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Testing the synchroneity of pollen signals using tephrostratigraphy

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Abstract

Since the advent of radiocarbon dating, the concept of synchronous pollen-vegetation events extending across broad regions such as the British Isles, which had emerged from earlier pollen-stratigraphic studies, has been largely refuted. Nevertheless the assumption that pollen profiles within a geographically coherent area should exhibit broadly comparable and synchronous pollen signals still holds currency among some palynologists. This assumption is tested here by comparing pollen spectra between lateglacial and postglacial sites in northern New Zealand, until recently unaffected by human activity, where independent correlations are obtained by tephrochronology. At sites of similar size, morphology, and depositional environment within the same phytogeomorphic region, it is possible to achieve accurate palynological correlations, provided local taxa and those representing ecologically disparate source species are omitted from the pollen datasets. However, anomalous correlations may still occur and are more likely when sites with different depositional environments or at greater distances are compared. These results suggest that the concept of synchronous pollen signals, even between nearby sites with similar depositional setting, is not universally applicable and it is possible that erroneous palynostratigraphic correlations have been made in the past. © 1999 Elsevier Science B.V. All rights reserved.

Keywords: pollen signals; tephrostratigraphy; vegetation history; New Zealand; Holocene; biostratigraphy

1. Introduction

The potential of pollen analysis for dating and correlating Quaternary organic sedimentary sequences was recognised at its very genesis as a scientific discipline (von Post, 1916). Sequences of successive pollen spectra following the end of the last glacial indicating a broad picture of postglacial vegetation change were interpreted as responses to changing climates (Moore et al., 1991). With the assumptions that such climate changes and the resulting vegetation developments were of broad geographical extent and more or less synchronous over wide areas, 'pollen zones' were established for some regions (e.g., England, Godwin, 1940; New Zealand, Cranwell and von Post, 1936). Prior to the advent of radiocarbon dating in the early 1950s, these regional pollen zones provided a useful relative chronological framework for further detailed stratigraphic and palaeoecologic investigations.

More recently, the notion of regionally synchronous, climate-forced, vegetation changes during the postglacial period has been questioned. Radiocarbon dating of key pollen profiles in western Europe has revealed that regional pollen zone boundaries

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may be diachronous (Smith and Pilcher, 1973; Birks, 1982; Juvigné et al., 1996). Similar changes to vegetation may have occurred at different times within a region, depending upon a variety of factors such as migration routes and speeds of various tree and shrub genera, as well as local conditions such as latitude, altitude, and exposure (e.g., Godwin et al., 1957; Moore, 1972; Smith and Pilcher, 1973; Birks, 1989). Nevertheless, the assumption that more or less synchronous temporal pollen-vegetation changes occurred across geographical areas which today display comparatively uniform topography, soils, vegetation, and climate, although the subject of debate, continues to underpin some pollen-stratigraphic studies to this day. Examples of regions where lateglacial and Holocene regional pollen assemblage zones have shown broadly coeval pollen signals between sites include central East Anglia, England (Bennett, 1988), Inner Hebrides islands, Scotland (Walker and Lowe, 1982, 1990) and Massif Central, France (Beaulieu et al., 1987; Juvigné et al., 1988). Key 'regional pollen events' include the *Ulmus* decline in northwest European at ca. 5 ka BP (Peglar and Birks, 1993) and the *Tsuga* decline at ca. 4.8 ka BP in North America (Allison et al., 1986). Regional palynological investigations of the lateglacial climatic oscillations in western Europe (e.g., Lowe and Walker, 1997, pp. 346–347) and the lateglacial and Holocene spatial patterns in pollen and vegetation categorised by isopollen and paleovegetation maps (e.g., Huntley and Birks, 1983; Birks, 1989; Huntley, 1990) show that it is possible to reconstruct vegetation patterns from pollen data that are broadly uniform in areal extent. In pre-Holocene investigations and especially those extending beyond the range of radiocarbon dating, pollen-stratigraphy assumes still greater importance as a tool for correlation between organic sequences.

Testing the concept of synchroneity in broad vegetation developments and pollen signals during the Holocene, however, is complicated by several sources of uncertainty.

(a) The role of humans in modifying vegetation patterns (e.g., Simmons and Innes, 1987).

(b) Inter-site differences, notably size and nature of the depositional basin, strongly influence pollen taphonomic processes and therefore distort regional pollen signals in ways that, although generally understood, are not easily quantified (Jacobson and Bradshaw, 1981; Prentice, 1985).

(c) Difficulties in defining a geographic region which would be expected to display comparatively uniform vegetation patterns and climate both today and in the past (cf. Bennett, 1988).

(d) Potential sources of error and uncertainty in radiocarbon (or other methods of) dating (cf. Lowe, 1991) which make it difficult to determine accurately the precise timing of a vegetation or pollen 'event'; generally such uncertainties increase with increasing age of the event.

The difficulties in accurately determining coeval pollen spectra, or sediment horizons, at different sites are especially problematic. The conventional method, radiocarbon dating, at best can only indicate the probability that the true radiocarbon age of the pollen sample lies within a time interval that depends upon the age and quality of the sample and the precision of assay. Even the more precise age estimates for peat and lake sediments, with statistical error margins of ca. 50 ^{14}C yr, will span a range of 200 ^{14}C yr at the 95% probability level. The resolution is not improved, and indeed may coarsen, when conventional radiocarbon dates are calibrated to calendar ages via dendrochronological records. Other well known potential sources of error such as contamination of organic sediment by younger or older carbon (Lowe, 1991) serve to illustrate the difficulties in confidently ascribing the same age to two pollen spectra at different sites. As a single pollen diagram can show markedly different spectra over a period of several hundred years, equivalent to the margins of error of the better dates on organic sediment, radiocarbon dating is not the most satisfactory method for testing the synchroneity of pollen signals between sites.

A more stringent test of this concept is possible using tephrostratigraphy. Deposition of tephra layers, following major eruptions, provide extensive, virtually instantaneous time-equivalent marker horizons. Where tephrostratigraphies are well established by direct fingerprinting methods (e.g., ferromagnesian mineralogy, Fe–Ti oxide or glass composition, radiometric age) the tephras provide a precise and regionally extensive chronological and stratigraphic framework for palaeoecological investigations (e.g., Westgate et al., 1992; Newnham et al., 1998).

This investigation aims to examine the concept of between-site synchroneity of pollen-stratigraphic signals by minimising the effects of the above listed complicating factors through appropriate choices of study area and methodology. In particular, a rich and extensive suite of independently and well-characterised tephra layers in northern New Zealand permits evaluation of palynostratigraphic correlations. A secondary focus of the paper is to consider ways in which pollen dataset construction and site selection can influence the strength of palynostratigraphic correlations. The results will have implications for regions where the reverse situation applies, viz. tephrostratigraphies are poorly established and palynology is expected to assist in the independent corroboration of tephra identifications and correlations. This critical examination of the degree of synchroneity in postglacial pollen signals will also shed light on important vegetation developments in northern New Zealand and the establishment of current phytogeographic patterns in the region.

