Fire in wetlands and scrub vegetation: studies in Southland, Otago, and Westland

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Peter N. Johnson

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CONTENTS

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Peter N. Johnson

Landcare Research, Private Bag 1930, Dunedin, New Zealand
Email: JohnsonP@LandcareResearch.co.nz

A B S T R A C T

Increased fire frequency since human arrival in New Zealand has led to impacts on wetlands and scrub vegetation that are an issue for conservation management. This report describes studies in a selection of South Island sites, documenting patterns of vegetation recovery after fire, the roles and growth characteristics of manuka (*Leptospermum scoparium*) in fire-prone vegetation, fire-induced changes to wetland communities, and the role of fire in encouraging invasion by weeds. Management of fire and vegetation are discussed, and comments made on avenues for future research.

Keywords: New Zealand, fire, vegetation, wetland, scrub, shrubland, *Leptospermum*, *Sphagnum,* manuka, serotiny, conservation.

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1. Introduction

In ancient philosophy, fire was one of the four elements of our planet, alongside earth, water, and air. Fire is the combustion or burning of fuel, typically visible in the form of flames; a process that all organic matter (including ourselves) is poised to enter provided there is oxygen and a sufficient trigger of heat.

Much is known about the ecological significance of fire in other countries (e.g. Bond & van Wilgen 1996; Whelan 1995). In New Zealand, however, the role of fire in the ecology of ecosystems is poorly understood, especially its role in prehuman times. Prior to human colonisation, agents such as lightning and volcanism would have triggered natural fires, but at a much lower frequency (e.g. Ogden et al. 1998).

The topic of fire generates numerous questions for conservation management in New Zealand and elsewhere. For example, are some ecosystems and organisms adapted to fire, or demanding of it? What frequency of fire can be considered as 'natural'? Do fires ruin or enhance natural habitats, or (and to what extent) do they restart a natural cycle of plant growth, colonisation, and vegetation succession? Do frequent fires encourage invasion by weeds or pests? Can controlled burning reduce the potential impacts of accidental or unplanned 'hot' fires during dry seasons or drought years?

This report is a contribution towards understanding the dynamics of native wetland and shrubland communities in relation to fire, and aspects of their management, in the southern South Island. The present study has arisen from the needs of three southern conservancies of the Department of Conservation (DOC) for information about fire in vegetation. These were, in summary: fire and its association with increase of manuka[1] scrub on Awarua Bog (Southland Conservancy); the role of fire in scrublands (Otago Conservancy); and the role of fire in the ecology of pakihi and other wetland vegetation (West Coast Conservancy).

The studies reported here include some ongoing monitoring of post-fire recovery of wetland vegetation, observations on the structure of vegetation containing manuka and other colonist woody plants at different stages of post-fire succession, a limited amount of data on apparent serotiny (seed retention within insulated structures held on a parent plant until seed release is triggered by an agency such as fire) in manuka; and an account of vegetation structure and condition in a suite of Westland pakihi and other wetland habitats having a recent fire history.

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[1] Botanical names are listed in Appendix 1 for plants referred to in the text by common or abbreviated names.

2. Background

This investigation arose from expressions of research needs by Southland, Otago, and West Coast conservancies of DOC. These expressions by conservancies are summarised here, to highlight the numerous issues associated with fire ecology research.

2.1 SOUTHLAND

On the coastal margin of the Awarua Plain, extensive peatlands are protected, along with coastal lagoon and estuary vegetation, mainly in the Waituna Wetlands Scientific Reserve, Seaward Moss Reserve, and some smaller scenic reserves. Most of the vegetation comprises sedgeland, fernland, wire rushland, scrub, and cushion bog. This area has a long history of repeated fires, and much of the present vegetation may have been preceded originally by forest. One of the consequences of repeated fires appears to be that regenerating manuka is displacing low-stature vegetation types, including the cushion bogs. In this location, cushion bogs are considered to be unusual, as they occur almost at sea level (Ward 2001).

The following research questions were raised by Southland Conservancy:

- What have been the changes in vegetation composition, structure, and distribution following reservation of the Awarua Plain peatlands?
- Is post-fire succession returning the community to what it had been at some point in the past?
- What was the prehuman and pre-European condition of the Awarua Plain wetland complex?
- Is management required to maintain the cushion bogs in their current condition, i.e. will manuka establish in all cushion bog areas?
- Are soils or hydrology good predictors of vegetation succession in this wetland?
- How can the impacts of surrounding land use be avoided, remedied, or mitigated?

2.2 OTAGO

The relatively dry climate of inland Otago has contributed to the removal of forests by fire following human settlement, and to the ongoing vulnerability of native scrub remnants, especially those adjacent to tussock grasslands when these are accidentally burnt. Native scrub and shrubland remnants in Central Otago are important in their own right, but also as refugia for a distinctive fauna, including invertebrates, lizards, and birds.

The following research questions were raised by Otago Conservancy:

- What are the long-term impacts of fire on shrubland composition and structure, and the capacity of shrublands for recovery?
- What is the potential for post-burn invasion by exotic weeds?

- What is the potential for using prescribed cool burns of adjacent tussock to reduce the risk to shrublands of highly damaging hot fires?
- What options and strategies can be explored to protect shrubland from fire threats, e.g. grazing regimes, firebreaks?

2.3 WESTLAND

Pakihi wetlands are a distinctive feature of Westland. Some are natural and others have been induced through burning associated with logging and mining. Many are still burnt periodically to attract deer to the subsequent green flush or to aggravate DOC.

Research questions that have been raised by West Coast Conservancy:

- What is the effect of fire on the vegetation succession of pakihi wetlands?
- Does fire merely retard succession or does it change its trajectory?
- Do bird, reptile, and invertebrate communities re-establish in burnt pakihi? How long does it take for this to happen?

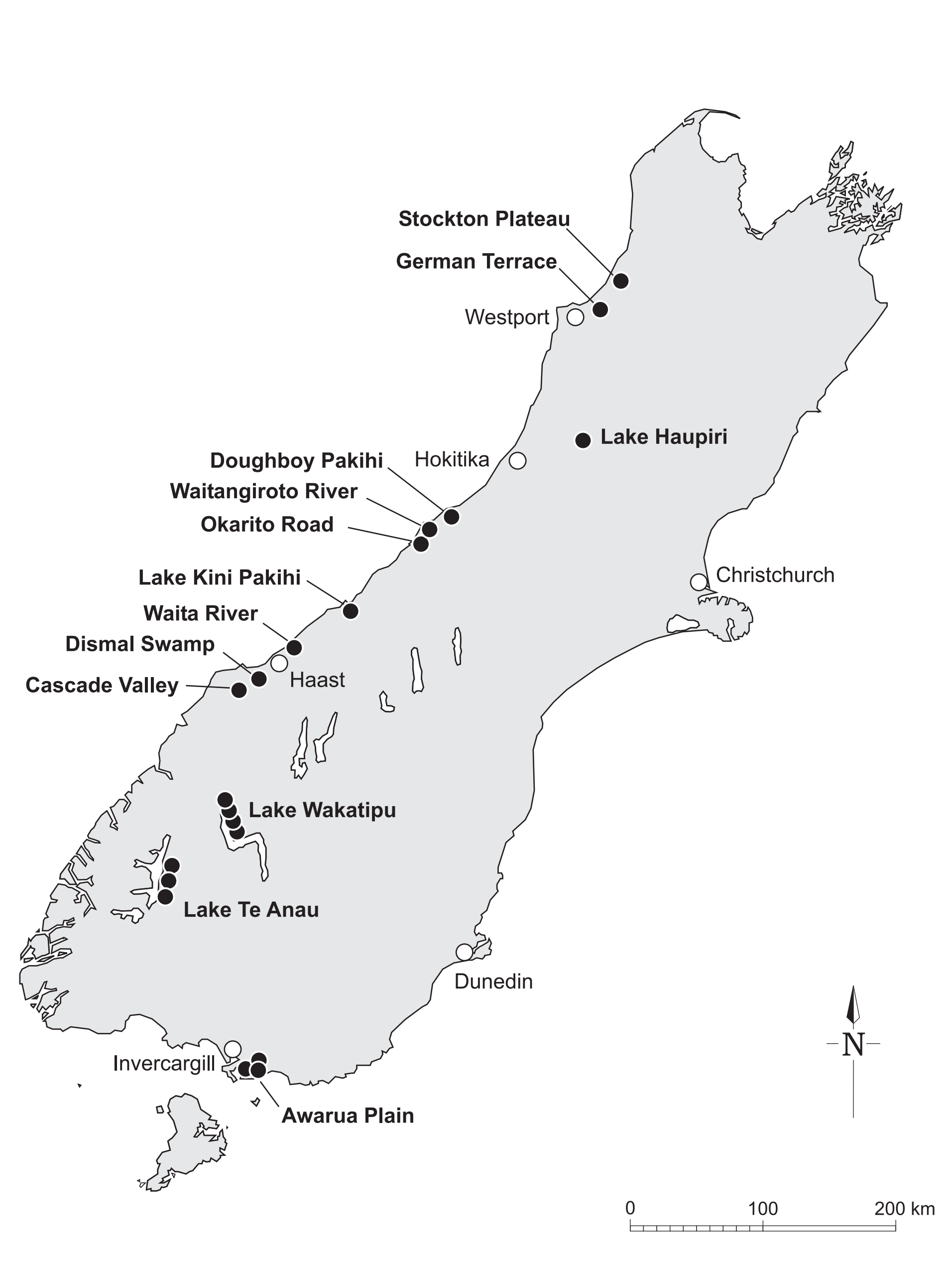
3. Objectives

- Visit selected sites in Southland, Otago, and Westland to assess the impacts of fire on a range of vegetation communities with varying fire histories.
- Document the fire history of selected study sites.
- Develop research proposals for more detailed investigations and experiments.

4. Study sites and methods

Study sites are located on the map (Fig. 1). A single sequence of site numbers (1–20) has been used for all the South Island sites. For the Awarua Plain sites a finer division (site 1A, 1B etc.) is applied to subsets of sampled vegetation covered by the same site map reference. Details of location, altitude, and recent fire history (where known) are listed in Table 1. Environmental data (from LENZ: Land Environments of New Zealand database) are listed for each site in Table 2. These indicate that all study sites have relatively low mean annual temperature and an annual rainfall that is, in general terms, sufficient to support forest vegetation. The sites having lowest rainfall are those at Lake Wakatipu, and these also have the greatest degree of water balance deficit (with rainfall : evapotranspiration values < 1.0). The Awarua Plain sites also exhibit a slight degree of water deficit, reflecting a climate that is subject to much wind, and therefore periodic proneness to fire. All Westland sites have plentiful rainfall, high humidity, and abundant excess of rainfall over potential evapotranspiration.

