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THE DEFORESTATION OF THE UPPER AWATERE CATCHMENT, INLAND KAIKOURA RANGE, MARLBOROUGH, SOUTH ISLAND, NEW ZEALAND

Summary: Pollen analysis of a high altitude bog (Winterton Bog) and an alluvial soil sequence in the upper Awatere catchment on the western flanks of the Inland Kaikoura Range, and radiocarbon dates on wood and charcoal from the Marlborough region, have established a Holocene (post 10 000 years B.P.) vegetation history for this area. The upper slopes of the catchment were almost entirely clad in *Podocarpus* and *Phyllocladus* dominant conifer/broad-leaved forest and the valley floor in *Prumnopitys taxifolia* for most of the Holocene, despite occasional forest fires in the region. *Nothofagus* forest spread into the wetter, mountainous region west of the Awatere valley at around *c*. 6000 years B.P., but failed to establish more than scattered stands on the drier Inland Kaikoura Ranges. Widespread fire broke out in the early Polynesian era and between 750 and 600 years B.P. the Awatere catchment lost most of its forest cover, which was replaced by bracken, grass and scrub. There was a slight recovery of forest and scrub after 600 years B.P. when burning frequency lessened. Increased burning, grazing, and introduction of exotic weeds accompanied the penetration of the region by European pastoralists in the 1860s. The post-1960 era is clearly indicated by the upsurge of *Echium vulgare* and *Pinus* spp. The Winterton bog has a finely balanced water budget, and it may have been initiated by changes in the seasonality of rainfall in the mid-Holocene.

Keywords: South Island; Inland Kaikoura Range; deforestation; fire; charcoal; pollen analysis; Polynesian settlement; European grazing; Holocene; *Podocarpus cunninghamii*; *Nothofagus*; *Phyllocladus*; *Pteridium esculentum*; *Echium vulgare*.

Introduction

The vegetation of the eastern South Island hill and high country of New Zealand has been extensively transformed by fire. Before human settlement there were many episodes of natural fire (McGlone, 1989). It is clear that widespread forest burning occurred during Polynesian settlement (McGlone 1983, 1989), although there is debate as to the age of Polynesian settlement, with some advocating a much earlier age than the conventional 1000 years Before Present (B.P) (Sutton, 1994). Little is known about the course of this burning, or the reasons for it. Subsequent European settlers used fire as a regular part of their landscape management strategy. Over very large areas of the South Island the vegetative cover is a product of many years of repeated burning. We are therefore uncertain as to what the unmodified vegetation was like, or what would be the eventual outcome if burning ceased, even without the additional complication of the naturalised biota.

Controversy over the best use for the rugged South Island high country continues. Over wide areas where economic potential is low, but where land protection, natural, scenic, and recreational values are high, it is likely that a minimal management regime that resembles the natural situation will be a goal. However, where fire and grazing have had a pervasive influence, the question as to what is "natural" is difficult to answer. Better knowledge of how the present vegetation has developed will help decide what it could eventually become.

The Inland Kaikoura Range provides an opportunity to examine these questions. The range is a rugged, relatively dry mountain chain some 50 km long and 20 km broad, rising over 1500 m for most of its length, and including the highest peak (Tapuae-o-Uenuku, 2885 m) in the north-eastern South Island (Fig. 1). It lies within the north-eastern edge of an extensive area of tussock and scrub covered mountains in which forest stands are scattered and small, and thus fire is likely to have played a major role in the origin of the modern vegetation cover. Work on the historical record has barely begun. Timing of deforestation has not been established. No radiocarbon dates for either wood or charcoal have been published for the Inland Kaikoura Range, and it is only supposition that the area was deforested by fire during the Polynesian settlement phase. Also, the role of natural fire in this area, one of the driest

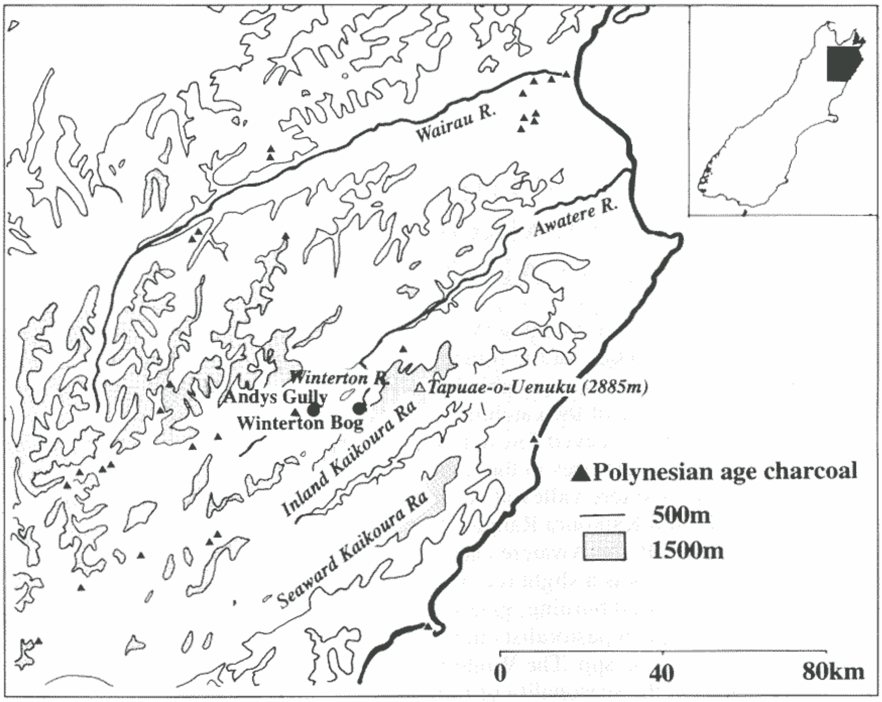

Figure 1: *Northeastern South Island and the Inland Kaikoura Range. Solid triangles indicate charcoal/wood samples dating to the Polynesian era.*

mountain regions of New Zealand, has yet to be assessed.

The Awatere catchment has few sediments suitable for fossil analysis. There is only one wetland on the Inland Kaikoura Range, a small bog high in the catchment of the Winterton River on the western flank. We have dated and analysed the pollen sequence from this shallow bog. A nearby alluvial pollen site and a suite of radiocarbon dated samples from subfossil wood and charcoal fragments from the general region provides supporting evidence. By utilising a full range of geomorphic, soil, charcoal, wood, and pollen evidence, in combination with what is known about the present vegetation, we provide a fuller picture of the original vegetation and its history than has hitherto been possible.

Environment and vegetation of the Inland Kaikoura Range

Williams (1989) and Courtney and Arand (1994) have provided a comprehensive account of the vegetation of the Inland Kaikoura Range and a general description of the climate, topography, geology, and soils. This brief description is based on their work. Botanical nomenclature follows Allan (1961), Connor and Edgar (1987), Healy and Edgar (1980), Moore and Edgar (1970), and Webb *et al.* (1988).