2. Study area and research rationale

The area investigated is the Waikato region, northern New Zealand (Fig. 1). The remote yet substantial islands of New Zealand in the southwestern Pacific Ocean offer virtually unparalleled opportunities to examine postglacial environmental changes without the veiling effects of human influence. According to the conventional view of New Zealand's prehistory, these islands have been settled for only ca. 1000 years (Davidson, 1984), although others have recently argued that the time of arrival could be several hundred years later (Anderson, 1991) or, alternatively, up to 1000 years earlier (Sutton, 1987). Regardless of which view is taken, human interference with natural vegatation cannot be detected unambiguously before 700–800 yr BP (McGlone, 1983, McGlone et al., 1994; Newnham et al., 1998). The first source of uncertainty cited above (a), therefore, is eliminated for almost the entire postglacial period.

The range of sites considered here permits an examination of the effects of site type and size on pollen taphonomic processes, the second source of uncertainty cited above (b). Pollen profiles from four

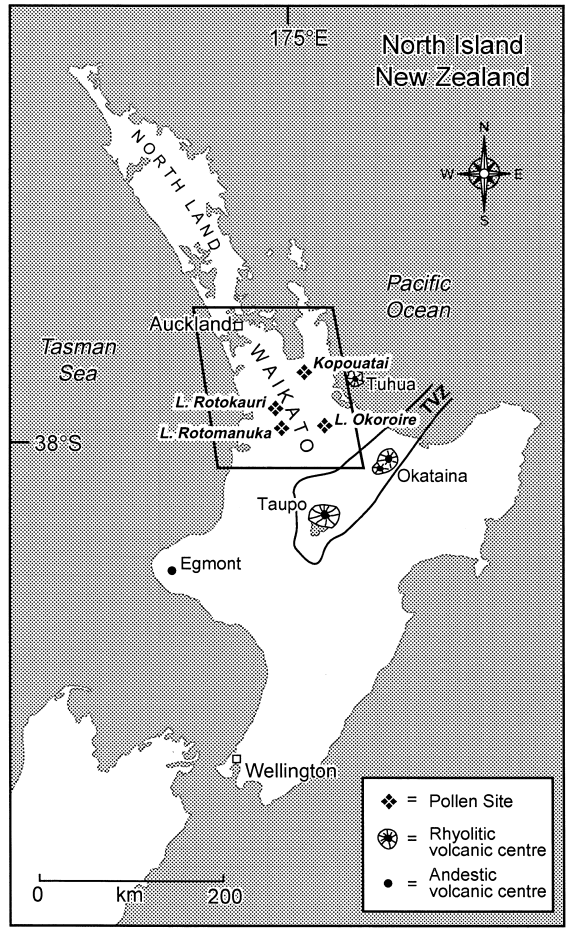


Fig. 1. Locations of the four pollen sites and the tephra-producing volcanic centres relevant to this study (after Froggatt and Lowe, 1990). The boxed area indicates the study area (Fig. 2).

sites were compared (Fig. 2; Table 1): three small, shallow, lake sites from the central Waikato lowlands—Rotomanuka, Rotokauri, and Okoroire—and Kopouatai, a large, raised peat bog from northeastern Waikato. The sites are all low altitude (< 100 m a.s.l) depositional basins formed in late Pleistocene sediments (Fig. 2). The detailed pollen profiles from these sites, together with descriptions of the regional geology, physiography, climate and modern indigenous vegetation have been published elsewhere (Newnham et al., 1989, 1995).

The geographic spread of these sites permits comparisons across a coherent phytogeographic region, which should provide insights into the third source