Figure 1. Fire in wetland and scrub vegetation—Southland, Otago and Westland study sites.



Study sites on the Awarua Plain were chosen to illustrate the broad range of age and size of manuka vegetation, and to include vegetation types that had been monitored in earlier years for post-fire recovery (Johnson 2001). Sites near Lake Te Anau were chosen to further the fire recovery study of Timmins (1992) and to illustrate the role of manuka in more advanced stages of post-fire succession nearby. Lake Wakatipu study sites were selected to illustrate some of the diversity of woody plant regeneration after fire. This portion of the study has been augmented by data collected in earlier years on the flora of fire-affected woody vegetation in this and other rainshadow southern lake basins. Westland study sites were selected to provide a broad north-to-south sequence with a diversity of pakihi, fen, and bog habitats, emphasising sites with a known fire history.

Fieldwork was conducted between March and June 2001 using qualitative field observations to record features considered to be informative of fire ecology at each site. Some quantitative data were gathered on canopy height, stem density and diameter, and estimated cover of manuka within 4 m × 4 m plots. Age of manuka at sample sites was based on growth ring counts of stem bases on one or two cut stems per site. Emphasis was placed upon recording the characteristics of manuka vegetation at all sites to provide a unifying theme to the overall study. Some sampling was done to assess the degree of serotiny of manuka populations, by counting numbers of closed and open capsules of the current and preceding seasons on selected canopy branches, the proximal end of the sampled branch being that point where stem diameter measured 6 mm (Bond et al. 2004). The observations on wetlands include comment on how the study sites fit within current thinking on wetland classification (Ward & Lambie 1999; Johnson & Gerbeaux 2004), insofar as this is relevant to understanding fire history of wetland vegetation.

TABLE 1. SOUTH ISLAND STUDY SITES.

SITE NO.	LOCATION	MAP	MAP REF.	ALTITUDE (m)	MOST RECENT KNOWN FIRE	TIME SINCE LAST FIRE
Awarua Plain						
1	Waituna coast	E 47	691 921	2		23+ years
2	Awarua Bog	E 47	568 954	10	Feb. 1985	16 years
3	Waituna Creek	E 47	683 024	15		25+ years
Lake Te Anau						
4	Eweburn Bog	D 42	025 308	260	Nov. 1985	16 years
5	Eglinton R. mouth	D 42	033 470	230		42+ years
6	Pleasant Bay	D 42	030 413	230		67+ years
Lake Wakatipu						
7	Bennetts Bluff	E 41	513 655	450		17+ years
8	Rees Valley	E 40	512 026	530		49+ years
9	Minor Peak	E 41	492 763	320		c.7 years
10	Rat Point	E 41	530 605	350		?50 years
Westland						
11	Stockton Plateau	L 29	174 480	700	Fire history not known	
12	German Terrace	K 29	984 333	130	Nov. 1998	3 years
13	Lake Haupiri	K 32	026 474	200	Late Nov. 2000	4 months
14	Doughboy Pakihi	I 34	995 930	5	29 Jan 1996	5 years
15	Waitangiroto River	H 34	863 810	5	Possibly never burned	
16	Okarito Road	H 35	836 693	70	Jan. 2001	2 months
17	Lake Kini Pakihi	G 36	368 294	5	24 Nov. 1995	6 years
18	Waita River	F 37	976 045	5	Possibly never burned	
19	Dismal Swamp	E 38	690 770	10	Dec. 1995	6 years
20	Cascade Valley	E 38	533 668	140		? 60+ years

Map references are to NZMS 260 series.

5. Results

5.1 VEGETATION RECOVERY AFTER FIRE: FURTHER MONITORING OF EARLIER STUDIES

This study provided an opportunity to make further observations at two Southland sites for which the earlier stages of vegetation recovery after fire had been already documented.

5.1.1 Awarua Bog

Recovery of vegetation in six peatland vegetation types on the Awarua Bog was described by Johnson (2001), from the monitoring of changes in plant composition and stature at nine sampling times over a 10-year period following fire in 1985. The situation after a further 6 years (i.e. in June 2001) was assessed by briefly noting plant height and composition at plot sites representing four of the pre-fire vegetation types: 'mixed bog' of *Baumea tenax*, tangle fern, wire rush, and shrubs; red tussock grassland; bracken fernland; and manuka scrub.

TABLE 2. ENVIRONMENTAL DATA FOR STUDY SITES: FROM LENZ (LAND ENVIRONMENTS OF NEW ZEALAND) DATABASE.

SITE NO.	LOCATION	MEAN ANNUAL TEMP. (°C)	MEAN ANNUAL RAINFALL (mm)	MEAN 9 a.m. HUMIDITY OF DRIEST MONTH (%)	RAINFALL : POTENTIAL EVAPOTRANSPIRATION RATIO
Awarua Plain					
1	Waituna coast	6.2	1065	76	0.88
2	Awarua Bog	6.3	1082	76	0.90
3	Waituna Creek	5.8	1054	76	0.89
Lake Te Anau					
4	Eweburn Bog	4.5	1305	74	1.08
5	Eglinton River mouth	4.5	1454	74	1.18
6	Pleasant Bay	4.9	1348	74	1.11
Lake Wakatipu					
7	Bennetts Bluff	4.4	982	69	0.76
8	Rees Valley	4.4	1762	73	1.35
9	Minor Peak	5.1	984	69	0.74
10	Rat Point	4.8	881	68	0.70
West Coast					
11	Stockton Plateau	4.2	5284	85	4.35
12	German Terrace	7.3	3429	81	2.72
13	Lake Haupiri	5.7	2854	79	2.40
14	Doughboy Pakihi	6.4	3182	80	2.52
15	Waitangiroto River	6.6	4025	78	3.11
16	Okarito Road	6.4	4159	78	3.23
17	Lake Kini Pakihi	6.7	3909	83	3.27
18	Waita River	7.2	4008	82	3.34
19	Dismal Swamp	7.6	4281	82	3.85
20	Cascade Valley	7.0	4645	80	4.23

Most plant species show no increase in their maximum height from year 10 to year 16. The two exceptions are manuka (2.1 m maximum height at 10 years, 2.8 m at 16 years) and tangle fern (0.4 m at 10 years, 0.7 m at 16 years).

Noteworthy changes in cover of dominant plant species from year 10 to year 16 are listed in Table 3. The cover of manuka increased slightly in three of the vegetation types, but decreased in the 'mixed bog'. Wire rush also increased in cover in the 'mixed bog' but decreased in the red tussock grassland. A very marked increase took place in the cover of tangle fern in both these vegetation types, from 2% maximum at 10 years to c. 20% at 16 years. The slow recovery of tangle fern within the first 10 years after fire was noted by Johnson (2001); it has largely recovered since then.

5.1.2 Eweburn Bog

Post-fire vegetation recovery on the Eweburn Bog, near Lake Te Anau, was recorded over a period of 55 months between November 1985 and June 1990 (Timmins 1992). My visit to the site in June 2001 enabled the observations to be extended a further 11 years, i.e. to 16 years after fire. Timmins (1992) recorded vegetation along five transects. I located one marker peg that would appear to tally with Timmins' transect 2 (table 4 of Timmins 1992), and recorded vegetation height and cover in a 4 m × 4 m plot in relatively uniform vegetation somewhere close to the previous transect 2.

Within the 5- to 16-year period following fire, the shrub tier has developed (which, in combination with the ground tier, accounts for the recorded 146% cover; Table 4). Shrubs have replaced the grasses and herbs of the initial colonising phase. The early resprouting sedge, *Baumea tenax,* has decreased in cover, while wire rush has maintained the 25% cover it had reached after 5 years. Tangle fern (= swamp umbrella fern), which Timmins recorded as

TABLE 3. ESTIMATED PERCENTAGE CANOPY COVER OF DOMINANT PLANTS IN FOUR VEGETATION TYPES ON THE AWARUA BOG, SOUTHLAND, AT 10 YEARS AND 16 YEARS AFTER 1985 FIRE.

VEGETATION	DOMINANT PLANTS	CANOPY COVER (%) 10 YEARS	16 YEARS	NOTABLE CHANGES OVER LAST 6 YEARS
'Mixed bog' (site 2A)	Manuka	55	30	Decrease
	Wire rush	14	30	Increase
	Baumea tenax	8	8	
	Tangle fern	0	20	Marked increase
Red tussock grassland (site 2B)	Wire rush	35	20	Decrease
	Baumea tenax	16	5	
	Red tussock	15	15	
	Manuka	12	20	Increase
	Gorse	0	8	
	Tangle fern	2	20	Marked increase
Bracken fernland (site 2C)	Bracken	17	15	
	Manuka	78	85	
Manuka scrub (site 2D)	Manuka	63	70	
	Bracken	4	10	
	Inaka	3	10	

having very limited recovery by 55 months after fire, had regained prominence within the 5–16 years after fire (Table 5), its relatively late recovery at Eweburn Bog being similar to that at Awarua Bog.

Timmins (1992) states: 'Recruitment of woody seedlings was scanty even at 55 months though the occasional seedling of manuka was noted establishing on old *Sphagnum* mounds as early as three months after the fire, and many tiny inaka seedlings were recorded 27 months after the fire in Transect 2'.

Plant heights and composition in 2001 are shown in Table 5. In the 11 years since sampling (Timmins 1992), woody species have attained a combined cover of 67%. Stems of manuka killed by the 1985 fire were still standing in 2001. Their mean height (3.9 m) was not reached by manuka regrowth (to 3.3 m) over the 16-year period. All other shrub species are of lower stature than the manuka regrowth. In the absence of fire it is probable that bog pine, inaka, and *Coprosma* spp. will assume greater cover, though without necessarily over-topping the manuka.

5.2 GROWTH RINGS ON MANUKA

Counts of growth rings on basal cut stems of manuka from both Awarua Bog and Eweburn Bog, at sites of known age since fire, allow for a comparison between expected age of manuka shrubs with that assessed by the ring counts.

At Awarua Bog, some manuka seedlings had been apparent 4 months after the January 1985 fire, with many more at 10 months, but few further recruits appeared at later sampling times (Johnson 2001). By June 2001 this cohort of manuka plants would be expected to show 15–16 growth rings; two cut stems had 14 and 15 rings.

TABLE 4. PERCENTAGE PLANT COVER AT SITE 4, EWEBURN BOG, SOUTHLAND, AT TWO PERIODS AFTER 1985 FIRE.