Precipitation is uniformly distributed throughout the year and ranges from 650 mm yr $^{-1}$ in the south to about 1000 mm yr $^{-1}$ in the north-east, and increases with altitude, much falling as snow in the winter. Dry periods are frequent, and most common in summer and autumn. Rainfall intensity is low. Average annual temperatures range from 5-10°C. Clear skies and high radiation lead to a pronounced seasonal cycle, with winters frosty and cool and summers dry and relatively warm. An average of 222 ground frosts a year occur at Molesworth Homestead in the upper Awatere Valley. The prevailing winds are from the northwest. The bedrock geology comprises moderately indurated and finely bedded sandstone and argillite. The major soils are Benmore, Muller, and Tekoa high country yellow-brown earths and alpine steepland soils, all of which have moderate to low fertility.

The main vegetative cover of the Inland Kaikoura Range is short tussock grassland and tussock herbland at lower elevations, *Rytidosperma* tussock grassland at higher elevations, and bare rock and scree along the crest of the Range. There are remnants in the form of small stands or individual trees and shrubs of the original woody vegetation throughout the general area. Mountain totara (*Podocarpus cunninghamii*), *Phyllocladus alpinus* and kowhai (*Sophora microphylla*) are the most common remnant trees. Occasional stands of mountain beech (*Nothofagus solandri* var. *cliffortioides*) are found, especially on the northeastern flank of the Range, but extensive tracts of beech are restricted to the west of the Awatere River under higher rainfall and on the strongly leached Tekoa soils.

In the Winterton River catchment, short tussock grassland predominates. Snow tussocks (*Chionochloa*) are restricted to precipitous bluffs, although further up the Awatere River they are common above 1200 m. The most extensive remnant of mountain totara consists of *c*. 2 ha in Totara Stream. At Limestone Creek, about 12 km to the northeast of Winterton Bog, there are numerous totara logs on the soil surface.

The earliest European accounts of the inland north-eastern South Island (see McCaskill, 1969; Kennington, 1978; Sherrad, 1966) indicate that the distribution and amount of forest has changed little since the 1860s when grazing of sheep and cattle began (Williams, 1989). Scattered remnants of native woody vegetation throughout the Inland Kaikoura Range suggest that it was probably originally covered in some form of forest up to around 1500 m altitude. Williams (1989) proposes that, before Polynesian settlement and subsequent fire, mountain totara forest covered the western side and much of the eastern side of the range. Mountain beech forest stands are confined to the north-eastern sector of the range and there is little evidence that it was previously more extensive, apart from individual trees in the lower Winterton Valley and Middlehurst Stream, *c*. 5 km to the north of Winterton bog.

Methods

Pollen analysis sites

Winterton Bog

Winterton Bog (NZMS 260 O30/536083) (Figs. 1, 2) is in the headwaters of the Winterton River, in a small gently sloping basin at an altitude of 1480 m. A central peat bog of about 1 ha is surrounded by colluvial footslopes and steep bedrock slopes. Vegetation of the area is described in Williams (1989) as *Carex gaudichaudiana* sedge-grassland on the wetland, and *Rytidosperma setifolium*-(*Celmisia spectablis*) tussock herbfield on the surrounding slopes. The site is probably near tree limit as forest remnants do not occur higher. Two profiles from the centre of the bog within 2 m of each other have been exposed by digging, and sampled for pollen and radiocarbon dating.

Andy's Gully

Andy's Gully (informal name; NZMS 260 O30/ 458085) is a tributary of the Tone River near the confluence with the Awatere River about 8 km due west of Winterton Bog. The valley bottom is at present in exotic grassland [browntop (*Agrostis capillaris*), sweet vernal (*Anthoxanthum odoratum)*, *Hieracium* spp.], shrubland [sweet briar (*Rosa rubiginosa*), matagouri (*Discaria toumatou*)] with scattered hard tussock (*Festuca novae-zelandiae*) and silver tussock (*Poa cita*) in the well drained areas, and wet grassland [tall fescue (*Festuca arundinacea*), tall oatgrass (*Arrhenatherum elatius*)], together with *Carex* spp. and other sedges in the poorly drained areas. The sample site is in the valley bottom at 810 m asl where a stream has cut into the floodplain and exposed the underlying alluvium.

Sample analysis

Samples for pollen analysis were taken from open cleaned faces or sampled in the laboratory from a boxed core taken in the field. At Winterton Bog, an initial profile (Winterton 1; field no. X91/4) was dug and sampled at coarse resolution for pollen. Later, a second profile (Winterton 2; field no. X91/5) approximately 2 m from Winterton 1 was taken as a complete core back to the laboratory and the uppermost sediments volumetrically sampled at 2 cm intervals. Winterton 1 and Andy's Gully sites were not sampled volumetrically. Winterton 2 was sampled by extraction of measured volumes (1 cm^3) of sediments. Tablets with a known quantity (11 300) of exotic *Lycopodium* spores were added at the first stage of preparation of the samples, and pollen concentration per cm^3 determined by the proportion of exotic *Lycopodium* to pollen counted. Pollen extraction followed standard palynological procedures of disaggregation of samples in 10% KOH, digestion in 40% HF, oxidation with a chlorine bleach, and acetolysis (Faegri and Iversen, 1964).

Pollen and spores were identified to the lowest taxonomic level possible. “Undiff.” written after a pollen or spore type indicates that although there was morphological variation, it was not possible to definitively attribute most grains to a lower taxonomic rank. The following types are used:
Aciphylla type: *Aciphylla* and *Anisotome*;
Cirsium type: tribe Cardueae - thistles;
Cyathea smithii type: *C. smithii* and *C. colensoi*;

Cyathea dealbata type: *C. dealbata* and *C. medullaris*; *Fuscospora*: subgenus of *Nothofagus* which includes *N. fusca*, *N. solandri* and *N. truncata*. *Taraxacum* type: tribe Lactuceae - the dandelions.

Pollen percentages are based on a pollen sum of all dryland plants, excluding those confined to or characteristic of mires, aquatic plants, and ferns and fern allies. In most instances a sum of 250 or more was used for percentage calculations.

Charcoal content was assessed using the point method of Clark (1982), and is expressed as a charcoal index (charcoal hits on a grid of 11 points for each field of view counted for pollen, expressed as a percentage of the pollen sum). Charcoal concentrations expressed as mm^2 cm^{-3} simply tracked peat growth rates and could not be as easily interpreted.

Bulk samples were taken for radiocarbon dating from Winterton 1 and a small soil sample from Andy's Gully. These samples were subsequently dated by the Radiocarbon Laboratory, Institute of Geological and Nuclear Sciences. All reported ages are given as conventional radiocarbon years before present (B.P.). Representative samples from Winterton 2 were burned at 550∞C until all organic material was gone, and the proportion of inorganic material calculated by loss on ignition.