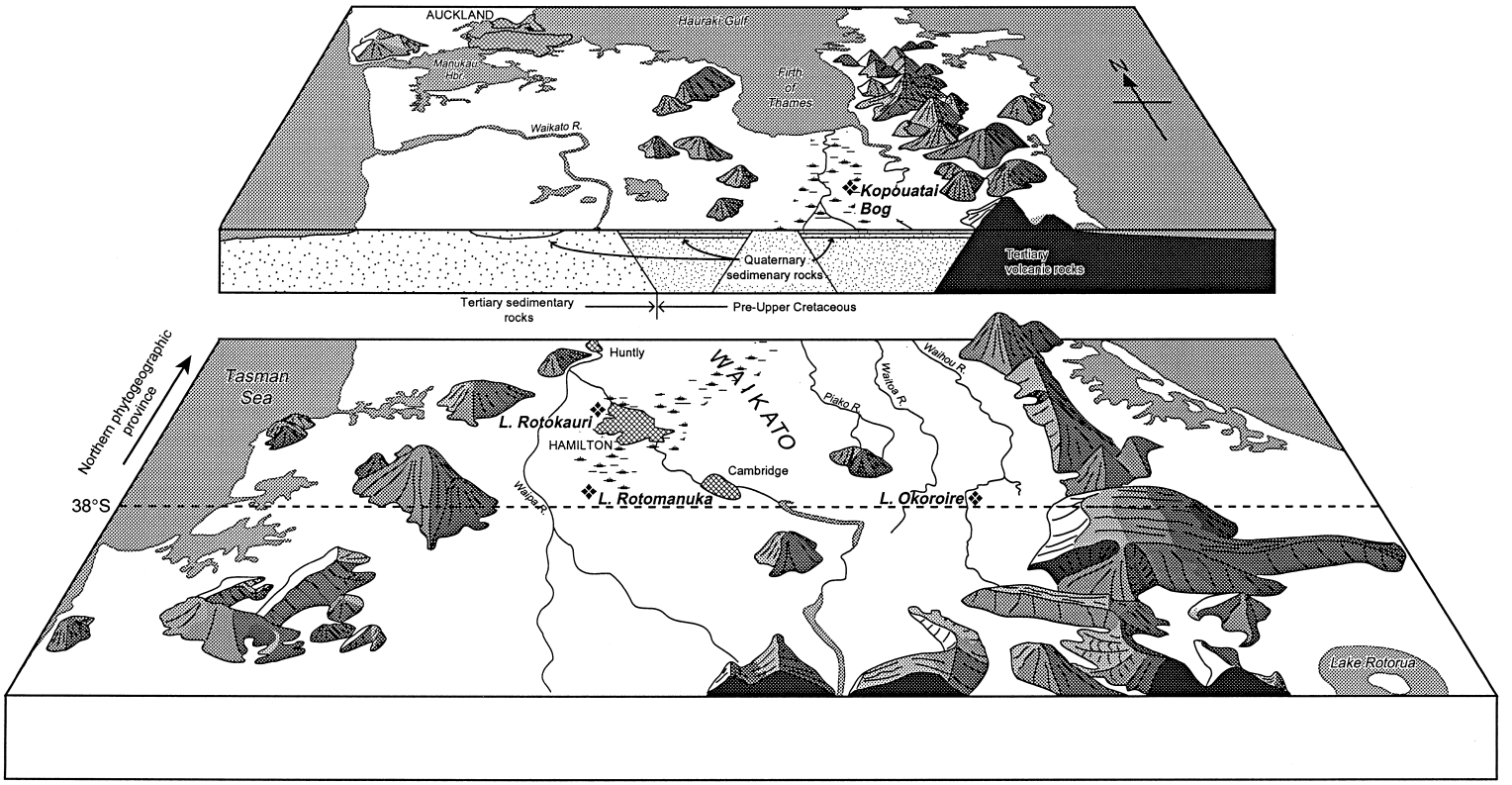


Fig. 2. Physiography and geology of Waikato region and location of the pollen sites in this study. Geology cross-section based on Selby and Lowe (1992).

Table 1
Details of the pollen-tephra sites used in this study

Site	Type	Area (ha)[a]	Depth water (m)	Altitude (m a.s.l.)	Sediment depth (cm)	Latitude (°S)	Distance from Rotomanuka (km)	Age range (ka)	Number of tephras
Rotomanuka	lake	14	8	33	350	37.50	–	18–0	10
Rotokauri	lake	74	4	50	400	37.30	18	13.1–0	9
Okoroire	lake	4	2–3	90	270	37.55	40	16–1	9
Kopouatai	bog	9000	n/a	0–5	1100	37.15	80	11–0	3

[a]Lakes Rotomanuka and Okoroire have recently been reduced in size by drainage (Newnham et al., 1989).

of uncertainty cited above (c). Although all these sites occur within the same phytogeographic province,the Waikato lakes (Rotomanuka, Rotokauri, Okoroire) form a strongly coherent group. These lakes occur within 50 km of one another, at approximately the same latitude and altitude, close to an important biogeographic boundary at around latitude 38°S (Cockayne, 1928; Figs. 1 and 2) The lateglacial and postglacial pollen and sedimentary records at these sites show strong similarities, and the major vegetation developments have previously been interpreted, from visually comparing pollen diagrams, as regionally consistent and broadly synchronous (Fig. 3; Newnham et al., 1989). The pollen profile at Kopouatai Bog revealed significant differences with the Waikato lakes, in particular stronger representation of *Nothofagus* forest taxa situated beyond lowland Waikato today, yet the same patterns and sequences of the major regional postglacial vegetation developments were discernible (Newnham et al., 1995). This part of northern New Zealand lies well beyond the limits of last glacial ice (Pillans, 1991).

The most important common attribute of the four sites is the presence of multiple discrete and equivalent tephra layers from distal volcanic centres in the central North Island (Figs. 1, 3 and 4). The tephra layers have been studied intensively using standard fingerprinting and dating methods together with discriminant function analysis so that the ages and diagnostic identification criteria for the main units are now well established (Hogg et al., 1987; Lowe, 1988; Stokes and Lowe, 1988; Froggatt and Lowe, 1990; Stokes et al., 1992). Not all tephra layers at one site are found at the others (Fig. 4; Table 2) because of their varying distance and direction from source volcanoes and differences in suitability of the sites for deposition and preservation of tephra (e.g., Hodder et al., 1991). A total of nine macroscopic tephra layers are common to the Waikato lakes; three of these also occur at Kopouatai Bog (Table 2). Where the same primary tephra layer occurs at two (or more) sites, it acts as an instantaneous isochronous marker horizon which permits the inter-site comparison of detailed pollen stratigraphy around that time horizon. The final source of uncertainty cited above (d) is therefore reduced.

3. Methodology

3.1. Correlation procedure

Lake Rotomanuka was designated as the 'master' site for this investigation as it has the longest and most detailed pollen and tephrostratigraphical records of the five sites. Of the 27 macroscopic tephra layers recorded at Rotomanuka (Newnham et al., 1989), 10 were selected for this study to provide an even temporal spread of time horizons (Table 2).

For each tephra layer at Lake Rotomanuka, correlation coefficients were calculated between the pollen spectrum immediately underlying the tephra and every other pollen spectrum at each of the other three sites. This is referred to as the pollen-tephra test. Pre-tephra (rather than post-tephra) pollen spectra were correlated to avoid the possibility of localised impacts resulting from tephra deposition (cf. Giles et al., in press)—the only exception was with the lowermost tephra layer at Lake Rotokauri, the Rotorua Tephra, where the pollen spectrum immediately overlying the tephra was correlated because the pollen profile did not extend beneath this tephra layer (Newnham et al., 1989). Spearman rank correlations were performed on the pollen data converted to ranked (ordinal) values because this correlation pro-