	COVER (%)	
	5 YEARS AFTER FIRE	16 YEARS AFER FIRE
Shrubs	6	69
Flax	0	5
Wire rush	24	25
Ferns	1	17
Baumea tenax	30	20
Other sedges	7	0
Grasses	5	0
Herbs	6	0
Mosses	9	10
Total cover (%)	88	146

TABLE 5. MAXIMUM HEIGHT AND ESTIMATED PERCENTAGE COVER OF DOMINANT PLANTS AT EWEBURN BOG, TRANSECT 2 SITE OF TIMMINS (1992) 16 YEARS AFTER FIRE. PLANT SPECIES ARE ORDERED FROM TALLEST TO SHORTEST.

PLANT	MAX. HEIGHT (m)	COVER (%)
Manuka	3.3	35
Coprosma sp. aff. *parviflora*	1.8	10
Bog pine	1.4	12
Coprosma propinqua	1.1	4
Flax	1.4	5
Coprosma elatirioides	0.7	6
Inaka	0.6	2
Baumea tenax	0.5	20
Tangle fern	0.5	12
Wire rush	0.4	25
Blechnum novae-zelandiae	0.4	5
Polytrichum sp.	0.2	10

At Eweburn Bog, occasional manuka seedlings appeared 3 months after the November 1985 fire (Timmins 1992). By June 2001, manuka plants would be expected to show a maximum of 16 growth rings; two cut stems revealed 13 and 15 rings.

These ring counts tally sufficiently closely with expected maximum ages, give-or-take the possible lack of a perceived growth ring being laid down in the first year, to give confidence to the generally held assumption that manuka growth rings provide a reliable measure of plant age.

5.3 STRUCTURE OF MANUKA VEGETATION, AWARUA PLAIN

The structure of manuka in vegetation of different ages after fire on peatlands of the Awarua Plain is illustrated by the profile diagrams in Fig. 2, and tabulated in Table 6. Site 1 shows very low-growing manuka adjacent to cushion bog just 20 m inland from the coastal storm beach. Site 1B in particular illustrates the effects of a high water table and severe wind exposure. Manuka grows with a high density of stems (608 live stems in a 4 m × 4 m plot) as a complete cover, excluding other understorey plants, and with a windshorn canopy: only 1.5 m tall, despite being 23 years old.

TABLE 6. CHARACTERISTICS OF MANUKA IN VEGETATION OF DIFFERENT AGES AFTER FIRE ON PEATLANDS OF AWARUA PLAIN, SOUTHLAND.

SITE NO.	CANOPY HEIGHT (m)	STEM DENSITY (4 m × 4 m PLOT)		COVER (%)	MAXIMUM BASAL DIAMETER (cm)	MAXIMUM AGE (y)
		LIVE	DEAD			
1A	0.5	280	0	71	1.5	13
1B	1.5	608	0	100	3.0	23
2A	0.7	7	0	8	1.4	14
2B	1.3	41	0	22	3.0	15
2C	2.8	58	17	85	4.2	15
2D	2.5	–	–	70	3.0	15
2E	3.2	–	–	95	5.0	18
2F	2.7	96	55	100	3.8	18
3A	8.3	8	15	35	10.1	25
3B	14.0	–	–	5	35.0	?100+

Site locations (map references are for map series NZMS 260, Sheet E47):
1A—Awarua Plain margin, cushion bog close to coast; 691 921
1B—Awarua Plain margin, hollow behind coastal storm ridge; 691 921
2A—Mixed bog (wire rush–tangle fern) burned in 1985; 568 954
2B—Red tussock bog burned in 1985; 568 953
2C—Bracken fernland burned in 1985; 567 954
2D—Manuka scrub burned in 1985; 565 955
2E—Manuka scrub beyond the 1985 fire margin; 565 955
2F—East of Tiwai Road, manuka scrub; 597 977
3A—Waituna Scenic Reserve, collapsing tall manuka close to forest edge; 683 024
3B—Waituna Scenic Reserve, manuka within margin of kamahi–matai forest; 683 024

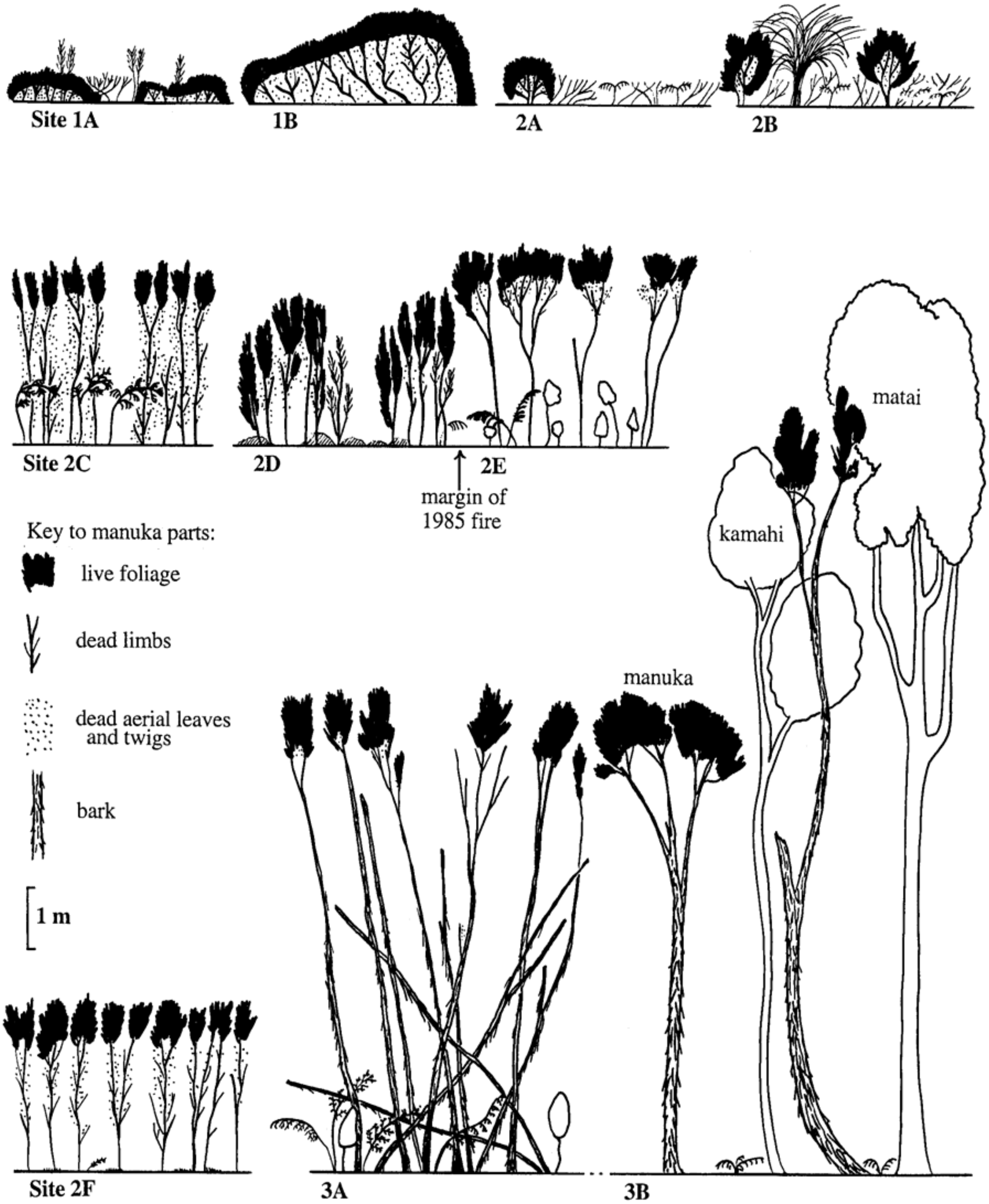


Figure 2. Profiles showing structure of vegetation dominated by manuka on peatlands of Awarua Plain, Southland. Refer to Table 6 for details of stand characteristics. The sites and their manuka ages are: 1A—cushion bog (6–13 years); 1B—hollow behind coastal storm ridge (23 years); 2A—mixed bog (wire rush–tangle fern; 15 years); 2B—red tussock grassland (15 years); 2C—former bracken fernland (15 years); 2D—manuka scrub (15 years); 2E—manuka scrub beyond the 1985 fire margin (18 years); 2F—manuka scrub (18 years); 3A—collapsing tall manuka close to forest edge (25 years); 3B—manuka within margin of kamahi–matai forest (100 years +).

Sites 2A to 2D show manuka structure in four of the vegetation types burned in 1985 (Johnson 2001; and see section 5.1). Vegetation on these four sites is the same age (15 years) since fire, but displays some of the plasticity of growth form and stature of manuka in different situations. Manuka regrowth is relatively low and sparse on those two sites, (which are on poorly drained peat—2A, the pre-fire 'mixed bog' and 2B the former red tussock bog) compared with that on better-drained peatland (2C, formerly bracken fernland on a scarp slope; 2D formerly manuka scrub on a slight crest). At site 2C, for example, the 15-year-old manuka is 2.8 m tall, forms 85% cover, and has 58 live stems, but also 17 dead stems in the 4 m × 4 m plot.

The slightly older manuka stands (18 years based on basal ring counts; these had escaped the 1985 fire), also on relatively well-drained peat, show how manuka at around 3 m tall can still be dense yet with many dead stems (site 2F). Whereas site 2F has 100% canopy cover of manuka, a high density of dead aerial material and litter, and deep shade beneath, site 2E shows a situation where the manuka canopy is slightly more open (95% cover) with an understorey of *Coprosma* shrubs and ferns.

Much-older manuka vegetation is present at sites 3A and the adjacent 3B, at Waituna Scenic Reserve, some 8 km inland on the Awarua Plain. These show the potential for manuka to grow very much taller, given longer fire intervals, lesser coastal exposure, and a relatively more fertile substrate where peat is augmented by stream alluvium. The manuka at site 3A has reached 8.3 m tall at an age of 25 years, and the stand is collapsing, with dead stems predominating and the live ones bearing sparse foliage. The adjacent site 3B, a fire-affected forest margin where peatland grades to floodplain alluvial soil, shows how old manuka can persist as spindly trees to 14 m tall among more long-lived tree species. These manuka were not aged, but the basal diameter of 35 cm suggests 100 years or more.

The profiles in Fig. 2 indicate the dead material, held upon aerial parts of manuka plants, which contributes to their flammability. Dense, relatively young stands contain many dead branches and fine twigs, especially at the stage (e.g. sites 2C, 2F) when intense competition is resulting in the death of many stems. In older manuka stands (e.g. site 3A) there are fewer dead stems of fine diameter, but the strips of hanging bark probably also contribute to the flammability of manuka vegetation.