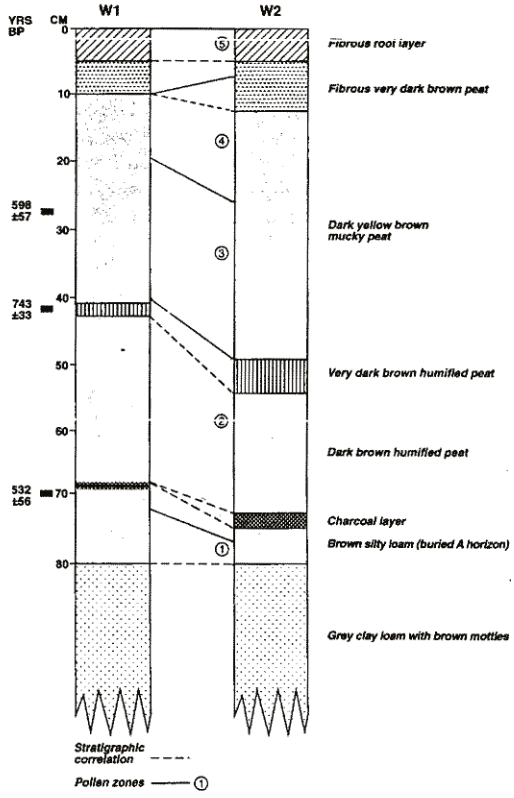

Figure 2: *Winterton 1 and 2 profiles; stratigraphy and correlation.*

Results

Stratigraphy and chronology

Winterton Bog

The profile stratigraphies are given in Fig. 2. The 41-43 cm dark brown peat layer in Winterton 1 was continuous with the 49-54 cm layer in Winterton 2, and a discontinuous charcoal-rich layer at 68 cm in Winterton 1 could be traced to the 72-74 cm layer in Winterton 2.

The lowermost date (NZ 8046) at Winterton 1 is younger than those derived for the sediments overlying it. As discussed later, the older overlying peat dates (NZ 8044, NZ 8045) are consistent with charcoal and wood dates in the region, and also with dates for deforestation in other parts of the South Island. In areas where the bedrock is low in carbon, such as the Inland Kaikoura Range, contamination of peats by older carbon is highly unlikely. However, largely inorganic sediments, such as the silty loam from which NZ 8046 was obtained, are highly vulnerable to contamination from downwards or lateral movement of water carrying young organic colloids. We therefore have assumed that the upper two dates (NZ 8044, NZ 8045) provide close estimates of the true age of the sediments they are derived from, but that the lower date (NZ 8046) has been massively contaminated by much younger organic material.

At Limestone Creek, about 12 km to the northeast of Winterton Bog, there are numerous totara logs on the soil surface. The outermost layers of two of these logs have been dated at 860 ± 50 yr B.P. (Wk 2887) and 1029 ± 58 yr B.P. (NZ 4979).

Andy's Gully

At this site *c*. 2.8 m of fine-textured, stratified alluvium (silt, sand, and fine gravel) have been exposed by a stream cut. Stratigraphy is as follows:

0-40 cm: recent sandy alluvium.

40-55 cm: prominent, very dark brown buried soil; pollen samples at 40 and 55 cm.

55-180 cm: silty stratified alluvium.

180-220 cm: gravel.

220-225 cm: buried soil, containing fine charcoal of herbaceous plants; 4928 ± 64 years B.P. (NZA 3505); pollen sample at 220 cm.

225-380+ cm: stratified silty alluvium.

The upper, very dark brown soil is found throughout the valley, and in some of the tributaries, at depths ranging from 20 to 50 cm below present soil surface. At another site in the valley, charred wood of *Discaria toumatou* in this soil was dated to less than 200 years (Wk 2886).

Pollen analysis

The chronology presented with the pollen diagrams is based on radiocarbon dates and also on age estimates made on the basis of the changes in the pollen assemblages which will be detailed in the discussion.

Winterton Bog 1 and 2

The Winterton Bog profiles (Figs. 3, 4 and 5) fall into 5 distinct assemblage zones the salient features of which are briefly described below.

Zone 1: *Prumnopitys taxifolia* assemblage zone; estimated age: >6000 years B.P.

This is represented by a single basal sample in Winterton Bog 1, dominated by *Prumnopitys taxifolia*, but with significant representation of *Fuscospora*, *Prumnopitys ferruginea*, *Podocarpus*, *Phyllocladus*, and tree ferns, in particular, *Cyathea dealbata* type. Minor amounts of Poaceae and shrubland types (*Coprosma*, *Myrsine*, and Asteraceae), represent the local open vegetation close to the site. Minor quantities of Cyperaceae and Apiaceae, along with a varied array of algal types indicate a wet, often flooded, low sedgeland occupied the site.

Zone 2: *Fuscospora-Prumnopitys taxifolia* assemblage zone; estimated age *c*. 6000 - 750 years B.P.

This zone is defined by the abrupt increase of *Fuscospora* to form over half of the pollen percentage sum, and a corresponding decrease in *Prumnopitys taxifolia. Myriophyllum* becomes abundant.

Zone 3: *Pteridium esculentum*-Poaceae assemblage zone; estimated age 750 years B.P. - 90 years B.P. (1860 AD).

Pteridium esculentum increases sharply to nearly 50% of the pollen sum, followed by a less abrupt rise in Poaceae. The charcoal index follows the *Pteridium* curve. All arboreal types decrease abruptly. *Fuscospora* declines to a low of 12% of the pollen sum but recovers to near zone 2 levels at the top. *Pteridium esculentum*, after its initial peak, declines steadily throughout the upper half of the zone. Cyperaceae, Apiaceae, and shrub types are common in the upper half of the zone.

Zone 4: *Rumex acetosella*-Poaceae assemblage zone; 1860 - 1960 AD.

A series of exotic pollen types appear in the course of this zone, most prominent being *Rumex acetosella. Fuscospora* decreases to about one half of its value at the termination of Zone 3, and *Pteridium esculentum* increases, then undergoes a sustained decline.

Zone 5: *Pinus-Echium* assemblage zone; 1960 AD to present.

Pinus is consistently represented at greater than 2%, and *Echium vulgare* pollen is present in every sample. Indigenous tree pollen types increase markedly in the uppermost two samples.

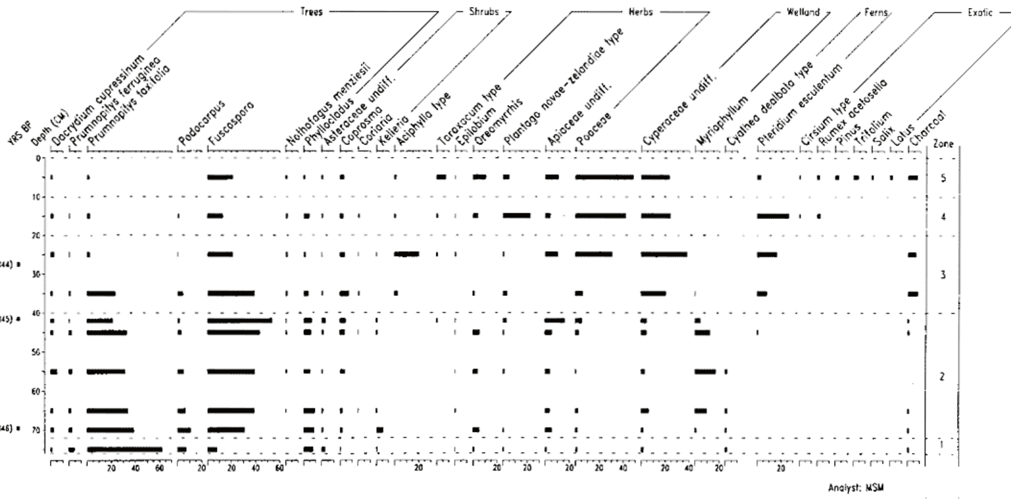

Figure 3: *Winterton 1, percentage pollen diagram. Pollen sum includes all terrestrial plants, but excludes wetland elements.*

