing of sediments.

DISCUSSION

Immediate post-tephra impacts

The most apparent post-Taupo vegetation change is an increase in *Libocedrus.* At sites that were forested at the time of the eruption (1020, 1140 and Gibson's Swamp) the increase has been sustained whereas at Site1170 (open) the increase was relatively short-lived. This expansion occurred independently of codominants *Dacrydium cupressinum* and *Phyllocladus aspleniifolius* var. *alpinus* on Hauhungatahi and *D. cupressinum* and *Prumnopitys taxifolia* at Gibson's Swamp.

The pollen evidence indicates that damage from blast or tephra fall-out was not sufficient to destroy extensive areas of forest on Mt Hauhungatahi, which is ≈70 km from the eruption centre. The thickness of the Taupo Tephra at Hauhungatahi sites (≤9 cm) indicates the source as air-fall, the overland pumice flow being channelled around the sides rather than over the top of the mountain (Atkinson, 1981). Sudden increases of pollen types indicative of extensive, open areas (e.g. herbs) did not occur on the mountain

(Horrocks, 1994). Rather, many small canopy gaps were probably created, initially mainly by blow-down of emergents, and subsequently by death of damaged but standing trees. Fine tephra particles may coat leaves, adversely affecting physiological processes, while coarser pieces falling through foliage can strip leaves and branches (McGlone, 1980). In addition, low-growing vegetation may be buried. Pumice pieces up to 7.9 cm diameter have been found on Hauhungatahi and up to 0.8 cm diameter at Gibson's Swamp ($\approx$85 km from the eruption centre), so damage to vegetation may have been considerable, particularly when blast effects are also considered.

Several interrelated effects may have favoured *Libocedrus* in the post-Taupo period: (1) more light gaps, (2) more slips, (3) more fallen logs, (4) better drained surface soil and (5) reduced competition. *Libocedrus* regenerates well in sites exposed to a high light intensity, even direct sunlight (Clayton-Green, 1977), and would consequently do well if the canopy became more open. The eruption may have also modified disturbance regimes on steeper slopes for some time after the eruption. Heavy rainfalls, perhaps induced by the eruption (Grant, 1989) could have caused more frequent and larger land-slips providing further sites suitable for *Libocedrus* regeneration (Veblen & Stewart, 1982; Boase, 1988).

The post-Taupo increase of *Libocedrus* pollen at Sites 1020 and above indicates an upwards expansion. Remarkably high *Libocedrus* pollen values at Site 1170, which was probably subalpine scrub at the time of the eruption, suggest that areas outside forest may have been rapidly (albeit temporarily) colonized by *Libocedrus.* Veblen & Stewart (1982) also found evidence of 'massive' *Libocedrus* regeneration after debris deposition in the South Island. Clayton-Green (1977) noticed many *Libocedrus bidwillii* saplings 1.0–1.5 m high and probably < 50 years old setting large quantities of seed, and suggested that such early reproductive maturity in a long-lived tree indicates an adaptation to rapid colonization of new habitats. The subsequent failure of *Libocedrus* regeneration following this expansion may be related to the high water table—within a short time the Taupo Pumice layer would have lost its free draining qualities as it became buried under plant litter.

In addition to the post-Taupo increase, Gibson's Swamp and Site 1170 show an apparent rise in *Libocedrus* pollen *prior to* the Taupo eruption, suggesting that this species may have been expanding in some areas before the eruption. A body of mainly palynological evidence indicates that a long-term Holocene trend towards a more seasonal climate in New Zealand intensified during the millennium prior to the eruption, i.e. *c.* 3000–2000 BP (e.g. McGlone & Moar, 1977; McGlone & Bathgate, 1983; Dodson *et al.*, 1988; Newnham *et al.*, 1989; Rogers & McGlone, 1989; Ogden *et al.*, 1992). Conditions may have become cooler and were almost certainly drier with more disturbance by fire (McGlone, 1980). By providing abundant establishment sites, the eruption may have facilitated an expansion of *Libocedrus* already under way as a result of climatic change to cooler and drier conditions *c.* 3000–2000 BP. Since disturbance can facilitate major vegetation change, disturbances at times after critical climatic thresholds have been reached may have dramatic consequences (Bradshaw & Hannon, 1992).