5.4 POST-FIRE VEGETATION, TE ANAU BASIN

The role of manuka in post-fire vegetation on the east side of Lake Te Anau is illustrated by vegetation profiles in Fig. 3, and corresponding data on stand characteristics in Table 7. The land east of Lake Te Anau is mostly undulating moraine and glacial outwash channels, lying in the rainshadow of the Fiordland mountains. The broad west–east vegetation sequence, from forest to scrub to grasslands, reflects the decreasing rainfall eastwards. The forest near its eastern limit is mostly mountain beech, tolerant of dryness, but also susceptible to fire at times of drought, so the modern pattern of vegetation is a large-scale mosaic of beech forest, fire-induced bracken fernland, and various stages of scrub and forest regeneration.

Site 4 (Fig. 3) shows manuka at the Eweburn Bog site (see section 5.2), a wetland site where dead manuka stems from the 1985 fire are still visible, and where manuka regrowth over 15 years has reached a height of 3.3 m. In this

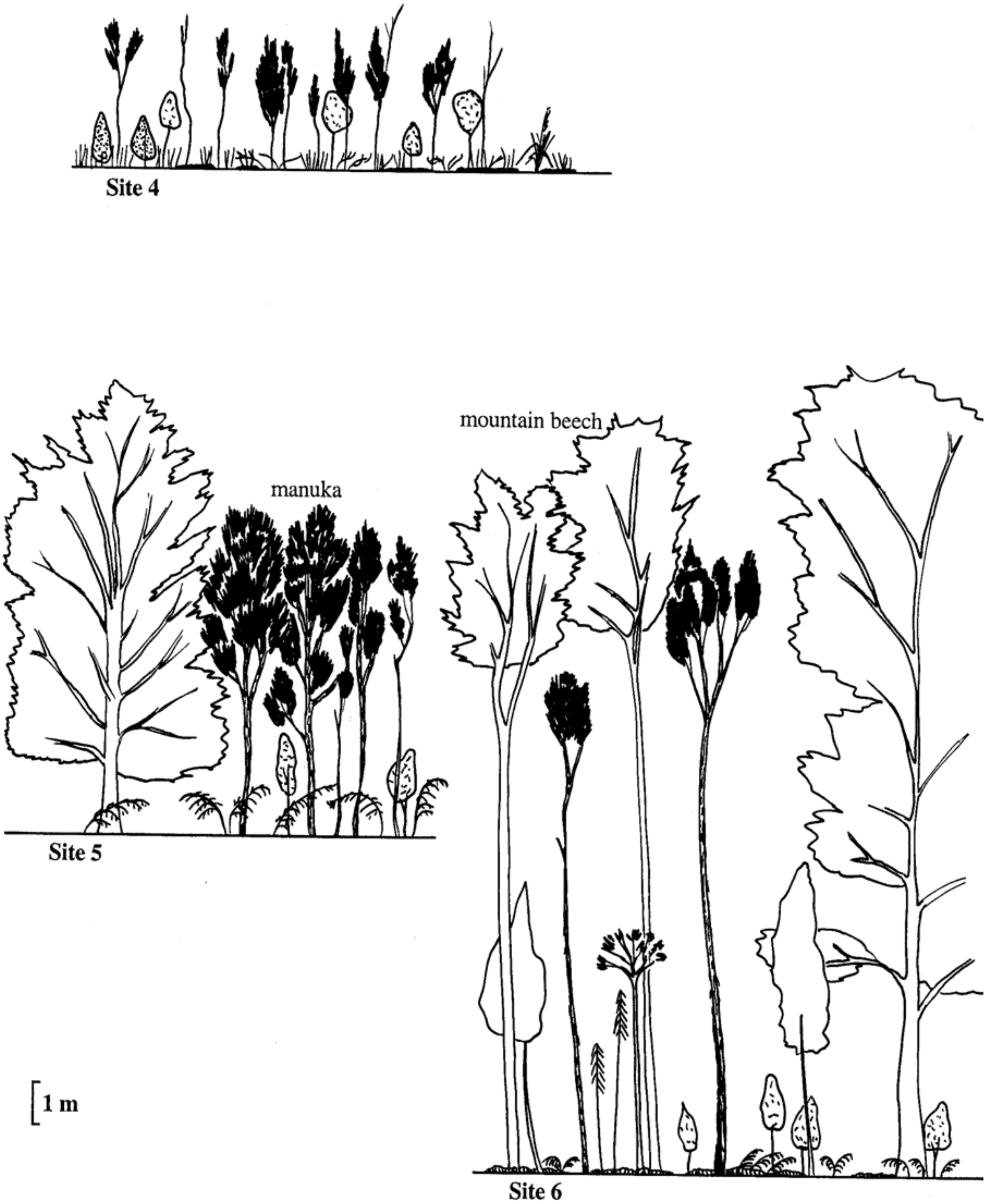


Figure 3. Profiles showing structure of vegetation containing manuka at three sites of different ages since fire near Lake Te Anau, Southland. Site 4—Eweburn Bog (16 years after fire); Site 5—Eglinton River delta (manuka age 27–42 years); Site 6—Pleasant Bay (manuka age 67 years). Refer to Tables 5 and 7 for details of stand characteristics.

vicinity, manuka plays a successional role in wetlands, and can persist as scattered shrubs in climax vegetation; while on impoverished drier soils of the surrounding moraine surfaces it forms successional scrub communities leading to forest. Site 5 upon moraine on the south side of the Eglinton River shows a post-fire succession where 42-year-old manuka forms an 80% cover at 11 m canopy height, above shrubs of *Cyathodes juniperina* and 2.5-m-tall bracken.

Manuka is being overtopped by mountain beech at this stage. Site 6 near Pleasant Bay shows more advanced succession to forest, with mountain beech 18–20 m tall, and remnant sparse manuka drawn to a height of 15 m. The 67 growth rings on one manuka indicate the time since the last fire.

5.5 POST-FIRE VEGETATION, WAKATIPU AND OTHER INLAND OTAGO LAKE BASINS

The lower hill slopes flanking Lake Wakatipu are dominated by bracken fernland, mostly probably induced from former forest by fires in prehuman as well as human times. Areas frequently burned, by pastoralists or accidental fires, can persist as bracken, but otherwise the successional trend is for invasion by shrubs and trees. Composition of the woody seral vegetation varies greatly, depending on soil depth, aspect, and position along the rainfall gradient, but two of the more common courses of woody plant regeneration after fire are shown by the examples profiled in Fig. 4.

5.5.1 Regeneration on shallow soils

Manuka plays a role in post-fire succession mostly on sites with relatively thin soils, especially those on glacially rounded knolls where the schist bedrock is near the surface. Site 7 is an example, where 17-year-old manuka 2.9 m tall and 35% cover (Table 8), grows with scattered kohuhu (2.0 m tall, age 10 years) and *Pinus radiata* (2.9 m; 9 years old). Cover of the lower tier (0.8–1.0 m) is bracken (50%) and shrubs of *Coriaria sarmentosa*, Spanish heath, *Coprosma lucida*, *C.* sp. aff *parviflora*, and *Gaultheria antipoda*.

TABLE 7. CHARACTERISTICS OF MANUKA IN VEGETATION OF DIFFERENT AGES SINCE FIRE AT THREE SITES NEAR LAKE TE ANAU, SOUTHLAND.

SITE NO.	CANOPY HEIGHT (m)	STEM DENSITY (4 m × 4 m PLOT) LIVE	DEAD	COVER (%)	MAXIMUM BASAL DIAMETER (cm)	MAXIMUM AGE (y)
4	3.3	28	2	35	4.4	15
5	11.0	35	1	80	14.1	42
6	15.0	9	9	20	16.0	67

Site locations: 4—Eweburn Bog; 5—Eglinton River delta; 6—Pleasant Bay.

TABLE 8. CHARACTERISTICS OF MANUKA IN VEGETATION OF DIFFERENT AGES SINCE FIRE AT TWO SITES OF DIFFERENT AGES SINCE FIRE NEAR LAKE WAKATIPU, OTAGO.

SITE NO.	CANOPY HEIGHT (m)	STEM DENSITY (4 m × 4 m PLOT) LIVE	DEAD	COVER (%)	MAXIMUM BASAL DIAMETER (cm)	MAXIMUM AGE (y)
7	2.9	23	0	35	7.1	17
8	5.5	52	14	75	9.5	49

Site locations: 7—South of Bennetts Bluff; 8—Rees Valley.