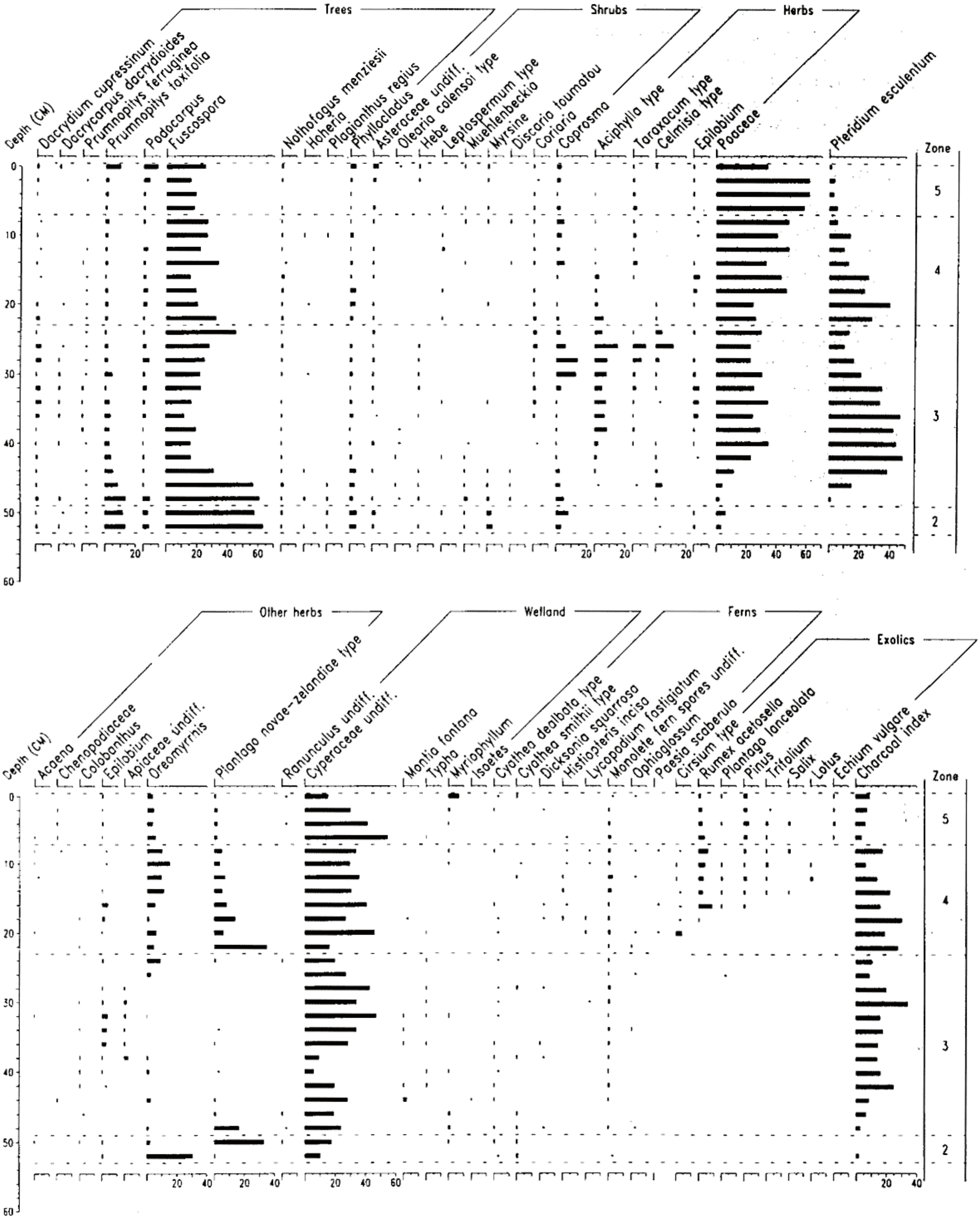

Figure 4: *Winterton 2, percentage pollen diagram. Pollen sum includes all terrestrial plants, but excludes wetland elements.*

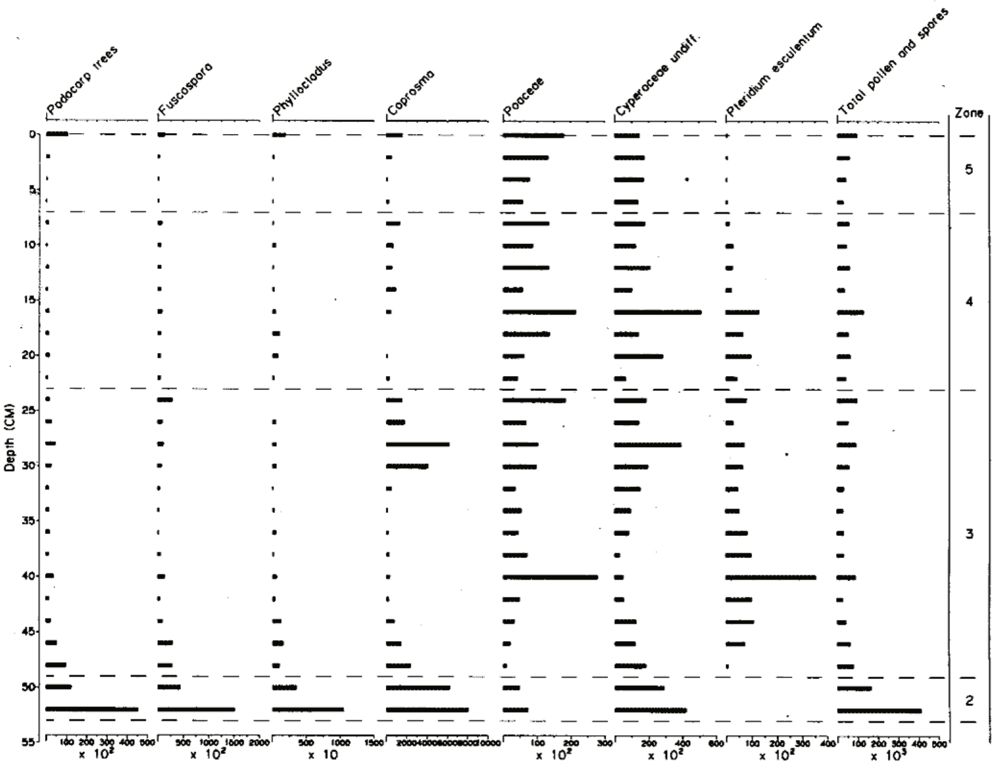

Figure 5: *Winterton 2, concentration pollen diagram. Concentrations expressed as pollen grains cm^{-3}. Note changes in scale.*

Table 1: *Andy's Gully, percentage pollen results. Pollen sum includes all terrestrial plants, but excludes wetland elements. + = trace.*