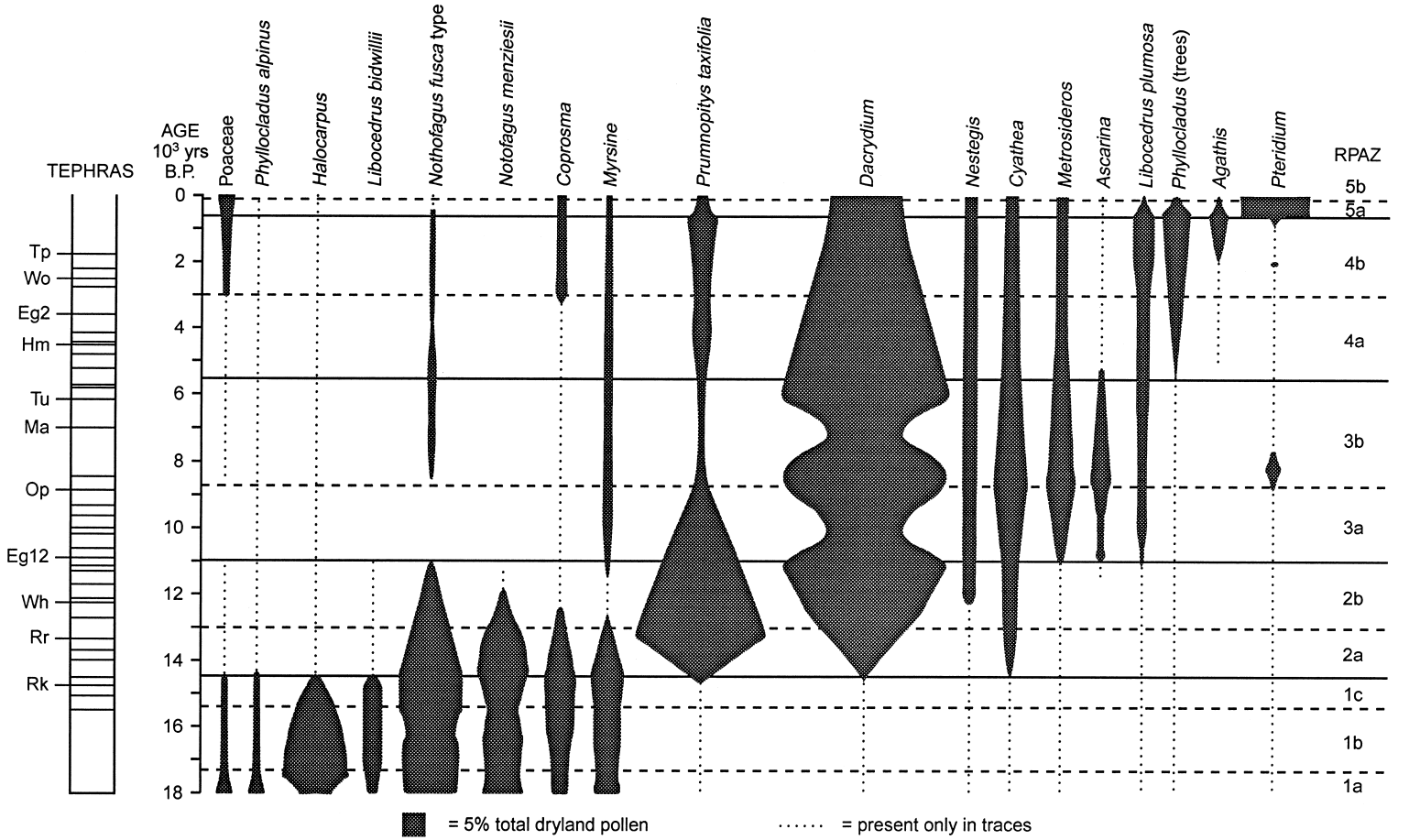


Fig. 3. Schematic regional pollen diagram and tephrostratigraphy for lowland Waikato sites based on palynology of Lakes Rotomanuka, Rotokauri, and Okoroire (after Newnham et al., 1989). RPAZ = regional pollen assemblage zone. Full names and ages for the abbreviated tephra names are given in Table 2.

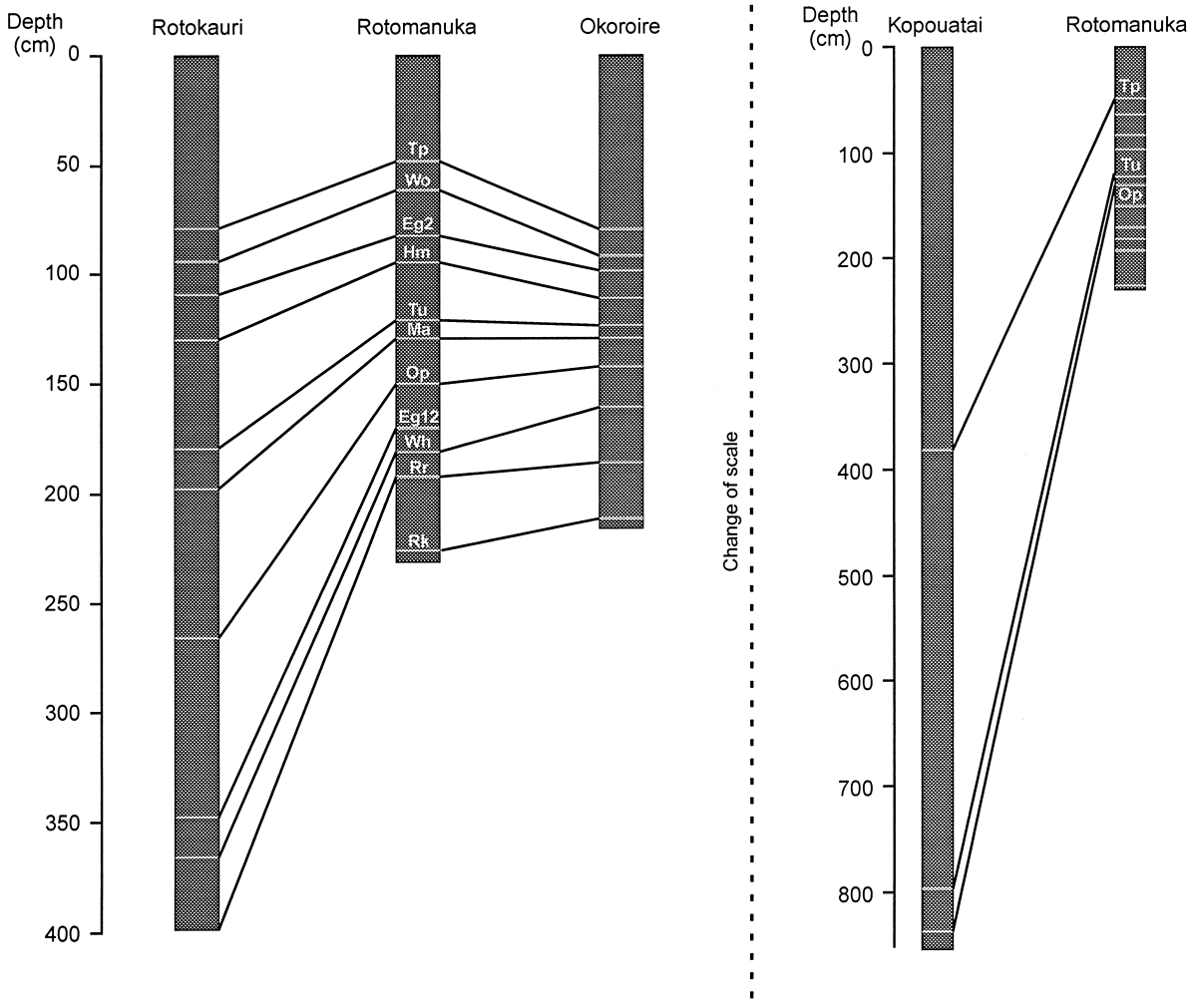


Fig. 4. Stratigraphy of tephra deposits at the four sites investigated here. Lake Rotomanuka site is shown twice for clarity of correlation. Tephra names and ages are given in Table 2.

cedure does not depend upon assumptions about the frequency distributions of the pollen spectra.

Several terms are introduced below to simplify descriptions of the correlation procedures used (Fig. 5).