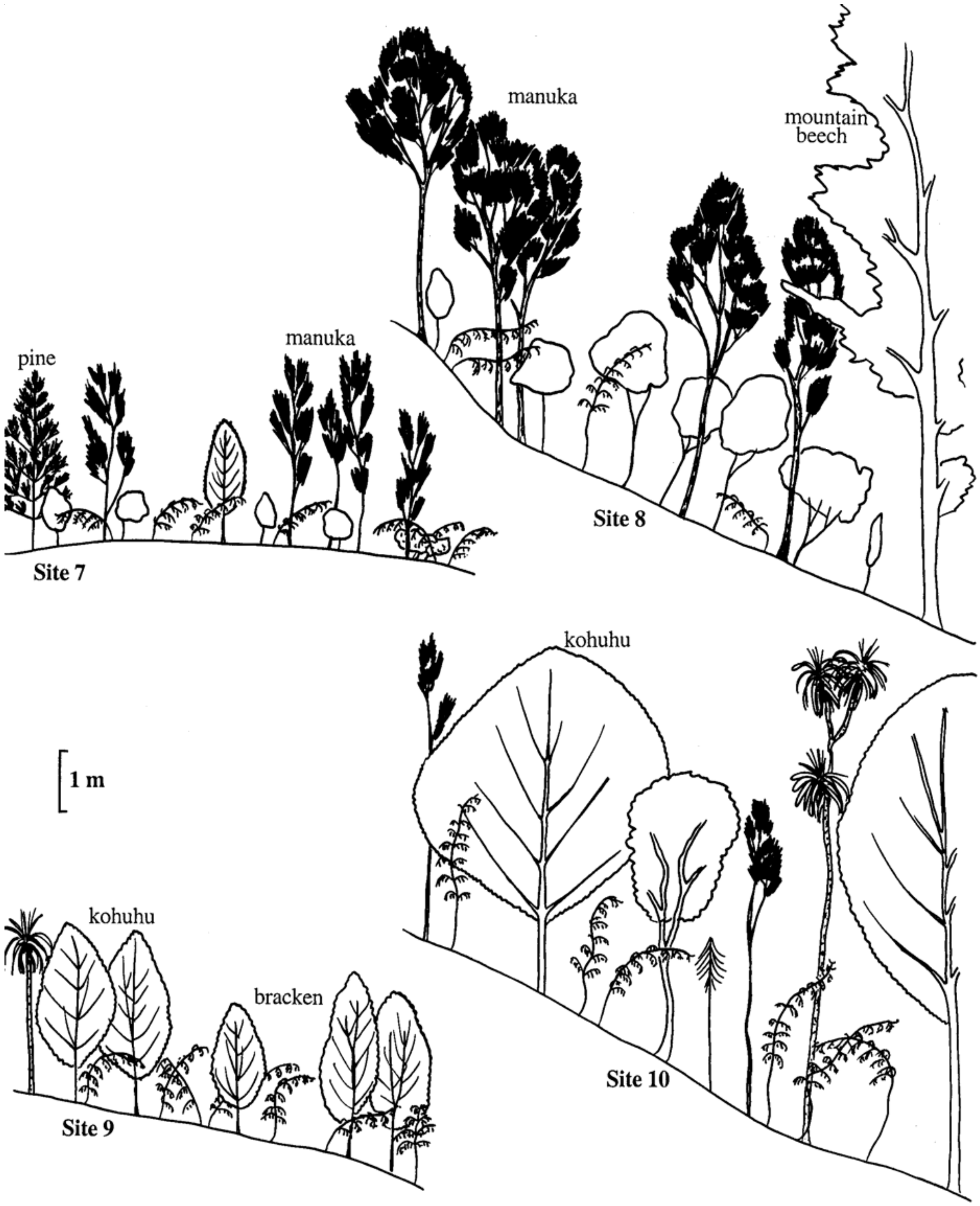


Figure 4. Profiles showing structure of vegetation at four sites of different ages since fire near Lake Wakatipu, Otago. Site 7—Bennetts Bluff (manuka age 17 years); Site 8—Rees Valley (manuka age 49 years); Site 9—below Minor Peak (kohuhu age 7 years); Site 10—Rat Point (c. 50 years after fire). Refer to Table 8 for details of stand characteristics.

Site 8 illustrates part of an older stand where manuka 49 years old is 5.5 m tall, with 75% cover, a reduced stem density (a quarter of the stems are dead), and an understorey of 2–3-m shrubs of mountain akeake (10% cover), mingimingi (10%), *Gaultheria antipoda* (10%), koromiko (10%), *Helichrysum aggregatum* (5%), mountain wineberry (5%), and matagouri (5%). At this site, at the head of Lake Wakatipu, the relatively higher rainfall facilitates mountain beech as the next successional stage.

5.5.2 Regeneration on deep soils

Kohuhu is the most conspicuous woody plant colonising bracken country in the Wakatipu Basin, especially on deeper soils where hillsides are mantled with ground moraine or colluvium. Site 9 shows a typical situation where burned bracken fernland has regenerated to relatively dense kohuhu, 3 m tall and 14 years old. Site 10 shows an older stage of post-fire regenerated forest, of likely age range 40–60 years, where the forest canopy reaches 8 m, the kohuhu (50% cover) shares dominance with three-finger (12%), marble leaf (10%), cabbage tree (5%), broadleaf (5%), lancewood (5%), tree tutu (5%), karamu (5%), and a few manuka, while the understorey still has abundant bracken as etiolated fronds to 3 m tall.

Table 9 lists the native and naturalised woody plant species of rain shadow vegetation flanking Lake Te Anau, Lake Wakatipu, and also Lake Wanaka where the landforms, climate, and vegetation patterns are broadly similar to those of the Wakatipu Basin. These data have been brought together from various earlier surveys and the author's unpublished observations. The second-to-last column of Table 9 notes the substantial number of tree and shrub species that are significant as colonists after fire, annotated as to their tendency to play a preferential role in revegetation upon either shallow or deep soils. The last column of Table 9 indicates the principal dispersal mechanisms of the woody flora. Of the total woody flora of 85 species, 63% are distributed by birds, 26% by wind, and 11% by other means (mainly gravity and water). These proportions are generally similar for the native, naturalised, and colonist-after-fire components of the flora.

5.6 WESTLAND FIRE AND WETLAND STUDY SITES

This section covers observations made on vegetation and fire impacts at a suite of Westland wetland and pakihi sites (see Fig. 1 for site locations, Fig. 5 for profiles of vegetation pattern at selected sites, Table 1 for site data, and Table 2 for environmental data). The following brief descriptions of each site provide a summary of landform, substrate, general vegetation pattern, and wetland types, and note the main points which each site illustrates about fire history and resulting vegetation.

5.6.1 Site 11 Stockton Plateau

An extensive undulating plateau, c. 5 km × 3 km, at 700–900 m a.s.l., of coal measure sediments, with very impoverished, shallow, mainly silty and sandy soils overlying bedrock. Soil depth and organic content are greater in subtle depressions and gullies, and these factors appear principally responsible for the vegetation pattern:

(a) Deep gullies with heath forest to c. 18 m tall of rimu, yellow silver pine, mountain beech, and southern rata.

(b) Depressions and gentle slopes with silty soils c. 1 m deep, with heath scrub 2–5 m tall of manuka, mountain beech, celery pine, and an understorey of sedges, wire rush, and tangle fern.

TABLE 9. NATIVE AND NATURALISED WOODY PLANTS OF RAINSHADOW VEGETATION FLANKING LAKES TE ANAU (T), WAKATIPU (K), AND WANAKA (W).

Abundance in each region is indicated by: a = abundant, f = frequent, o = occasional, r = rare.
Principal colonists following fire are annotated by: S = on shallow soils, D = on deeper soils.
Seed dispersal agents are annotated by: B = bird, W = wind, O = other means.

WOODY PLANT SPECIES		T	K	W	COLONISTS	DISPERSAL
Native						
Aristotelia fruticosa	mountain wineberry		o	r		B
A. serrata	wineberry	o	f	o	D	B
Calystegia tuguriorum	native bindweed		r	r		O
Carmichaelia petriei	native broom		r	o	S	O
Carpodetus serratus	marble leaf	o	o	o	D	B
Clematis paniculata	clematis	o	o	o		W
Coprosma crassifolia				o		B
C. foetidissima	stinkwood	a				B
C. linariifolia		o	o	o		B
C. lucida	shining karamu	f	f	a	S	B
C. sp. aff. *parviflora*		a	o	o	S	B
C. propinqua		a	f	o	S	B
C. rotundifolia		f				B
C. rugosa		r	o	o	D	B
C. virescens			r	r		B
Cordyline australis	cabbage tree	o	f	a	D	B
Coriaria arborea	tree tutu	a	f	f	D	B
C. sarmentosa	tutu	a	f	f	D	B
Corokia cotoneaster	korokio	f	o	a	S	B
Cyathodes juniperina	prickly mingimingi	a	f	o	S	B
Dacrycarpus dacrydioides	kahikatea	o				B
Dacrydium cupressinum	rimu	o				B
Discaria toumatou	matagouri	o	f	o	S	O
Dracophyllum longifolium	inaka	f				W
Fuchsia excorticata	tree fuchsia	r	r	r	D	B
Gaultheria antipoda	fool's beech	o	o	o	S	B
Griselinia littoralis	broadleaf	o	o	f	D	B
Halocarpus bidwillii	bog pine	f				B
Hebe salicifolia	koromiko	f	f	f	D	W
Helichrysum aggregatum			o	f	S	W
Hoheria glabrata	mountain ribbonwood		r			W
Kunzea ericoides	kanuka			f		W
Leptospermum scoparium	manuka	a	f	o	S	W
Lophomyrtus obcordata		o		r	S	B
Melicope simplex				o		O
Melicytus alpinus	porcupine shrub		o	o		B
M. ramiflorus	mahoe	r	o	o	D	B
Metrosideros umbellata	southern rata	r	r	r		W
Muehlenbeckia australis	muehlenbeckia	r	o	o		B
Myrsine australis	matipo	o	r	o		B
M. divaricata	weeping matipo	f	r	f	D	B
Neomyrtus pedunculata	rohutu	o				B
Nothofagus fusca	red beech	o	o			W
N. menziesii	silver beech	o	o			W
N. solandri var. *cliffortioides*	mountain beech	a	f	f	S	W
Olearia arborescens		r	r	o	D	W
O. avicenniifolia		o	o	f	S	W

Table 9 contd.

PLANT		T	K	W	COLONISTS	DISPERSAL
Ozothamnus leptophylla	cottonwood	r	r	r	S	W
Parsonsia heterophylla	native jasmine	o	o	o		W
Phyllocladus alpinus	celery pine	f			D	B
Pittosporum eugenioides	lemonwood		r			B
P. tenuifolium	kohuhu	a	a	a	D	B
Podocarpus hallii	Hall's totara	f	r	r		B
Prumnopitys ferruginea	miro	o				B
P. taxifolia	matai	r				B
Pseudopanax crassifolius	lancewood	f	o	o	D	B
P. colensoi	three-finger	o	d	o	D	B
P. ferox	fierce lancewood		r			B
Rubus cissoides	lawyer	o	r	r		B
R. schmidelioides	lawyer	o	f	f	D	B
Schefflera digitata	pate	r	r			B
Sophora microphylla	kowhai	r	o	o		O
Weinmannia racemosa	kamahi	f	r	r		W
Naturalised						
Berberis darwinii	Darwin's barberry	o			D	B
B. wilsonae				r		B
Buddleja davidii	buddleia		o		D	W
Cotoneaster spp.	cotoneaster	r	o	r	D	B
Crataegus monogyna	hawthorn		r	r		B
Cytisus scoparius	broom	a	o	o	D	O
Erica lusitanica	Spanish heath		f		S	W
Eucalyptus spp.	eucalypts	r	o	r	D	W
Euonymus europaeus	spindle tree			r		B
Larix decidua	larch		f		D	W
Leycesteria formosa	Himalayan honeysuckle	o	o	r	D	B
Lupinus arboreus	tree lupin	o	r	o	D	O
Malus domestica	apple	r	r			O
Pinus radiata	radiata pine		f	r	S	W
Pseudotsuga menziesii	Douglas fir		f	r	D	W
Ribes sanguineum	flowering currant		r	r		B
R. uva-crispa	gooseberry			r		B
Rosa rubiginosa	sweet brier		o	o	D	B
Rubus fruticosus	blackberry	r	r	r		B
Sambucus nigra	elder			r		B
Sorbus aucuparia	rowan	r	r	r		B
Ulex europaeus	gorse	o	o	o	D	O

(c) Planar or convex slopes with skeletal soils having low tangle fern, *Baumea tenax*, tetraria, wire rush, *Gahnia rigida* tussocks, and dwarf shrubs of manuka and *Epacris pauciflora*.

(d) Terracettes with loose quartz gravels, with a bog-like flora of donatia, square sedge, *Lycopodiella ramulosa*, sundews, and algal crusts.