Taxa	Depth (cm) 40.0	55.0	220.0	Taxa	Depth (cm) 40.0	55.0	220.0
Dacrydium cupressinum	0.6	-	2.3	*Aciphylla* type	2.6	0.9	-
Dacrycarpus dacrydioides	-	-	0.8	*Colobanthus*	0.3	8.1	1.0
Metrosideros undiff.	0.3	-	0.3	*Taraxacum* type	9.1	5.4	-
Fuscospora	10.9	5.7	18.4	Brassicaeae	-	-	0.5
Nothofagus menziesii	-	-	0.3	*Gentiana*	0.3	-	-
Prumnopitys ferruginea	-	-	0.8	*Geranium*	-	-	0.2
Prumnopitys taxifolia	0.6	0.8	15.6	Poaceae	5.0	3.8	0.3
Podocarpus	0.6	1.5	5.9	Cyperaceae undiff.	10.2	5.4	1.0
Halocarpus	-	-	0.8	*Cyathea dealbata* type	0.3	1.9	16.1
Hoheria	-	-	0.3	*Cyathea smithii* type	-	1.1	3.1
Phyllocladus	0.3	1.5	6.6	*Lycopodium australianum*	-	0.8	0.3
Asteraceae undiff.	0.9	2.7	15.6	*Lycopodium fastigiatum*	-	0.4	0.3
Coprosma	0.3	-	6.1	Monolete fern spores undiff.	0.9	1.5	3.3
Coriaria	0.3	-	-	*Ophioglossum*	-	-	0.3
Leptospermum type	0.3	-	-	*Pteridium esculentum*	69.4	72.8	-
Muehlenbeckia	-	-	0.8	*Cirsium* (exotic)	+	-	-
Myrsine	0.3	-	2.0	*Anthoceros*	2.9	6.9	-
Kelleria	0.3	-	-	Undeterminable	-	0.4	4.1
Terrestrial pollen sum	320.0	261.0	391.0	All taxa	382.0	332.0	402.0

Table 2: *Radiocarbon dates and identifications of subfossil wood and charcoal from the Marlborough area. Radiocarbon numbers are "NZ" unless otherwise indicated; A = AMS date.*

Date	^{14}C No	Locality	Material	Collector	ID
101 ± 55	4623	Head of Enchanted Stream, Wye River, Wairau River	Charcoal	P. Simpson	*Nothofagus*?
117 ± 70	7610	Severn River	Charred wood	L.R. Basher, R.D. Sutherland	*Nothofagus* and Asteraceae shrub
126 ± 64	7601	Dillon River 1 km above confluence with Half Moon Stream	Wood	L.R. Basher	Asteraceae shrub
134 ± 176	A 477	Isolated Flat	Charcoal	J. McAlpin	
171 ± 64	7602	Yarra River near Yarra Hut	Wood	L.R. Basher, R.D. Sutherland	*Discaria toumatou*
<200	Wk 2886	Andy's Gully, Tone River tributary of Awatere River	Charred wood	L.R. Basher	*Discaria toumatou*
242 ± 65	7609	Big Bush Stream	Charred wood	L.R. Basher	*Phyllocladus alpinus*, *Hebe* sp., *Discaria toumatou*
345 ± 104	7674	Island Gully	Charcoal	J. McAlpin	
351 ± 53	7718	Summit of Raglan Range	Charcoal	G. Howard	
375 ± 48	7721	Near Lake Chalice, ridge between Mt Patriarch and Trig Z	Charcoal	G. Howard, M.J. McSaveney	
407 ± 67	7638	Tarndale	Soil	J. McAlpin	
453 ± 66	7670	Isolated Flat	Soil	J. McAlpin	
463 ± 62	7612	Amuri Skifield road	Charcoal	P.J. Tonkin	*Nothofagus*
490 ± 153	A 478	Isolated Flat	Charcoal	J. McAlpin	
502 ± 67	7604	Nightingale Stream	Charcoal	L.R. Basher	*Nothofagus*
507 ± 66	7600	Dillon River 3.5 km above confluence with Half Moon Stream	Charred wood	L.R. Basher, R.D. Sutherland	*Phyllocladus*
512 ± 62	7720	Near Lake Chalice, ridge between Mt Patriarch and Trig Z	Charcoal	G. Howard, M.J. McSaveney	
629 ± 105	7672	Lake Sedgemere	Soil + Charcoal	J. McAlpin	
670 ± 49	7559	Head of Leatham River	Charcoal	J.M. Mitchell, R.D. McNabb	
860 ± 50	Wk 2887	Limestone Creek tributary of Awatere River	Charred log	L.R. Basher, I.H. Lynn	*Podocarpus* sp.
869 ± 61	7659	Upper Wairau River	Soil + Charcoal	J. McAlpin	
870 ± 114	7684	Acheron River	Charcoal + soil -	J. McAlpin	
899 ± 61	7719	Summit of Raglan Range	Charcoal	G.Howard	
1029 ± 58	4979	Near top of Wadsworth track to Hodder River	Burnt tree trunk	A.S. Pitts, S.A.L. Read	*Podocarpus* sp.
1281 ± 42	6463	East side of Saxton River on low terrace	Charcoal	G.H. Blick	
1401 ± 108	7673	Wairau River	Charcoal	J. McAlpin	
1622 ± 53	7558	Saw Spur, Upper Wairau River	Charcoal	J.M. Mitchell, R.D. McNabb	
1790 ± 90	7611	Tarndale	Charcoal	L.R. Basher, R.D. Sutherland	*Nothofagus*
2075 ± 77	7608	Half Moon Stream near confluence with Dillon River	Wood	L.R. Basher	*Hebe* sp.
4425 ± 67	7717	Black Birch Observatory road	Charcoal	G. Howard	
4928 ± 64	A 3505	Andy's Gully, Tone River tributary of Awatere River	Charcoal	L.R. Basher, I.H. Lynn	Herbaceous (sp. unknown)
7566 ± 116	7606	Amuri Skifield	Charcoal	P.J. Tonkin	*Phyllocladus alpinus*
9170 ± 139	7603	The Ribble	Charcoal	L.R. Basher, R.D. Sutherland	*Podocarpus* cf. *cunninghamii*
9292 ± 135	7605	Gloster River	Charcoal	L.R. Basher, R.D. Sutherland	*Pseudopanax arboreus/colensoi* type (probably latter)

Andy's Gully

Only three samples yielded countable pollen assemblages (Table 1). The others had abundant charcoal fragments, but no pollen.

220 cm: Podocarpaceae pollen types (in particular *Prumnopitys taxifolia*, *Podocarpus*, and *Phyllocladus*) are more abundant in this sample than *Fuscospora*. It is therefore probably the equivalent of the transition between zone 1 and 2 at the Winterton 1 site. *Coprosma* and undifferentiated Asteraceae types are abundant. A striking feature of this sample is the abundance of *Cyathea dealbata* type and *Cyathea smithii* type spores. Tree fern spores are often over-represented in alluvial sites because of differential corrosion. Nevertheless, a substantial source of tree fern spores must have been close by. Microscopic charcoal fragments are abundant in this and subsequent samples.

55 cm: base of prominent dark brown buried soil. Bracken (*Pteridium esculentum*) is the overwhelming dominant type in this sample, and bracken must have been the main vegetative cover. Tree types, and, in particular, Podocarpaceae, are at very low percentages, but *Cyathea smithii* type and *Cyathea dealbata* type are still represented. *Colobanthus*, *Taraxacum* type, sedge and *Anthoceros* type point to a wet, low turf occupying the immediate site.