3.1.1. Pre-tephra pollen spectrum

The pollen spectrum immediately below a tephra layer. Although pollen samples in most cases (70%) were taken from immediately below (< 1 cm) the tephra layer, for some samples this gap was wider (2–5 cm; Table 3). The exact time gap between deposition of the tephra layer and the pollen spectrum is also dependent upon the rate of sediment accumulation, which at these sites can be estimated from the tephrochronology (Newnham et al., 1989; 1995). Estimated time gaps for each of the pre-tephra pollen spectra are listed in Table 3. The size of some of these time gaps, due primarily to very slow sedimentation rates in some sections of the Waikato lakes profiles must be taken into account when drawing conclusions from these results. However, in the majority of cases, where pollen sampling was taken as close as practicable to the tephra layer, the real age of the pollen spectrum is likely to be much closer to that of the tephra layer.

Table 2
Details of tephra layers used in this study. Arrows indicate the macroscopic tephra layers at each pollen site used to correlate between pollen spectra (see text for details)

Tephra	Symbol	Age (BP)[a]	Eruptive centre	Rotomanuka (Ro)	Rotokauri (Rk)	Okoroire (Ok)	Kopouatai (Kp)
Taupo (Unit Y)[b]	Tp	1850 ± 10	Taupo	→		→	→
Whakaipo (V)[b]	Wo	2685 ± 20	Taupo	→	→	→	
Egmont-2[c]	Eg2	3670 ± 45	Egmont	→	→	→	
Hinemaiaia (K)[b]	Hm	4510 ± 20	Taupo	→	→	→	
Tuhua	Tu	6130 ± 30	Tuhua	→	→	→	→
Mamaku	Ma	7250 ± 20	Okataina	→	→	→	→
Opepe (E)[b]	Op	9050 ± 40	Taupo	→	→	→	
Egmont-12[c]	Eg12	11,050 ± 130	Egmont	→	→		
Waiohau	Wh	11,850 ± 60	Okataina	→	→		
Rotorua	Rr	13,080 ± 50	Okataina	→	→	→	
Rerewhakaaitu	Rk	14,700 ± 110	Okataina	→		→	

[a]Ages for tephra from Taupo, Okataina, and Tuhua volcanic centres are error-weighted mean and pooled error based on multiple radiocarbon dates using old half-life (from Froggatt and Lowe, 1990). Ages for Egmont tephra are estimated from several radiocarbon dates using old half-life (from Lowe, 1988).
[b]Probable equivalent units based on Wilson (1993) nomenclature.
[c]Proximal correlatives, based on Alloway et al. (1995) nomenclature, are: Eg-2, Inglewood Tephra; Eg-12, Mahoe Tephra.

3.1.2. Correlation matrix

A table of correlation coefficients between each Rotomanuka pre-tephra pollen spectrum and all other pollen spectra at each of the other sites.

3.1.3. Expected best match

For a pre-tephra pollen spectrum at the 'master' site (Lake Rotomanuka), the strongest correlation with all samples at another site is expected to be

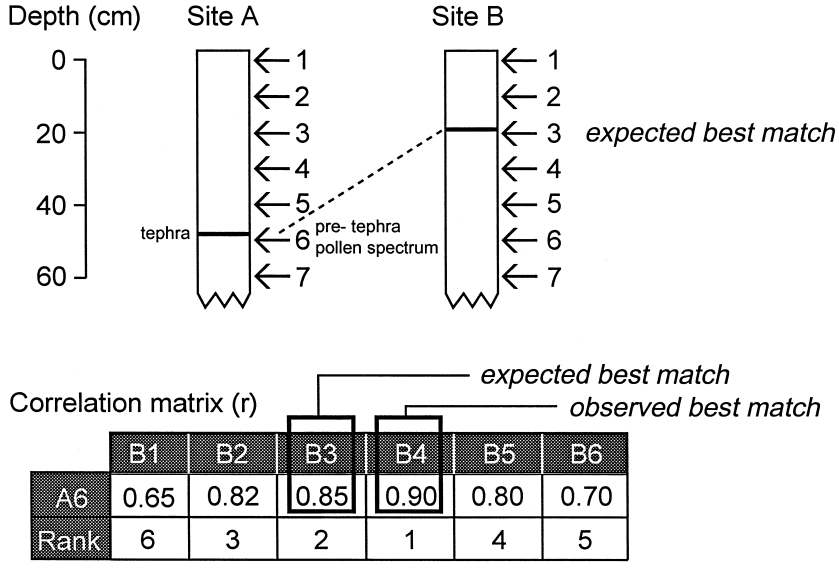


Fig. 5. Illustration of correlation procedure. In this example, the expected best match at Site B for spectrum 6 from Site A (A6) is B3. From the correlation matrix, between A6 and all spectra at B, the observed best match is with B4. B3 is ranked 2nd in the correlation matrix.

Table 3
Estimated sedimentation rate, vertical sampling distance and estimated time gap between tephra layer and pre-tephra pollen spectrum for each pre-tephra pollen spectrum in this study. An estimated sampling distance of < 1 cm was the smallest possible; for these data estimated time gaps are maxima

Tephra	Rotomanuka			Rotokauri			Okoroire			Kopouatai		
	Distance below tephra (cm)	Sedimentation rate (cm/100 yr)	Pollen-tephra time gap (yr)	Distance below tephra (cm)	Sedimentation rate (cm/100 yr)	Pollen-tephra time gap (yr)	Distance below tephra (cm)	Sedimentation rate (cm/100 yr)	Pollen-tephra time gap (yr)	Distance below tephra (cm)	Sedimentation rate (cm/100 yr)	Pollen-tephra time gap (yr)
Taupo (Y)	< 1	2.8	< 36				< 1	1.4	< 71	< 1	16.6	< 6
Whakaipo (V)	2	1.6	125	< 1	1.6	< 63	2	0.7	286			
Egmont-2	< 1	1.5	< 67	3	2.1	143	3	1.3	231			
Hinemaiaia (K)	3	1.5	200	< 1	1.2	< 83	< 1	1.2	< 83			
Tuhua	< 1	0.5	200	< 1	0.6	< 167	< 1	0.3	< 333	< 1	2.9	< 35
Mamaku	< 1	1.3	< 77	4	3.7	108	< 1	0.4	< 250	< 1	4.9	< 21
Opepe (E)	< 1	0.8	< 125	< 1	5.2	19	2	0.8	250			
Egmont-12	< 1	0.5	< 200	< 1	2.2	< 45						
Waiohau	< 1	0.9	< 111	3	2.5	120						
Rotorua	< 1	2.0	< 50	5[a]	2.5	200	< 1	1.3	< 77			
Rerewhakaaitu	5	7.1	70				3	7.7	39			
Mean	< 1.6	1.9	< 115	< 2.0	2.5	< 105	< 1.7	< 1.7	180	< 1	8.1	21

[a] Pollen spectrum taken from above Rotorua Tephra at Rotokauri.

with the corresponding pre-tephra sample. The primary focus of this paper is on the strength of that correlation.