(e) Gully heads with shallow peat, having bog vegetation similar to the third vegetation type above, but also with short tussock–sedgeland of *Chionochloa juncea* and *Carpha alpina*.

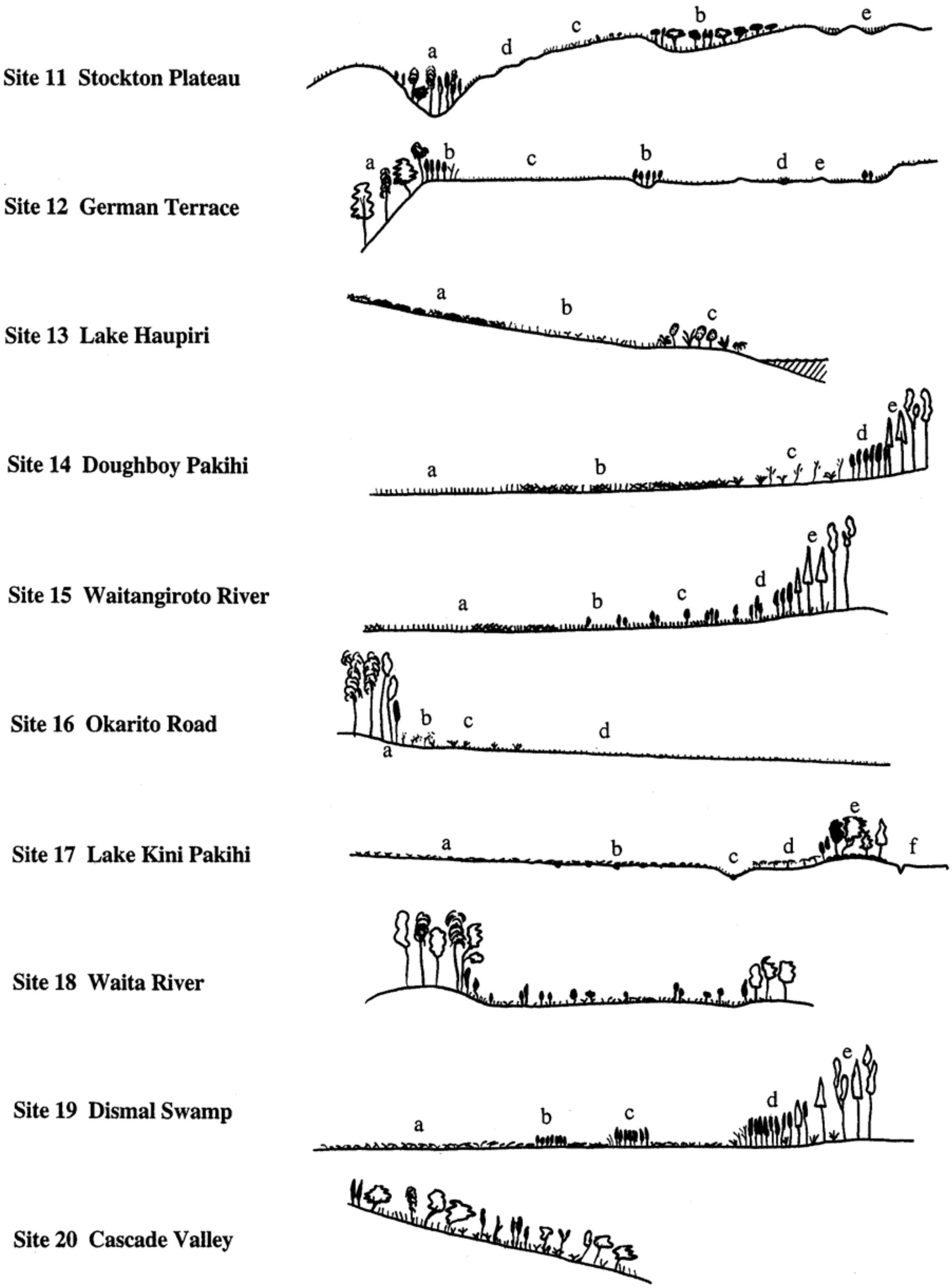


Figure 5. Profiles showing general pattern and structure of vegetation at West Coast study sites (not to scale).

The Stockton Plateau holds evidence of a long fire history. Charcoal is common in the soils and standing trees bear fire scars (Peter Williams, Landcare Research, pers. comm.). The pattern of tallest woody vegetation being restricted to deep gullies may be partly a factor of soil depth, but is likely to be have been accentuated by fire. Repeated and widespread fires, both pre- and post-human (Overmars et al. 1998) across this plateau have also probably been encouraged by the presence of coal deposits and by the extensive area of flammable heath vegetation.

5.6.2 Site 12 German Terrace

An extensive uplifted marine terrace (c. 2.5 km × 2.0 km, 130 m a.s.l.) covered with fluviatile gravels. Fire ecology of this pakihi has been described by Grainger (2000). In summary, the vegetation pattern is:

(a) Terrace scarp forest of hard beech, rimu, kamahi, and *Quintinia acutifolia*.

(b) Forest margin and gulley-head scrub of regenerating (post-1998 fire) manuka with bracken, tangle fern, and *Baumea teretifolia*.

(c) The main extent of level terrace surface with firm ground having various mixtures of manuka (dwarf plus prostrate forms), wire rush, tangle fern, and *Baumea teretifolia*.

(d) Damper ground in the numerous fingers of very slightly incised stream heads where wire rush and mosses are the main cover.

(e) Slight mounds between stream courses, very drought-prone, having extremely stunted *Baumea* sedgeland, much bare mineralised soil, and a partial cover of algal scum.

German Terrace represents a type of site that has had a long history of repeated fires, despite which the flora is relatively rich and mostly native.

5.6.3 Site 13 Lake Haupiri

The extensive wetland on the south-west side of Lake Haupiri is a gently sloping area c. 1.5 km × 1.3 km, of peat at least 2 m deep, with indicators suggesting a gradient of fertility increasing downslope towards the lake margin, and a resulting sequence from bog to fen to swamp vegetation. Observations were made here 4 months after a fire in November 2000.

(a) Bog, unaffected by recent fire: cushions of *Sphagnum subnitens* (30% cover), with interlacing wire rush (30%), tall protruding culms of *Baumea rubiginosa* (15%), flax (5%, just 1.5 m tall, indicative of low fertility), *Sphagnum cristatum*, and low shrubs of *Coprosma elatirioides* and *C.* sp. aff. *parviflora*. The effect of past fires on this vegetation has been to wholly consume some of the *Sphagnum*–wire rush cushions, or to leave fire-undercut pedestals 2–3 m across and 55–60 cm tall, this representing the depth of bog vegetation perched upon a basement of firmer peat which, in effect, is the fen substrate of the following:

(b) Fen, where the gentle peat slope is dissected by muddy hollows and runnels to 20 cm deep, and where the immediate post-fire cover comprises resprouted *Baumea rubiginosa* (30%), and a regenerated rush–herb sward of the naturalised plants *Juncus canadensis* (30%) and lotus (25%).

(c) Swamp in a c. 50-m zone adjacent to the lake, on peat with 30-cm hummock / hollow topography: shrubs of mingimingi (2 m tall, 15% cover), gorse (2 m, 10%), with flax (2.3 m., indicating greater fertility than upslope, 10%), sedgeland (30%) of *Carex secta*, *C. sinclairii*, and *C. gaudichaudiana*, and the naturalised plants *Juncus canadensis* (20%), lotus (10%), and *Galium palustre* (10%).

The recent fire did not kill all the woody plants. On 20% of both mingimingi and gorse shrubs about 10% of the canopy was alive. Some *Coprosma* shrubs were resprouting from the stem at ground level; gorse had resprouts to 20 cm long, on both basal and mid-level stems. Some lichens (*Usnea, Hypogymnia*) had survived fire even on *Coprosma* stems that had died and become brittle. Large tufted plants (flax, *Carex secta*, *Astelia grandis*) had been partly scorched or defoliated yet were all resprouting. Rapid recovery of the sedge *Baumea rubiginosa* has been from rhizomes. The abundant recovery of *Juncus canadensis* and lotus has probably been from seed. The main impact of recent fire here has been to remove the deep cushions of *Sphagnum* and wire rush. Germination of gorse seed has been stimulated, as has the growth of several weeds (*Juncus canadensis*, lotus, *Galium palustre*, *Holcus lanatus*, creeping buttercup), though their abundance will probably decrease as *Carex* spp. and other native sedges increase their cover.

5.6.4 Site 14 Doughboy Pakihi

This occupies a 1.0 km × 0.5 km depression behind a coastal sand dune at the mouth of the Wanganui River. It has dark, red-brown, fibrous peat, almost undecomposed, and a virtually level surface. The last fire here was in January 1996, 5 years before this survey. Vegetation pattern from the centre outwards:

(a) A central wet area of soft, quaking ground: *Baumea teretifolia* 90% cover with a little tangle fern and wire rush; this area might have escaped the last fire judging by the relatively large amount of dry *Baumea* litter.

(b) The main surface with uniform cover of wire rush (0.5 m, 50%), *Baumea teretifolia* and *B. tenax* (60 cm, together 30%), tangle fern (0.4 m, 20%), and *Lycopodium ramulosum* (10%).

(c) Near-perimeter zone of burned manuka bog, the dead manuka stems indicating a former canopy height rising from 1 m to 3.5 m across the zone; post-fire vegetation of manuka (0.6 m, 15%), *Gahnia rigida* (as conspicuous 1.5-m tussocks, 30%), *B. teretifolia* (30%), tangle fern (20%), and wire rush (10%).

(d) Perimeter zone, partially unburned, of 4-m manuka (90%) over *Gahnia rigida* (60%), tangle fern (30%), and flax (15%).

(e) Forest of silver pine and kahikatea.

Basically, Doughboy is a bog, though the effects of fire, in removing upper organic layers and releasing nutrients, have probably induced the character of a fen, and it does grade to flax swamp on the margin facing the river. Doughboy appears typical of relatively large basin wetlands that have had a history of repeated fires, in that it displays a relatively uniform main cover of sedgeland and wire rush, and with manuka scrub restricted to the perimeter, in contrast to the following site.

5.6.5 Site 15 Waitangiroto River

A wetland of c. 1.7 km × 0.5 km, situated south of the Waitangiroto River, relatively distant from a road or other easy access, and understood from local knowledge to have had no fire in the last 40 years. This is one of two wetlands in the Waitangiroto Nature Reserve for which Wardle (1980a) provided the following description: 'Two large infertile swamps are dominated by tangle fern, *Baumea teretifolia*, and wire-rush. Better-drained parts have been prevented by fire from developing to manuka scrub.' This wetland can be classified as fen, with much of it evolving to bog. The site examined did not appear to have had recent fire, judging from the gradual nature of the transition, over 100 m or so, from herbaceous fen through scattered manuka of increasing height, to silver pine forest (Table 10).