40 cm: top of prominent dark brown buried soil. This assemblage is closely similar to that at the 55 cm level. The occurrence of *Cirsium* pollen (thistle), but no other exotic taxa, places this at the beginning of zone 4 of the Winterton profiles.

Wood and charcoal distribution

Fig. 1 and Table 2 give the distribution and details of all wood and charcoal dates for the Marlborough area, and identification of the species where this was recorded. There are a large number (23) of modern or Polynesian-era dates which establish wide spread burning during this period (see Fig. 1), and a smaller number (11) of older dates that show fires have occurred as far back as *c*. 9000 years B.P. These dates indicate totara has grown in the area since at least 9170 years B.P. Dates on *Fuscospora* are all less than 2000 years B.P. and are from wetter areas west of the Awatere and Acheron Rivers. Dates from *Podocarpus cunninghamii*, *Phyllocladus*, and shrub species in general tend to come from drier parts of the region, and charcoal from these species is found mainly in alluvium or as charred logs lying on the surface of the ground. In wetter areas most charcoal is found in colluvium.

Discussion

Vegetation history

The early matai (*Prumnopitys taxifolia*) pollen dominated zone of Winterton 1 probably dates to 6000 years B.P. or earlier. Beech (*Fuscospora*) spread rapidly throughout the northeastern South Island at around 6000 years B.P. (Moar, 1971; Russell, 1980; Dodson, 1978). The 220 cm sample at Andy's Gully has both abundant matai pollen and beech (although in a pollen poor matrix), and dates to *c*. 5000 years B.P.

The source of the matai pollen is not as clear. There is no matai in the upper Awatere or on the Inland Kaikoura Range, and the nearest living trees are probably those at the head of the Seaward Kaikoura Range, 30 km due east (Peter Williams, Landcare, Nelson, *pers. comm.* 1994). Nevertheless, the upper Awatere River valley is within the potential upper altitudinal limit for matai. We suggest that matai-dominated conifer/broad-leaved forest occupied the valley floor of the Awatere River catchment, while mountain totara forest occupied the upper slopes and more stressed and less fertile sites throughout. *Phyllocladus alpinus* was the most prominent small tree to shrub at tree line at around 1400 m, but must have been important at lower altitudes as evidenced by its relatively high pollen percentages at Andy's Gully. *Hoheria glabrata* almost certainly was also common in the tree line scrub, but it is poorly represented in the pollen rain.

The absence of matai charcoal and wood from the area is a problem for this interpretation, but nevertheless consistent with results from the rest of the eastern South Island. Totara wood, and beech and *Phyllocladus* charcoal are the most common soil and surface Holocene fossils in the South Island (Molloy *et al*., 1963). *Halocarpus* and *Libocedrus bidwillii* sometimes are found as surface logs. However, these species are found mainly in wetter regions, whereas logs survive on the soil surface mainly in drier areas. Other podocarp species and most angiosperms seem only rarely to be represented by wood or charcoal in soils in most areas, probably a consequence of their rapid decay when in contact with the soil.

Mountain totara and *Phyllocladus* pollen are not at all abundant in this or subsequent assemblages, despite persuasive evidence in the form of wood and charcoal, and forest remnants for these species having been dominant on the Inland Kaikoura Range before deforestation. While beech and matai are well represented to over represented in the modern pollen rain (Macphail and McQueen, 1983); *Phyllocladus* and, in particular, mountain totara, seem to be under-represented (Pocknall, 1982; Moar, 1970; Bussell, 1988; McGlone, 1982). Pocknall (1980) suggests that mountain totara pollen is abundant only within a few tens of metres of the parent tree. The pollen assemblages therefore give a misleading impression of the actual abundance of matai and beech in the Winterton catchment. The upland forest must therefore be represented solely by the small quantities of totara and *Phyllocladus* pollen recorded in the Winterton and Andy's Gully profiles, with the dominant beech and matai pollen types mainly derived from distant forests. In particular, the high percentage values for beech pollen at the Winterton site reflect the immense pollen production of beech species, the large area in mountain beech forest immediately west of the Awatere river, and the prevailing wind direction. The rise of beech pollen recorded at Winterton Bog in zone 2 therefore does not represent growth of beech forest east of the Awatere, but the rapid spread of mountain beech to the west of the river after 6000 years B.P. From the present scattered distribution of mountain beech remnants (Williams, 1989) it seems unlikely that it ever consisted of more than isolated patches on the drier western and southeastern slopes of Inland Kaikoura Ranges. The more substantial areas of mountain beech remaining on the northeastern slopes suggest that it was a major forest type there before deforestation. The strong representation of *Cyathea dealbata* and *C. smithii* type spores at the lower altitude Andy's Gully site, when combined with the lesser but still significant amounts recorded at the Winterton sites, suggests that these tree ferns grew within the Awatere Valley, probably in gullies on the lower slopes of the ranges in tall conifer/broad-leaved forests.

The area immediately surrounding the Winterton bog site was most probably in shrubland-grassland, the low percentage values for Poaceae and shrubs being typical of local upland vegetation representation in the modern pollen rain (Moar, 1970). Accumulation at the Andy's Gully site is a result of episodic alluvial events, and the abundance of microscopic charcoal in the sediments suggests they may have been caused by infrequent natural fires. The open scrub and herbaceous vegetation at the site suggested by the pollen analysis of the lower (220 cm) level is, therefore, probably biased by the effects of the fires that induced the sedimentation. Presumably, similar fire-induced vegetation was common throughout the Holocene in drier areas of the range, and the presence of charred wood and charcoal in the soils of the general area confirm this. While charcoal fragments are not abundant at the Winterton 1 site, their continuous presence suggests low frequencies of local fire.

The sequence in zone 3 of bracken spore increase in association with rapidly rising charcoal concentrations, followed by expansion of grass and falling tree pollen levels, is the classic South Island deforestation sequence (McGlone, 1983; Anderson and McGlone, 1992). Variable sedimentation rates at the Winterton sites make a detailed chronology of deforestation difficult. The prominent dark brown peat in Winterton 1 and 2 has been dated to 743 ± 33 (NZ 8045). Contamination by young carbon introduced by downgrowth of roots or percolation of humic acids is always a possibility in shallow peats. Nevertheless, the broad coincidence of the date on this peat soil with the ages for charcoal and wood in soils in the district (Table 2) gives some confidence. Overlying sediments at 27-28 cm are dated to 598 ± 57 (NZ 8044) at Winterton 1. From their pollen content, and assuming a proportional peat accumulation rate, these sediments correspond to the 35 cm level at Winterton 2. The major deforestation event at this site was therefore essentially complete within 150 years, and it is probable that most forest went within the first 50 years of burning.