3.1.4. Observed best match

The pollen spectrum at any level at another site with the strongest correlation with the Rotomanuka pre-tephra pollen spectrum.

3.2. Construction of the pollen datasets

Several correlation matrices were produced using a variety of pollen spectra constructions, with a view to determining the most efficient pollen dataset definition. For example, correlation coefficients were found to be universally higher when the pollen spectra dataset was restricted to the principal taxa, rather than the full spectrum of >100 taxa. The final pollen spectrum definition was arrived at as follows.

1. All local wetland or aquatic taxa and all fern and moss taxa were omitted. Pollen and spore percentages of these taxa can vary markedly because of local site conditions.

2. The dryland pollen curves at each site were scrutinised for possible evidence of significant response to changes in local hydrology at the site. For example, at Lake Okoroire and Kopouatai Bog, there is pollen and macrofossil evidence that *Dacrydium cupressinum*—often the predominant dryland pollen taxon and usually over-represented in pollen assemblages (Macphail and McQueen, 1983)—at times grew in swamp forest stands very close to the core site (Newnham et al., 1989, 1995). Similarly, *Leptospermum*, the source species of which can also tolerate wet substrates, may also have occurred very close to the core site on occasion in these records. Omission of these two taxa resulted in higher correlation coefficients overall by removing the effect of local over-representation on the rest of the pollen spectrum.

3. Some pollen taxa represent source species with quite different ecological affinities and geographical distribution. For example, the genus pollen taxon *Libocedrus* consists of two species with disjunct distributions and presumed biostratigraphic ranges that reflect their modern distribution (Newnham et al., 1989; Fig. 3; Table 4). Splitting this taxon into two, on the basis of biostratigraphy rather than pollen morphology, strengthened the correlation coefficients obtained. Using the same rationale, the pollen taxon *Phyllocladus* was split between the northern warm-temperate species common at these sites during the

Table 4
Pollen taxa used to correlate between sites

Taxon	Family	Ecological group	Number of source species
Agathis	Araucariaceae	tall tree	1
Dacrycarpus	Podocarpaceae	tall tree	1
Elaeocarpus	Elaeocarpaceae	tall tree	2
Halocarpus	Podocarpaceae	tree, shrub	3
Laurelia	Monimiaceae	tall tree	1
Libocedrus 1	Cupressaceae	tall tree	1
Libocedrus 2	Cupressaceae	tall tree	1
Metrosideros	Myrtaceae	tree, shrub, liane	12
Nestegis	Oleaceae	tall tree	3
Nothofagus menziesii	Fagaceae	tall tree	1
Phyllocladus 1	Podocarpaceae	tree, shrub	1
Phyllocladus 2	Podocarpaceae	tall tree	2
Podocarpus	Podocarpaceae	tall tree, shrub	5
Prumnopitys ferruginea	Podocarpaceae	tall tree	1
P. taxifolia	Podocarpaceae	tall tree	1
Ascarina	Chloranthaceae	shrub	1
Poaceae 1	Poaceae	herb	many
Poaceae 2	Poaceae	herb	many
Pteridium	Dennstaedtiaceae	fern shrub	1

postglacial period, and the southern, cool-temperate species common during the last glacial maximum (Fig. 3). The grasses (Poaceae) were also split into two biostratigraphic groups: those common during the late postglacial period and those common during the last glacial maximum (Fig. 3; Table 4). These changes avoided spurious correlations between postglacial and lateglacial spectra. The pollen taxon *Nothofagus fusca* type, representing three species with very different ecology and distribution, was omitted from the datasets, as no such division could be confidently made on the basis of biostratigraphic range.

Of the 19 taxa used in this investigation (Table 4), eight include more than one potential source species, but are retained here because either their potential source species in this study area have similar ecological affinities (e.g., Poaceae 1 or 2) or the biostratigraphic range of the taxon, and the other taxa with which it typically occurs in these spectra, suggests that a single species (or group of species with similar ecological affinities) is likely to be the major contributor. For example, the pollen taxon *Elaeocarpus* consists of two species with distinct distributions: one in true lowland forests; the other in montane forests or lowland forests at higher latitudes. As *Elaeocarpus* pollen usually occurs in association with pollen of lowland forest taxa in these assemblages, the *Elaeocarpus* pollen curves are assumed to represent primarily the lowland species. This procedure of including pollen taxa with potentially diverse source species is nevertheless recognised as a potential source of error in the correlations. In practice, however, pollen datasets can rarely, if ever, be restricted to just those taxa with single source species, without significant data loss. The procedure employed here is considered to be a suitable compromise that permits the detection of unambiguous ecological signals without significant data reduction.

4. Results

Correlation coefficients for all pre-tephra pollen spectra are given in Table 5, together with means and standard deviations for each pollen-tephra test across all sites and, conversely, across all common tephra layers. The same data are illustrated in Fig. 6.

Table 5
Correlation coefficients between Rotomanuka Pre-tephra pollen spectrum and the corresponding spectrum at Okoroire, Rotokauri, and Kopouatai

Tephra	Okoroire (Ok)	Rotokauri (Rk)	Kopouatai (Kp)
Taupo (Y)	0.91		0.57
Whakaipo (V)	0.86	0.31	
Egmont-2	0.92	0.52	
Hinemaiaia (K)	0.72	0.28	
Tuhua	0.79	0.87	0.14
Mamaku	0.36	0.63	0.12
Opepe (E)	0.89	0.85	
Egmont-12		0.87	
Waiohau		0.89	
Rotorua	0.96	0.88	
Rerewhakaaitu	0.86		
Mean	0.82	0.67	0.28
Standard deviation	0.18	0.24	0.25

Correlation coefficients are highly variable, particularly between sites, but show some broad patterns.

The strongest correlations generally are those for coeval spectra between the three Waikato lake sites, Rotomanuka, Rotokauri and Okoroire, although some exceptions are evident. Okoroire has the strongest overall similarity to Rotomanuka, yet the pre-Mamaku Tephra pollen spectra between these two sites are comparatively weakly correlated. The Rotokauri–Rotomanuka correlations are strongest for the lateglacial and early Holocene (>0.85) and weakest for the late Holocene (0.28–0.56). Correlations between Rotomanuka and Kopouatai are much weaker generally.