Other central North Island pollen studies which include the Taupo eruption (i.e. McGlone & Topping, 1977; Rogers & McGlone, 1989; Steel, 1989) support the contention that where *Libocedrus* occurred in any quantity prior to the eruption, as at Hauhungatahi and Gibson's Swamp, it responded favourably to that disturbance. Negligible post-Taupo increase in *Libocedrus* in some areas was due to local pre-Taupo population levels being insufficient to capitalize on the newly created open sites. For example, at Wairehou, 30 km north-east of Hauhungatahi, McGlone & Topping (1977) showed that pre-Taupo *Libocedrus* pollen levels were low (max. $\approx$10%) and did not increase after the eruption. (However, the pollen record at this site showed a massive *Leptospermum* expansion (85%) which may have masked other vegetation changes.) Steel's (1989) pollen profiles from west Ruapehu sites (< 10 km from Hauhungatahi) likewise showed low pre-Taupo *Libocedrus* percentages that did not increase after the eruption. Clarkson *et al.* (1992) identified one *Libocedrus* log in a pre-Taupo forest 75 km north of Hauhungatahi, where this species is no longer present and suggested that the eruption actually caused its local extinction. In contrast, a pollen profile from Reporoa Bog, 70 km to the south-east of Hauhungatahi in north-west Ruahine Range, with pre-Taupo *Libocedrus* levels comparable to those recorded in Hauhungatahi profiles showed a marked expansion of this species from the spectrum immediately below the Taupo Tephra (Rogers & McGlone, 1989).

Long-term impacts and forest dynamics

How has *Libocedrus* maintained its higher post-Taupo abundance at some sites in the absence of subsequent disturbance of similar magnitude? Changes favouring *Libocedrus* regeneration would be more frequent storms and also perhaps cooler conditions (McGlone, 1989). On Mt Egmont, McGlone *et al.* (1988) suggested that during periods of stormier and cooler conditions during the last 3500 years *Libocedrus bidwillii* dominated upper montane forest at the expense of *Weinmannia racemosa. Libocedrus* was apparently better able than competitors to take advantage of fresh slip faces because of its tolerance of cooler conditions.

Endogenous factors would also have contributed to the persistence of *Libocedrus* as a canopy dominant long after the Taupo eruption. In the absence of major disturbance *Libocedrus* stands may persist for > 700 years (Veblen & Stewart, 1982). If individual trees commonly have a life span $\approx$600–800 years, senescence of the first post-Taupo generation would have commenced *c.* 1100 BP and continued for $\approx$200 years. This period of disintegration falls within one of Grant's (1983, 1989) postulated New Zealand-wide erosion periods, the pre-Kaharoa (1300–900 BP), in which storm-induced erosion and sedimentation was apparently of an intensity sufficient to destroy > 52% of the forest cover on the Ruahine Ranges ($\approx$90 km south-east of Hauhungatahi). If overstorey collapse of large areas of senescent forest occurred on Hauhungatahi during such a period of intense storminess, extensive wind-throw would have enabled *Libocedrus* to replace itself over a wide area. Elsewhere in New Zealand (Herbert, 1986; Norton *et al.*, 1988; Lusk & Ogden, 1992), sites have been described where abundant conifer regeneration was induced by the rapid disintegration of previous stands. At Horopito, Lusk & Ogden (1992) found that this occurred over a period of ≈120 years.

An average age span of 600–800 years, with recruitment occurring only in relatively open forest, suggests only three main cohorts of *Libocedrus* since the Taupo eruption. Even taking into account the progressive depletion of subsequent cohorts (Ogden, 1985), *Libocedrus* is thus able to retain possession of sites for considerable periods following its expansion after major disturbance.