The date of around 750 years B.P. for the beginning of permanent deforestation is about 100 years younger than a cluster of charred log and charcoal dates from the region centred on 870 years B.P. (Table 2). Allowing for the age of the wood before burning in the charcoal, decay of outer layers of the logs, or possibly some minor contamination by younger carbon at the Winterton site, these are highly likely to date the same deforestation event. There are few deforestation dates based on pollen analysed profiles for the South Island interior, although many charcoal and wood dates fall into the time range of the Marlborough samples reported here (Molloy *et al.,* 1963). Deforestation of beech dominated country in the upper Hope river area began at 554 ± 43 (NZ 7586) (Cowan and McGlone, 1991), and at Porters Pass at 744 ± 57 (NZ 5234) (N.T. Moar, *unpub. data*). In central Otago, upland forest was destroyed by fire at around 650 years B.P. (McGlone *et al.*, 1995). Similar dates in the range 600-700 years B.P. have been obtained from coastal sites (McGlone, 1983, Anderson and McGlone, 1992). Anthropogenic deforestation of the Inland Kaikoura Range and upper Awatere Valley therefore began at about the same time as in other areas, both inland and coastal, of the South Island.

After the initial burnoff of forest and other woody vegetation a bracken dominated fernland-grassland vegetation established, and was maintained by repeated fire. There is a slow decline in bracken dominance as a grassland, that may have had a considerable *Aciphylla* component, established. The most likely explanation for this sequence is that bracken initially thrived in the forest soils exposed after deforestation, but subsequent progressive loss of organic matter and soil nutrients gave an advantage to grassland. A similar sequence of events is inferred for seral tussock grasslands in the central North Island (Rogers, 1994). Towards the end of zone 3, the charcoal influx fell, bracken was at low levels, beech underwent a sustained recovery, and *Coprosma*, *Phyllocladus* and *Celmisia* formed a dense community close to the Winterton bog. The increasingly woody nature of the vegetation indicates less frequent burning in the region. The pollen percentages are somewhat misleading during this zone. Destruction of so much forest had lowered the overall pollen production of the region, and the remaining beech forest is therefore over-represented. Beech forest probably did not, as a literal reading of the pollen diagram might suggest, almost recover to pre-deforestation levels. More likely is some marginal recovery by beech west of the Awatere River.

Why so much forest was burnt in the early years of the Polynesian settlement of the South Island is not entirely clear. It is, moreover, impossible to be sure that it was not natural fire rather than Polynesian set fires (Nunn, 1994). However, the coincidence of the first secure indications of Polynesian settlements with evidence for New Zealand-wide conflagrations strongly suports the idea that Polynesian settlement and exploitation was involved. McGlone (1983) showed that driest areas - such as the Inland Kaikoura Range - tended to be burnt first and most extensively. This coincidence, not of settlement density or accessibility, but of vulnerability to fire, suggests that most of the burning in these remote areas was a more or less accidental result of widespread use of fire to clear tracks. Other predisposing factors were probably involved, such as exceptional drought years. The apparent decline in firing and regrowth of vegetation at the top of zone 3 may indicate a lessening of Maori use of these remote regions after the extinction of the moa between 650 and 400 years B.P. (Anderson, 1989).

With zone 4, European pastoralism began in the region. The first sign of this event is the increase in the charcoal index and bracken, and the renewed decline of beech. An early record of *Plantago lanceolata* at the 26 cm level at Winterton 2 is almost certainly laboratory contamination. The first runholders moved into this area in the late 1850s-early 1860s, and zone 4 thus can be dated to *c*. 1860 AD. Exotic plants accompanied the early European sheep farmers as contaminants in seed and on stock brought into the country. Thistle (*Cirsium*) pollen is strongly represented first, followed by sheep sorrel (*Rumex acetosella*), both common early weeds. Bracken and *Aciphylla* diminish rapidly after an early peak induced by firing of the slopes, as a result of sustained grazing and repeated burning. From early in zone 4 grass (by now including many introduced species) is the dominant pollen type along with long-distance dispersed beech from west of the Awatere River. A number of other introduced tree and herb types are present in the pollen rain.

The rise of viper's bugloss (*Echium vulgare*) permits confident dating of the beginning of zone 5 to *c*. 1960. A.D. Moore (1976) records the spread of this introduced weed in the nearby Molesworth Station in the late 1950s and early 1960s. As well, there is a doubling of *Pinus* percentages which may reflect the increased pine planting in the general region since the 1950s.

Peat growth

Peat growth has been extraordinarily slow and erratic at the Winterton Bog site. If we accept a date of *c*. 6000 years B.P. for the initiation of zone 2, it has averaged *c*. 0.14 mm yr^{-1} for the whole profile, but this figure conceals major variations. Growth during zone 2 averaged 0.07 mm yr^{-1}; zone 3, 0.40 mm yr^{-1}; zone 4, 1.6 mm $y^{-1}r$; and zone 5, 2.3 mm yr^{-1}. Pollen concentrations depend on accumulation rates as well as pollen influx. The sharp fall in pollen concentration at the end of zone 2 before deforestation began in the catchment shows a major acceleration of peat accumulation. Fluctuations in pollen concentration after this event are minor, but there is some indication of a slowing in peat accumulation (as judged by total pollen and spore concentration) at the top of zone 3 and beginning of zone 4. This slowing of accumulation rate coincides with the slight recovery of woody vegetation noted previously.

The peat bog was initiated at a time of major vegetation change in which beech was replacing low forest and podocarp scrub in the wetter districts to the west. Rogers and McGlone (1989) have argued that rainfall patterns shifted at that time towards drier summers and wetter winters, and that this favoured bog growth. Certainly, the location of the Winterton bog in an area largely devoid of wetlands (Courtney and Arand, 1994) suggests that it has a finely balanced water budget, and the abundance of algal remains and *Myriophyllum* during zone 2 time is characteristic of a seasonally wet, peaty pool rather than a true bog, and this could account for the slow accumulation rate.

Table 3: *Summary vegetation history, Winterton catchment.*

Age	Zone	Vegetation and events
1960 A.D.- present	5	Continuing burning and grazing and further weed invasion, including *Hieracium* and vipers bugloss.
1860-1960 A.D.	4	Entry of European pastoralists; renewed destruction of forest; burning and grazing reduces bracken; introduction of many exotic weeds, in particular thistle and sorrel.
750 years B.P. - 1860 A.D.	3	Arrival of Polynesian settlers. Rapid destruction of most forest east of the Awatere, and its replacement with bracken and grass, and some inroads into beech forest west of the Awatere. Limited recovery of forest and scrub by 600 years B.P.
6000 years B.P.-750 years B.P.	2	Rapid spread of beech west of the Awatere; Inland Kaikoura range and Awatere valley remain in matai, totara and *Phyllocladus*. Occasional forest fires.
pre 6000 years B.P.	1	Matai and tree ferns abundant in Awatere valley; *Phyllocladus* and totara dominant forest on upper slopes. Forest fire occasional in region.

Rapid growth of the peat, and sedge dominance on the site, coincided with the major deforestation of the catchment and later increases in accumulation followed the introduction of grazing with associated modification of the surrounding vegetation and increased nutrient inputs. Without these major modifications of the vegetation and landscape, the bog vegetation may not have become productive enough to rapidly accumulate organic matter. Nevertheless, the fact that the peat accumulation rate, as determined by pollen concentrations, increased before deforestation may be an indication that there was also an increase in rainfall during the Polynesian era. However, other than the increased growth of the bog, there is no other evidence for this interpretation.