No tephra layers stand out as being consistently associated with strongly correlated pollen spectra, except when comparisons are restricted to between Waikato lake sites only (Fig. 6). For each tephra layer recorded at Kopouatai, correlation coefficients with Rotomanuka spectra are lower than the equivalent correlation between the Waikato lake sites (Table 5).

Linear sum-of-squares trend lines were fitted to the correlation data to determine whether any temporal pattern in strength of correlation between sites exists (Fig. 6a). The correlation data are too few and too variable for any firm conclusions to be drawn, although a positive relationship between age and degree of correlation is evident at the more strongly

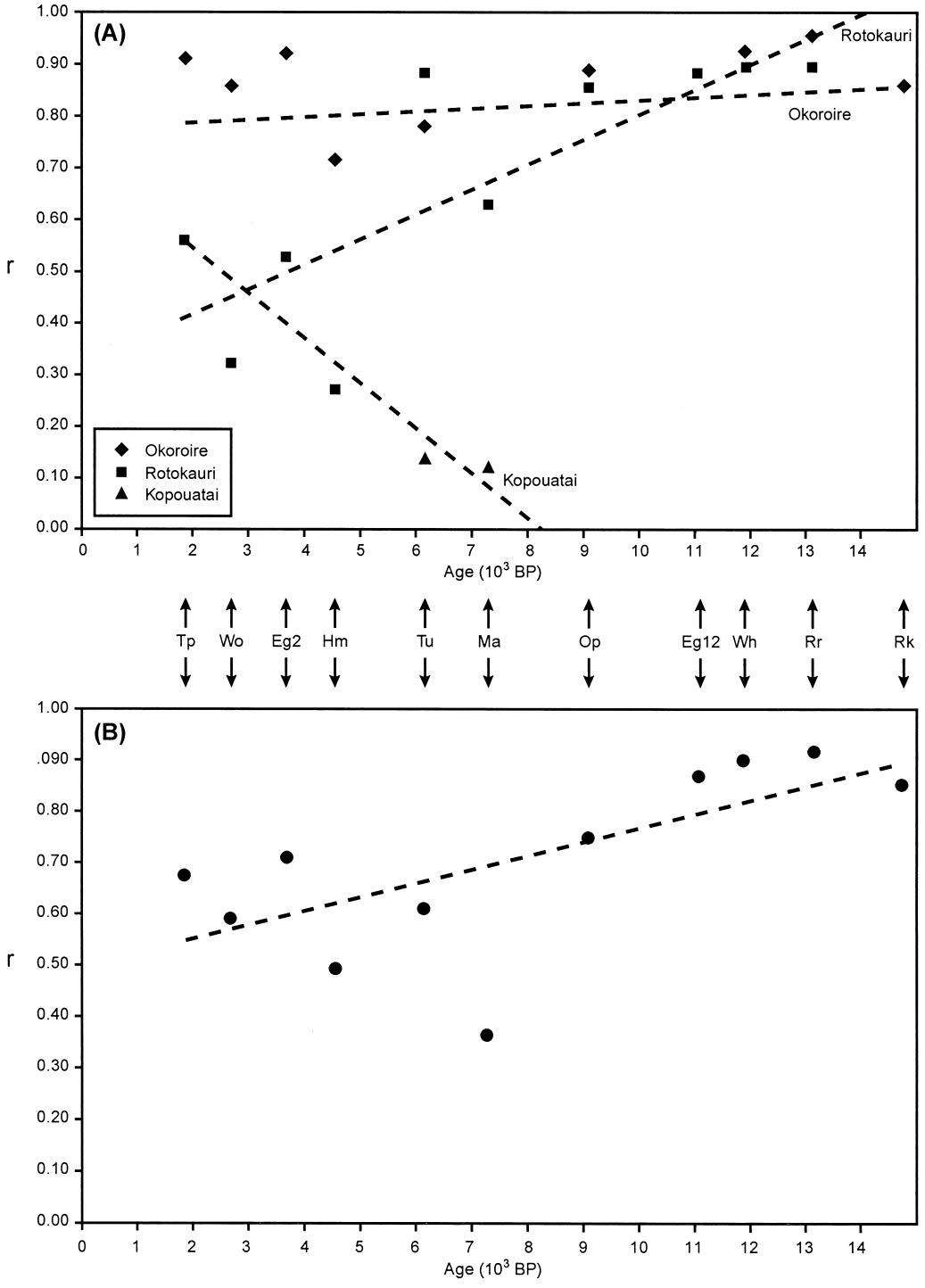


Fig. 6. Individual (a) and averaged (b) correlation coefficients between Rotomanuka pre-tephra pollen spectra and the corresponding spectra at Okoroire, Rotokauri, and Kopouatai. Tephra names and ages are given in full in Table 2. Linear trend lines are determined by least sum of squares.

Table 6
Rank (see text for definition) obtained for each Rotomanuka pre-tephra pollen spectrum correlated with spectra from Okoroire, Rotokauri, and Kopouatai. The number in brackets after each abbreviated site name refers to the total number of pollen spectra at that site and hence the lowest possible rank that could be achieved at that site. A rank of 1 indicates the observed best match equalled the expected best match

Tephra	Okoroire (53)	Rotokauri (27)	Kopouatai (46)
Taupo (Y)	4		14
Whakaipo (V)	15	19	
Egmont-2	6	14	
Hinemaiaia (K)	1	15	
Tuhua	5	1	29
Mamaku	41	1	32
Opepe (E)	1	2	
Egmont-12		1	
Waiohau		3	
Rotorua	4	4	
Rerewhakaaitu	6		

correlated sites (Rotokauri, strongly positive; Okoroire, weakly positive), whereas this relationship is negative at the more weakly correlated site, Kopouatai (Fig. 6a). The mean trend across all sites is positive (Fig. 6b), reflecting the influence of the Waikato lake sites which provide the majority of correlations.

In Table 6, each pre-tephra correlation is ranked according to its value relative to all other correlations (see Fig. 5 for explanation), providing an indication of the strength of correlation between coeval (sub-tephra) pollen spectra relative to non-coeval spectra. Some considerable departures between expected and observed match are evident and these outnumber the exact or close matches. Exact matches —where observed best match equals expected best match—are found at just three of the nine pre-tephra correlations with Rotokauri and two (of nine) with Okoroire. No exact matches were found in correlations with Kopouatai.

5. Discussion

The results indicate that correlating between postglacial sites by palynology alone is a haphazard process. Even within the Waikato lakes group, which generally show strong correlations, individual pre-tephra correlations as low as 0.31 (Rotokauri) and 0.36 (Okoroire) are observed (Table 5). No single tephra layer is associated with consistently strong pollen correlations except when they are confined to the Waikato lakes group. Overall, the consistently strongest Rotomanuka pre-tephra pollen spectra correlations are with Okoroire (distance: 40 km), rather than the nearest site, Rotokauri (18 km), although Rotokauri correlations are very strong for the lateglacial and early Holocene.