5.6.6 Site 16 Okarito Road

An open clearing of c. 1.3 km × 1.0 km, where frequent fires have pushed the scrub zone hard against the edge of the perimeter forest. Being alongside the road to Okarito Lagoon, the area is a ready and regular target for vandalistic fire. This pakihi site would probably have had the characteristics of a bog at an earlier time but, as a result of fires, it now has the character of a fen, having a slight slope, weakly decomposed peat that is dark grey-brown and fibrous in the top 20 cm, then brown and more sloppy beneath with wood fragments indicating a former scrub or forest cover. The ground surface is quite firm, recent fire having removed all soft surface cushions and litter, and revealing the normally hidden pattern of 15-cm-deep runnels in the firm peat surface.

At the time of study, 2 months after the latest fire, the notable visible features were:

(a) An abrupt forest margin with, at most, a very narrow band of manuka scrub.

(b) Gorse on parts of the margin, the former bushes 1–2.5 m tall, with resprouts to 15 cm long from the stem bases.

(c) *Gahnia rigida* resprouting from burnt bases, with foliage to 30 cm tall, the tussocks conspicuous, though only at 1–5% cover.

(d) A relatively uniform expanse of regenerating sedge-fernland containing:

TABLE 10. ESTIMATED PERCENTAGE COVER OF PRINCIPAL PLANTS IN A SEQUENCE OF ZONES SPANNING c. 100 m FROM HERBACEOUS FEN TO MARGINAL SCRUB AND FOREST AT WAITANGIROTO NATURE RESERVE, WESTLAND (SITE 15).

PRINCIPAL PLANTS		ZONE				
		a	b	c	d	e
		VEGETATION HEIGHT (m)				
		0.8	1.6	2.2	5.0	16.0
Empodisma minus	wire rush	50	35	35	30	
Baumea teretifolia		25	25	15	20	5
Gleichenia dicarpa	tangle fern	10	20	25	20	15
Gahnia rigida		8	10	10	5	20
Dracophyllum palustre	swamp neinei	5	5	5		
Leptospermum scoparium	manuka		5	25	35	5
Lagarostrobus colensoi	silver pine				20	30
Dacrycarpus dacrydioides	kahikatea					20
Dacrydium cupressinum	rimu					10
Astelia grandis	swamp astelia					10
Blechnum novae-zelandiae						10

- Bright green *Baumea tenax* 20–40 cm tall as regrowth from rhizomes (30% overall cover) and also masses of *B. tenax* seedlings 2 cm tall and locally to 20% cover.
- Former patches of wire rush 2–5 m wide evident from the pale colour of the surface roots, and from very scattered regrowth shoots to 8 cm long.
- The remains of former *Sphagnum* cushions 0.3 m tall and 0.3–1.5 m diameter, all dead.
- Regrowth of tangle fern 5 cm tall and 15% cover: a very early reappearance of this species compared with the lag of several years for its reappearance after fire on Southland sites.
- *Gonocarpus micranthus* 20% cover as a rapid recolonist after fire, undoubtedly from a soil seed bank.
- Forked sundew 5% cover, conspicuous in glistening red, as another colonist from the seed bank in a stage of immediate post-fire abundance.
- Mosses, mainly *Campylopus* spp. at 5% cover.

5.6.7 Site 17 Lake Kini Pakihi

An extensive wetland (c. 4.5 km × 3.0 km), its north-west margin displaying a transition from raised bog (last burned 6 years prior to study) to lagg stream to bog forest:

(a) Bog with fibrous red-brown peat, relatively soft and quaking with the water table at 10 cm depth during the dry spell at time of study. Main cover: wire rush 20–60% cover, but relatively dwarfed at only 25 cm tall, with some *Baumea teretifolia* and tangle fern, and a high cover (30–50%) of mosses (*Dicranum billardierei, Campylopus* spp., *Pulchrinodus inflatus*). *Sphagnum* is very localised.

(b) Numerous runnels to 20 cm deep and 30 cm wide, and also soft-based pools 1–3 m wide with cushions of *Centrolepis ciliata*, a carpet of *Campylopus clavatus, Drosera spathulata*, and floccose films of iron bacteria.

(c) Lagg stream with vegetation similar to second vegetation type above.

(d) Dense, tall tangle fern and partly burnt manuka 4–5 m tall.

(e) Forest bog of 8 m silver pine, yellow silver pine, celery pine, lancewood, manuka, over tall tangle fern and deep bryophyte carpets.

(f) Roadside ditch and highway.

5.6.8 Site 18 Waita River

A small bog (0.2 km × 0.2 km) with soft quaking peat in a slight depression on the inland side of a series of forested, former beach ridges, part of a much larger wetland complex, but this site relatively unlikely to have been burned, being small and surrounded by forest. Vegetation: manuka shrubs (0.8–2 m tall, 20% cover), scattered across the bog surface and around the margin, typically upon slightly raised portions of peat surface; scattered shrubs of *Dracophyllum palustre*, pink pine, and *Olearia laxiflora*; *Sphagnum cristatum* (40%), tangle fern (20%), *Baumea rubiginosa* (20%), *B. teretifolia* (5%), square sedge (5%), and *Blechnum novae-zelandiae* (5%).

The vegetation at this site has several indicators of lack of fire over recent decades. Manuka is present as round-headed shrubs suggestive of being relatively old, slow-growing, and of variable age, as opposed to dense even-sized vigorous stands that would follow a recent fire. There is a diversity of both shrub and herbaceous species. Wire rush was not recorded.

5.6.9 Site 19 Dismal Swamp

Dismal Swamp (more broadly, Sponge Swamp on the topographic map) is an area of bog c. 2.7 km × 2.0 km that occupies part of a coastal plain, is traversed by the road to Jacksons Bay, and has a history of repeated fires, one having occurred 6 years before these observations, which are close to the study sites of Mark & Smith (1975) and Scott & Rowley (1975) who have documented the sequence from bog to forest vegetation. My observations on composition concur with their studies; the vegetation of the open herbaceous bog, in particular, still being dominated by wire rush and the moss *Dicranum billardierei*. The profile in Fig. 5 summarises the general pattern and emphasises the presence here of patches of manuka of different stature that appear to represent how certain stands have variously escaped different fires:

(a) Bog of wire rush (40 cm tall, 60%), over *Dicranum billardierei* (20%), *Lycopodium ramulosum* (20%), *Centrolepis ciliata* (20%), and *Campylopus* spp.

(b) Manuka 1.5 m tall over 1-m-tall wire rush and tangle fern.

(c) Manuka 3.5 m tall over mainly 1.2-m-tall tangle fern.

(d) Manuka 7 m tall over tangle fern, *Gahnia rigida*, and young (2 m) silver pine.

(e) Forest of silver pine, rimu, celery pine.

5.6.10 Site 20 Cascade Valley

This site is a surface of moraine composed mainly of ultramafic material, having a thin stony soil that is drought-prone and very low in nutrients, but also poorly drained slopes where a shallow, slightly humic mineral soil has accumulated in seepages. The vegetation is low heath scrub and forest, having a generally similar woody flora on both dryland and wetland soils, though a greater abundance of sedges on the wetter parts. An undulating moraine-crest area of c. 2 km × 1 km of scrub and sedgeland to the west of Martyr Saddle appears to be fire-induced. Charred standing trunks are present. Air photos of 1953 indicate a low scrub cover, suggesting a fire date of at least 60 years ago. The vegetation now on a 20º slope of south-west aspect is woodland (30% cover) of 5–7 m manuka (15%), yellow silver pine (5%), pink pine, celery pine, southern rata, Hall's totara, and rimu, over sedgeland 0.9 m tall of *Baumea tenax* (70%), *Schoenus pauciflorus* (5%), tangle fern (10%), wire rush (5%), square sedge (5%), and *Gahnia procera* (5%).

5.7 WEEDS OF WETLAND SITES IN WESTLAND

Naturalised plants were recorded from Westland wetland study sites as follows:

- Stockton Plateau (site 11): Yorkshire fog (*Holcus lanatus), Juncus articulatus, J. bulbosus, J. canadensis, J. squarrosus*.
- Lake Haupiri (site 13): creeping bent (*Agrostis stolonifera*), *Carex vulpinoidea, Galium palustre,* Yorkshire fog*, Hypochoeris radicata, Juncus*

canadensis, lotus, creeping buttercup, *Schedonorus phoenix, Senecio jacobaea,* gorse.

- Doughboy Pakihi (site 14): lotus.
- Okarito Road (site 16): gorse.

No naturalised plants were noted at other Westland study sites. The absence or relatively small number of naturalised plant species from most of the 'pakihi' habitats visited can probably be ascribed to their very low nutrient status. By contrast, the larger number of weed species at Lake Haupiri reflect the more fertile soils of the fen and swamp habitats there. No obvious encouragement of weed species by fire can be concluded from these observations, with the exception of gorse which has established on the margins of the frequently burned Okarito Road wetland.

5.8 NEW RECORDS AND APPARENT SPREAD OF *Sphagnum subnitens*

Nine species of *Sphagnum* moss are known in New Zealand (Fife 1996) and *S. subnitens* is one of those having a relatively localised distribution, being known in New Zealand only from Westland, though it is otherwise known from the Northern Hemisphere. Suggestions have been made that this species could have been introduced to New Zealand. Its apparent increase on the West Coast may be, in part, an artefact of increased intensity of field observations in wetlands, or it may be a real change, resulting from the extent to which new habitats have been created for this and other *Sphagnum* spp. that are wont to colonise wet areas of cutover or burnt forest. The species preferred by the moss harvesting industry are the more robust species *S. cristatum* and *S. australe*. By contrast, the more wispy *S. subnitens* ('weasel moss') is regarded as something of a nuisance, needing to be separated out from the more desirable material at the sorting and drying stage, and because it is not selected for harvest it probably increases at some collecting sites, aided also by the disturbance accompanying moss picking.

Notwithstanding these factors, *S. subnitens* does seem to have increased its geographical extent in the last decade or so. Whereas at the time of field investigations on *Sphagnum* (Buxton et al. 1990, 1991, 1995), it was not observed south of Ianthe Forest, my observations in 2001 have recorded it as far south as Dismal Swamp, south of Haast. At this site and also at Okarito Road Pakihi, vigorous cushions of *S. subnitens* were noted only in wetlands adjacent to the road, giving the appearance of having recently colonised.

It is not yet clear to what extent the colonisation of wetlands by *S. subnitens* might be encouraged by fire, but this question could be addressed by ongoing monitoring of wetlands. Table 11 lists the currently known distribution based on records held in the Allan Herbarium, Lincoln, and recent collections.