Conclusions

A summary of our vegetation history conclusions is presented in Table 3. Our results firmly establish that the Inland Kaikoura Range was fire-prone for most of the Holocene period, but that it was not until Polynesian settlement that fire frequency increased to such a level that permanent deforestation occurred. While it is clear that the range was mainly in mountain totara forest, some doubt remains as to the exact nature of the forest at lower elevations on the valley floors. In particular, our suggestion that matai and tree ferns formed part of these valley floor forests needs confirmation from other lines of evidence.

Inland South Island high country is valued by both visitors and pastoralists alike for its tussock-clad landscapes. It is clear now that for the most part these tussock landscapes are artificially maintained by fire, and that forest and scrub are the natural cover. While there is an understandable desire to both preserve the tussock and reduce fire, the historical record suggests that reduction of fire leads to replacement of tussocks by scrub and forest. Enrichment of the local flora by a number of exotic woody weeds, some well adapted to fire, has further tipped the balance in favour of woody growth and increased the complexity of the situation. The difficulties of maintaining fire-induced tussock grasslands are discussed in Rogers (1994). On the other hand, natural afforestation in the presence of exotic trees and shrubs is likely to result, at least in the short-term, in fire-prone mixed woodlands. Regardless of any other considerations, the historical and ecological value of the remaining forest remnants as examples of the natural vegetation cover is clearly high. Small wetlands in these drier areas of New Zealand, as typified by Winterton bog, are also not only important as ecological examples and reservoirs of species diversity, but are also extraordinarily valuable archives of environmental change.

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References

Allan, H.H. 1961. *Flora of New Zealand. Vol. I.* Government Printer, Wellington, New Zealand. 1085 pp.

Anderson, A.J. 1989. *Prodigious birds: moas and moa-hunting in prehistoric New Zealand.* Cambridge University Press, Cambridge, U.K. 238 pp.

Anderson, A.J.; McGlone, M.S. 1992. Living on the edge - prehistoric land and people in New Zealand. *In:* Dodson, J.R. (Editor), *The naive lands*, pp. 199-241. Longman Cheshire, Melbourne, Australia. 258 pp.

Bussell, M.R. 1988. Modern pollen rain, central-western North Island, New Zealand. *New Zealand Journal of Botany 26:* 297-315.

Clark, R.L. 1982. Point count estimation of charcoal in pollen preparations and thin sections. *Pollen et Spores 24:* 523-535.

Connor, H.E.; Edgar, E. 1987. Name changes in the indigenous New Zealand flora, 1960-1986, and *Nomina Nova* IV, 1983-1986. *New Zealand Journal of Botany 25*: 115-170.

Courtney, S; Arand, J. 1994. *Balaclava, Sedgemere and Dillon Ecological Districts. New Zealand Protected Natural Areas Programme No. 20.* Department of Conservation, Nelson, N.Z. 294 pp.

Cowan, H.A.; McGlone, M.S. 1991. Late Holocene displacements and characteristic earthquakes on the Hope River segment of the Hope Fault, New Zealand. *Journal of the Royal Society of New Zealand 21:* 373-384.

Dodson, J.R. 1978. A vegetation history from north-east Nelson, New Zealand. *New Zealand Journal of Botany 16:* 371-378.

Faegri, K; Iversen, J. 1964. *Textbook of pollen analysis.* Blackwell Scientific Publications, Oxford, U.K. 295 pp.

Healy, A.J.; Edgar, E. 1980. *Flora of New Zealand. Vol. III.* Government Printer, Wellington, New Zealand. 220 pp.

Kennington, A.L. 1978. *The Awatere: a district and its people.* Marlborough County Council, Blenheim, N.Z. 238 pp.

Macphail, M.K.; McQueen, D.R. 1983. The value of New Zealand pollen and spores as indicators of Cenozoic vegetation and climates. *Tuatara 26:* 37-59.

McCaskill, L.W. 1969. *Molesworth.* AH and AW Reed Ltd, Wellington, N.Z. 292 pp.

McGlone, M.S. 1982. Modern pollen rain, Egmont National Park, New Zealand. *New Zealand Journal of Botany 20:* 253-262.

McGlone, M.S. 1983. Polynesian deforestation of New Zealand: a preliminary synthesis. *Archaeology in Oceania 18:* 11-25.

McGlone, M.S. 1989. The Polynesian settlement of New Zealand in relation to environmental and biotic changes. *New Zealand Journal of Ecology 12:* 115-129.

McGlone, M.S.; Mark, A.F.; Bell, D. 1995. Late Pleistocene and Holocene history, Central Otago, South Island, New Zealand. *Journal of the Royal Society of New Zealand 25:* 1-22.

Moar, N.T. 1970. Recent pollen spectra from three localities in the South Island, New Zealand. *New Zealand Journal of Botany 8:* 80-145.

Moar, N.T. 1971. Contributions to the Quaternary history of the New Zealand flora: 6. Aranuian pollen diagrams from Canterbury, Nelson, and north Westland, South Island. *New Zealand Journal of Botany 9:* 80-145

Molloy, B.P.J.; Burrows, C.J.; Cox, J.E.; Johnston, J.A. 1963. Distribution of subfossil forest remains, eastern South Island, New Zealand. *New Zealand Journal of Botany 1:* 68-77.

Moore, L.B. 1976. *The changing vegetation of Molesworth Station, New Zealand, 1944-1971.* New Zealand Department of Scientific and Industrial Research Bulletin 217, Government Printer, Wellington, N.Z. 118 pp.

Nunn, P.D. 1994. Beyond the Naive Lands: human history and environmental change in the Pacific basin. *In:* Waddell, E.; Nunn, P.D. (Editors), *The margin fades: geographical itineraries in a world of islands*, pp. 5-27. Institute of Pacific Studies, The University of the South Pacific, Suva, Fiji. 297 pp.

Pocknall, D.T. 1980. Modern pollen rain and Aranuian vegetation from Lady Lake, north Westland, New Zealand. *New Zealand Journal of Botany 18:* 275-284.

Pocknall, D.T. 1982. Modern pollen spectra from mountain localities, South Island, New Zealand. *New Zealand Journal of Botany 20:* 361-371.

Rogers, G.M. 1994. North Island seral tussock grasslands: 1. Origins and land-use history. *New Zealand Journal of Botany 32:* 271-286.

Rogers, G.M.; McGlone, M.S. 1989. A postglacial vegetation history of the southern-central uplands of North Island, New Zealand. *Journal of the Royal Society of New Zealand 19:* 229-248.

Russell, J.B. 1980 (unpublished). *Aranuian pollen diagrams from montane Canterbury, New Zealand.* Ph.D. thesis, University of Canterbury, Christchurch, N.Z. 248 pp.

Sherrad, J.M. 1966. *Kaikoura.* Kaikoura County Council, Kaikoura, N.Z. 373 pp.

Sutton, D.G. 1994. Conclusions: origins. *In:* D.G.Sutton (Editor), *The origins of the first New Zealanders*, pp. 243-258, Auckland University Press, Auckland, N.Z. 269 pp.
Webb, C.J.; Sykes, W.R.; Garnock-Jones, P.J. 1988. *Flora of New Zealand. Vol. IV*. Botany Division, DSIR, Christchurch, New Zealand. 1365 pp.
Williams, P.A. 1989. Vegetation of the Inland Kaikoura Range, Marlborough. *New Zealand Journal of Botany 27:* 201-220.