Weinmannia is currently the most important species in the montane forest on Hauhungatahi, especially in gullies (Druitt *et al.*, 1990). However, it was apparently rare at these altitudes until just before the Taupo eruption, and increased dramatically only some time after this. The stratigraphic position of significant *Weinmannia* pollen on Hauhungatahi (≈ half way between the Taupo Tephra and the surface) suggests that major expansion started *c.* 900–850 BP. However, a more recent date is more likely. Evidence for this is found at two sites where significant *Weinmannia* pollen increases (indicating the expansion of this taxon in surrounding forest) coincide with charcoal layers, dated at 466–316 cal. BP (NZA 3423) (Site 1170) and 650–556 cal. BP (NZA 3433) (a site at the base of Hauhungatahi (Horrocks, 1994)).

At Gibson's Swamp, significant *Weinmannia* pollen is found only in samples also containing *Pinus* pollen, indicating an even more recent *Weinmannia* expansion there of 150 years ago at the most, although some mixing of sediments may have confounded the interpretation of the upper layers at this site. According to Atkinson (1981), *Weinmannia* forest in this area regenerated after milling of the previous conifer-dominated forest last century.

The increased abundance of *Weinmannia* on Hauhungatahi may be due to the expansion of small local populations and/or an invasion from successional forests surrounding the mountain. A pollen profile from the base of Hauhungatahi (Horrocks, 1994) indicates fire *c.* 600 BP. This date coincides with the period suggested by McGlone (1983a, 1989), between 800 and 600 BP, for Polynesian land clearance by fire on a New Zealand-wide basis. Although radiocarbon dates associated with post-Taupo tephras from Hauhungatahi (Horrocks, 1994) and west Ruapehu (Steel, 1989) suggest that some fires at this time may have been the result of volcanic eruptions, areas outside the region and not directly affected by volcanism (McGlone, 1983a; Newnham *et al.*, 1989) also show evidence of frequent fires. The widespread synchrony of this destruction suggests that the New Zealand vegetation at this time was undergoing change which may have predisposed it to fires lit by people (M. McGlone, personal communication).

Weinmannia appears to have expanded upwards into subalpine vegetation on parts of Hauhungatahi. Significant pollen values for *Weinmannia* at Site 1140, and especially at a nearby site at the same altitude (included in Fig. 2b), indicate an on-site presence. This suggests an upward movement of the tree-line. Values suddenly decline near the surface at both sites suggesting recent disappearance of this species at this altitude. The species can form dense pole stands by seed dispersal into an area after fire has destroyed other vegetation, and may also coppice after fire damage (Wardle, 1966). Payton & Allen (1984) found that 60–80 years after fire had destroyed podocarp-*Beilschmiedia* forest, *Weinmannia racemosa* was either the dominant canopy species or codominant with *Leptospermum.*

On Mt Hauhungatahi montane forests were not subjected to burning, but the dynamics of the conifer canopy at a time when *Weinmannia* populations were increasing may explain the local *Weinmannia* expansion *c.* 650 BP. We postulate that the demise of the second cohort of *Libocedrus* since the eruption would create a scatter of gaps commencing *c.* 650 BP in which the faster growing *Weinmannia* seedlings would succeed better than the highly light-demanding and slow growing *Libocedrus* seedlings. *Libocedrus* appears to benefit from gap formation only when drainage is so poor that other species are excluded (Veblen & Stewart, 1982). Also, Ogden *et al.* (1991) found that canopy *Weinmannia* trees uprooted by the fall of other trees on Hauhungatahi frequently resprouted but conifers rarely did. Consequently, in a situation where disturbance is small-scale and frequent, and provided a seed source is available, *Weinmannia* might be expected to increase at the expense of *Libocedrus.*