This late postglacial change in palynological similarity between the two nearest sites, Rotokauri and Rotomanuka, is perplexing, especially since the same pattern is not observed with Okoroire–Rotomanuka comparisons. Human influence—a factor that could be invoked elsewhere—is not applicable at these New Zealand sites as discussed above. Rotomanuka and Okoroire occur at a very similar latitude, although in different catchments (Figs. 1 and 2). Although Rotokauri is situated just 18 km northwest of Rotomanuka, its pollen profile indicates a far greater late postglacial expansion of trees now confined to the northern phytogeographic province, e.g., *Agathis australis*, *Phyllocladus* spp. , and *Libocedrus plumosa*, than is evident in the Rotomanuka and Okoroire profiles (Newnham et al., 1989). These northern taxa were largely absent from the Waikato region during the lateglacial and early Holocene when correlations between Rotomanuka and Rotokauri pollen spectra are consistently very strong (Fig. 6a; Table 5). This pattern might be explained by the gradual southwards migration of these northern tree species to reach the Waikato lowlands around latitude 38°S during the late Holocene (between ca. 6000 and 2000 BP) prior to human settlement in the region, as has been suggested previously (Ogden et al., 1992). The location of Rotokauri, just to the north of Rotomanuka, could be sufficient to explain the lower correlations between the two pollen profiles for late postglacial spectra. If this explanation is correct, the implication for this study is that even closely-spaced pollen sites within the same broad depositional basin, such as Rotomanuka and Rotokauri, can nevertheless at times exhibit diachronous pollen vegetation patterns.

Correlations between Rotomanuka and Kopouatai Bog show not unexpectedly greater differences given their contrasting size and depositional environment

(Fig. 6a; Table 5). Theoretical studies into pollen taphonomic processes indicate that the size of depositional basin can have an important bearing on the relative contribution of different pollen sources, with more extensive sites more likely to have stronger representation of regional and long-distance pollen sources (Tauber, 1965; Jacobson and Bradshaw, 1981; Prentice, 1985). The comparatively poor correlations between Rotomanuka, a small closed lake, and Kopouatai, a large peat bog, are thus more readily understood, despite their occurrence within the same phytogeographic province. The lowland and upland vegetation of Waikato are quite different today, as they have been in the past, principally in that the montane to subalpine vegetation tends to be dominated by cool temperate species more typically associated with higher latitudes in New Zealand (Clayton-Greene, 1978; Newnham et al., 1989). Palynologically, this upland vegetation is typically represented by pollen of *Nothofagus*, *Halocarpus*, *Phyllocladus asplenifolius* var. *alpinus.*, *Libocedrus bidwillii*, and to a lesser extent herbaceous and shrub taxa such as Poaceae, Asteraceae, *Myrsine*, and *Coprosma* (Fig. 3). Regional pollen 'signals' in the Waikato region would be expected to include these elements as well as those representing the podocarp-angiosperm forests that characterise the pre-settlement lowland areas. Based on pollen taphonomical 'principles' it could be expected that pollen spectra from large lowland depositional basins, such as Kopouatai Bog, would have greater upland and regional components than small lowland sites such as Rotomanuka, regardless of relative proximities to upland source vegetation. This appears to be the case here because the Kopouatai Bog pollen profile indicates far greater representation of upland taxa, e.g., *Nothofagus*, during the postglacial than does the Rotomanuka profile (Newnham et al., 1989; 1995). These between-site differences in sensitivity to regional and long-distance pollen sources may help to explain the poor correlation between Rotomanuka and Kopouatai spectra.

6. Conclusions

The concept of regional synchroneity in pollen spectra is not universally applicable, even in nearby sites of a similar type, size, and shape, although such sites can show a strong degree of concordance between spectra, for at least some sections of their profiles. These variable results, obtained in a tephrostratigraphic investigation freed from the major constraints restricting such comparisons in the past, suggest that some correlations based on pollen stratigraphy could be misleading.

The strongest synchroneity evident here was between nearby sites of the same type and similar size and shape. In the non-glaciated Waikato region, three pollen records from very similar sites exhibit regional synchroneity for the lateglacial and postglacial periods, but this concordance breaks down for the northernmost of the three sites during the (pre-human era) late Holocene, when a far greater expansion of northern tree species is recorded than is evident at other sites. This lack of concordance, in a non-glaciated region, is consistent with earlier studies suggesting that postglacial tree spread can result in diachronous pollen signals even within the same phytogeographic province (Smith and Pilcher, 1973; Birks, 1982, 1989; Juvigné et al., 1996).

If pollen-stratigraphic correlations are to be attempted, similar depositional sites should be chosen. In this study, the weakest correlations with Lake Rotomanuka were achieved at Kopoutai Bog, presumably because of marked differences between the nature, size, and morphology of their depositional basins. The significance of these site parameters appears to be that they strongly influence the regional and long-distance components of pollen spectra, as has been predicted by models of pollen transport and deposition (e.g., Jacobson and Bradshaw, 1981; Prentice, 1985).

Although pollen sum construction in theory permits direct comparisons between lake and bog sites, 'dryland' pollen sources may occur considerably closer to the pollen core or section site in bogs than in lakes, yet are still included within the pollen sum. This situation could readily lead to erroneous interpretations of regional pollen signals at bog sites. In this study, it was found that stronger correlations between both types of site were achieved when the pollen datasets were reduced to around 20 key taxa after omission of local taxa, dryland taxa with source species that may have been local at times, and taxa comprising potential source species with different ecological affinities and distributions.

This study reveals some of the problems inherent in correlation of sedimentary sequences under the assumption of regional synchroneity in pollen-vegetation signals. Undoubtedly accurate correlations have been achieved in the past, as in this study, but these successes should not encourage indiscriminate or uncritical applications as highly inaccurate pseudo-correlations are also possible.

These conclusions are based on a study area containing a comprehensive and well-studied suite of macroscopic tephra layers, which provide a more reliable basis for stratigraphic correlation here than does palynology or radiocarbon dating. In areas lacking tephras, or indeed, where very thin or microscopic tephras are suspected, other stratigraphic criteria, including palynology, become more critical. Such a situation occurs in northern Britain where detailed regional pollen stratigraphic datasets have been compiled. These offer the potential to assist with investigations to detect a tephra layer regionally once its approximate age or regional stratigraphic position are known. However, our results suggest that, whilst palynology can provide corroborative support for tephrostratigraphic determinations, it should be applied with caution and, wherever possible, in conjunction with other diagnostic criteria.

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