More frequent, but relatively mild, volcanic activity in the Tongariro region commencing *c.* 650 BP may have contributed to the *Weinmannia* expansion by favouring this species over *Libocedrus.* On Mt Egmont, McGlone *et al.* (1988) found that *Libocedrus* decreased and *Weinmannia* increased slightly after volcanic disturbance, and suggested that this was due to its ability to root adventitiously and coppice from damaged trunks. *Weinmannia* did not increase extensively on Hauhungatahi immediately after the Taupo eruption, suggesting that it was not present in sufficient abundance to compete with *Libocedrus* at the time. In forests buried by the Taupo Tephra in the Benneydale-Pureora area, Clarkson *et al.* (1992) found no *Weinmannia* remains, suggesting that before the eruption *Weinmannia* was less common in the region generally.

The existing forest dominants of Hauhungatahi (*Libocedrus* in subalpine forest and *Weinmannia* in montane forest) did not hold these positions prior to the eruption. The expansion of these species supports an individualistic view of plant communities and nonequilibrium theories of community composition. The expansion also illustrates the extent to which a catastrophic disturbance can influence the structure and composition of forest in an area for an extended period (in this case almost 2000 years), when long-lived species such as *Libocedrus* are involved.

While this study emphasizes the effects of a particular volcanic eruption, it also highlights the importance of the long-term role of volcanism in vegetation development across the central North Island region (and in other regions where this type of disturbance is prevalent). The 1718 BP Taupo eruption was the most recent in a long line of late Quaternary eruptions from Taupo Volcanic Centre (Wilson, 1993). Some of the earlier Taupo eruptions were on a much larger scale (e.g. that responsible for the 22,600 BP Kawakawa Tephra); while during the Holocene alone there are at least five other tephras from Taupo that would be expected to have had some impact at Hauhungatahi. Then there are the other late Quaternary volcanic centres that could have affected the area, including Okataina, Tongariro (Froggatt & Lowe, 1990) and Egmont (Lowe, 1988). The three Tongariro volcanoes, Mts Tongariro, Ngauruhoe and Ruapehu, for example, although andesitic and therefore less violent than the rhyolitic Taupo volcano, have nonetheless been more active during the Holocene and are < 20 km from Hauhungatahi (Fig. 1). Two pre-Taupo and one post-Taupo tephra horizons were found at Site 1170. The pre-Taupo layers both coincided with decreases of *Phyllocladus* pollen and one with a decrease of *Libocedrus* pollen. A possibly coeval decrease of *Phyllocladus* pollen at Site 1140 indicates that vegetation change due to volcanism had occurred at Hauhungatahi during the Holocene prior to the Taupo eruption (see also Ogden *et al*., 1997).

On a longer time scale (i.e. full Quaternary) there are other volcanic centres with larger eruptions that must have had still greater impact on the vegetation of this region. If the Taupo 1718 BP eruption was a major determinant of present forest composition and structure, then the same must be true for at least some of these earlier eruptions.

CONCLUSIONS

The Taupo eruption of *c.* 1718 BP was a major determinant of forest composition at Hauhungatahi. This catastrophic event changed regeneration conditions for *Libocedrus,* allowing its expansion into new areas.

Immediately after the eruption, *Libocedrus bidwillii* expanded rapidly into montane and subalpine forest and has remained a dominant tree in the latter. Regeneration in nonforest subalpine areas also occurred but was short-lived. *Lidocedrus* also increased at Gibson's Swamp, suggesting a regional response of this species where it was present in sufficient numbers to colonize the new sites.

Regional forest successions during the post-Taupo period may have resulted in an increase in *Weinmannia* seed rain on Hauhungatahi. Loss of synchroneity in regenerating cohorts of *Libocedrus* probably predisposed the montane forest to an invasion by *Weinmannia* *c.* 650 BP as a consequence of changing gap size and forest structure. This species is now an important component of the montane forest zone.

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