5.9 SEROTINY IN MANUKA POPULATIONS

Serotiny is the production of closed cones or seed capsules, leading to the delayed liberation of seeds. Capsule opening generally requires extreme temperatures, such as those associated with fire. Table 12 summarises observations on the proportions of open and closed capsules recorded on a sampling of manuka plants for most of the South Island study sites. Observations of the 'current year' were made in June 2001 for the Awarua, Te Anau, and Wakatipu sites, and in March 2001 for Westland sites. With the exception of site 8 (Rees Valley), virtually all capsules of the current year were closed. The capsules of the current year are not a reliable indicator of serotiny. More informative are the data from one-year-old capsules. At most sites all capsules were open and had released their seed. But four sites (1—Waituna coast; 2—Awarua Bog; 7—Bennetts Bluff; and 11—German Terrace) showed the opposite trend, with the proportion of closed capsules ranging from 65% to 91%. These data suggest that genotypes adapted to fire have been selected for, with the inference that these sites may have experienced relatively frequent fires, a topic that will be further discussed below.

TABLE 11. DISTRIBUTION OF *Sphagnum subnitens* IN WESTLAND, BASED ON RECORDS HELD IN ALLAN HERBARIUM (CHR) AND RECENT COLLECTIONS; LISTED IN NORTH-TO-SOUTH ORDER.

LOCATION	MAP	MAP REFERENCE	COLLECTOR(S)	YEAR
Stockton Plateau	L 29	175 442	D. Glenny	1998
German Terrace	K 29	972 330	D. Glenny	1985
German Terrace	K 29	974 328	P. Johnson	2001
Paparoa Range, Omanu Creek	K 29	939 291	D. Glenny	1996
20 km south of Westport			J. Child	1983
Maher Swamp	K 30	713 914	P. Johnson	1996
Four Mile River Pakihi	K 30	833 116	D. Glenny	1997
Big River Pakihi, Reefton	L 31	186 833	D. Glenny	1986
Waiuta goldmine	K 31	080 812	D. Glenny	1985
Waiuta	L 31	115 794	P. Johnson & R. Buxton	1989
Mossy Creek	K 31	061 783	D. Glenny	1985
Pattison Creek, Ahaura River	K 31	067 646	P. Johnson	1990
Pattison Creek, Ahaura River	K 31	064 643	D. Glenny	1985, 1986
10 km south of Greymouth			J. Child	1983
Lake Haupiri	K 32	024 473	P. Johnson	2001
Dillmanstown	J 32	608 360	A. Dobson	1971
Hokitika airport	J 32	45- 30-	R. Buxton	1994
Kawhaka Forest	J 33	631 289	P. Johnson & R. Buxton	1989
Kawhaka	J 33	626 284	P. Johnson & R. Buxton	1989
Mahinapua walkway	J 33	415 216	P. Johnson	2001
Ianthe Forest	I 34	155 977	P. Johnson & R. Buxton	1989
Waitangiroto River	H 34	863 810	P. Johnson	2001
Okarito Road Pakihi	H 35	832 693	P. Johnson	2001
Dismal Swamp	E 38	689 771	P. Johnson	2001

6. Discussion

6.1 VEGETATION RECOVERY IMMEDIATELY AFTER FIRE

The sequence of vegetation recovery in the initial years after fire on peatlands and wetlands has now been relatively well-documented for several sites throughout New Zealand, e.g. McQueen & Forester (2000) for Kaimaumau gumland, Northland; Clarkson (1997) for Waikato peatlands; Wardle (1977) for Westland; Timmins (1992) for Eweburn Bog near Te Anau, Southland; and Johnson (2001) for Awarua Bog, Southland. The general pattern from these studies is one of rapid resprouting by those plant species—especially rhizomatous sedges—having fire-resistant below-ground stems, in combination with plants which establish from seed, mainly in the first year or two after fire, when there is a high proportion of bared ground. Plants establishing from seed include pioneering herbs and grasses, both native and naturalised, that are abundant for just a few years, and woody plants which gradually assume greater cover as they gain height and shade out the pioneers. Weedy plants that gain a foothold immediately after fire, and persist, are mostly woody species.

For several of the above study sites, the authors note a return to pre-fire composition and vegetation stature after about 10 years, but that observation partly reflects the fact that the 'pre-fire vegetation' had, itself, been affected by earlier fire. Although these study sites have fulfilled their initial purpose of

TABLE 12. INDICATIONS OF SEROTINY IN MANUKA AT SOUTH ISLAND STUDY SITES: PERCENTAGE OF CLOSED CAPSULES HELD ON MANUKA PLANTS.

SITE NO.		NUMBER OF PLANTS SAMPLED	CURRENT YEAR		ONE-YEAR-OLD		TWO-YEAR-OLD	
			TOTAL CAPSULES	% CLOSED	TOTAL CAPSULES	% CLOSED	TOTAL CAPSULES	% CLOSED
Awarua Plain								
1	Waituna coast	10	330	97	93	65		
2	Awarua Bog	5	328	99	80	95		
3	Waituna Creek	2	53	100	186	0		
Lake Te Anau								
4	Eweburn Bog	5	110	100	184	3		
5	Eglinton River mouth	5	29	100	135	0		
Lake Wakatipu								
7	Bennetts Bluff	5	147	99	274	91		
8	Rees Valley	5	134	0	80	0		
Westland								
11	Stockton Plateau	1	0	–	9	0	4	0
12	German Terrace	8	317	100	413	81	143	42
13	Lake Haupiri	2	113	100	58	0	7	0
15	Waitangiroto River	2	3	100	21	0		
16	Okarito Road	1	73	100	31	0		
17	Lake Kini Pakihi	2	0	–	15	0	5	0
19	Dismal Swamp	6	168	100	179	1		
20	Cascade Valley	5	21	100	140	14	58	0

study of immediate post-fire recovery, the sites do offer the potential for longer-term study of vegetation trends which, in some cases, will be documenting the effects of inevitable repeat fires and, in other cases, following the course of extended fire-free periods. For either eventuality, these study sites should be regarded as valuable documented baselines. Accordingly, DOC conservancies should ensure that study site locations are precisely documented with GPS methods, such as would often not have been available at the time the study sites were established.

6.2 STRUCTURE OF MANUKA VEGETATION

The environmental tolerances of manuka in New Zealand are exemplified by its broad latitudinal distribution, diversity of habitats, and ability to grow in both wet and dry soils (e.g. Burrell 1965; Esler & Astridge 1974; Esler & Rumball 1975). Its genotypic variability and phenotypic plasticity (Yin et al. 1984) enables it to grow as a prostrate mat, bushy shrub, or small tree, depending on site conditions, and to assume each of these growth forms in sequence as it ages. The profile diagrams of Figs 2–4 illustrate how the height, architecture, canopy cover, and stem density of manuka vary at different ages and stages of post-fire vegetation. These diagrams also hint at two aspects of manuka structure that must be relevant to the fire ecology of manuka, and which would be pertinent topics for more detailed study: firstly, the degree of canopy cover insofar as this affects understorey shade and hence the composition and establishment rate of plant species that will eventually replace fire-induced manuka; and secondly, the relationships between stand age, density, and fuel load. It is probable that dense stands of manuka, at an age when competition between individuals is intense and there is a high biomass of dead leaves, twigs, and limbs held in an aerial (above-ground) position, will be the most prone to fire. On the Awarua Plain peatlands, it would appear that this would especially be the case in manuka stands 15 to 18 years old (Fig. 2C to 2F).

6.3 SEROTINY IN MANUKA

The phenomenon of manuka exhibiting serotiny in some New Zealand habitats and the implications of this for selection of fire-adapted populations has been recently reported by Harris (2002) and Bond et al. (2004). As part of a study on flowering patterns in 61 cultivated provenances of manuka, Harris made the serendipitous observation that inherent variation of capsule splitting suggests that fire-adapted genotypes have been selected for since human settlement. He relates his observations of manuka being most strongly serotinous in northern latitudes of New Zealand to those areas that would have experienced frequent fire where Maori populations were most intensive.

The study by Bond et al. (2004) had the deliberate aim of assessing serotiny by field observation in 45 widely scattered South Island populations of manuka. Their results show that manuka populations tend to be either non-serotinous or serotinous, with only a few populations of intermediate character. They conclude that serotinous populations are not related to fire history per se, but are strongly related to areas having sufficient size and lack of geographic obstacles to fire spread such that frequent and severe landscape-scale fires can occur. For areas of wetland and pakihi, serotiny was found especially in sites exceeding 30 km^2.

My observations of apparent serotiny in manuka (see section 5.9), despite being based on a small sample set, nevertheless tally with those of Bond et al. Of my four sites exhibiting high proportions of closed manuka capsules, sites 1 and 2 on the coastal margin of Awarua Plain match the serotiny recorded by Bond et al. for their [Seaward] Moss Reserve site; site 11 (German Terrace) has high serotiny values like their values for other large areas of pakihi in North Westland; and site 7 (Bennetts Bluff, Lake Wakatipu) exhibits marked serotiny, comparable with the similar Lakes Hawea–Wanaka habitats sampled by Bond et al.

What implications might manuka serotiny have for conservation management? Might ongoing frequent fires on wetland sites such as those in South Westland lead to serotinous populations starting to be selected for in land areas of smaller extent than those recognised by Bond et al. as serotiny-inducing? If, on the Awarua Plain peatlands, an increase in fire frequency since human arrival has, indeed, been a selection influence for a manuka population that releases vast amounts of seed after each fire, then might this explain the apparent recent increase in manuka? Over the last few decades, areas of cushion bog dominated by donatia have been encroached upon and invaded by manuka (and also inaka), leading to the shading-out of the cushion communities (Ward 2001). Among the factors that have been suggested as possible contributors to this process are hydrological change, climate change, increase in nutrient levels in the peatlands, and changes resulting from fire. Certainly, fire can destroy or weaken the cushion plants (Johnson 2001). Fire consumes litter as well as surface layers of uncompacted peat, accentuates wind-drying and surface runoff of rain, and adds ash-fall nutrients to sites, like the cushion bogs, which would naturally have very low soil fertility. Repeated fires have probably brought about a compounding increase in manuka abundance and seed source, i.e. something of a snowballing effect, whereby manuka assumes a greater presence after each fire. Fire-selection of serotiny then becomes a further adaptation in favour of manuka.

The topics of serotiny and, indeed, of selection for other fire adaptations, have only recently been considered for New Zealand vegetation, and much remains to be investigated. Harris (2002) points the way to further experimental observations on fire-adaptive characteristics of manuka, including flammability of different essential oil chemotypes, heat responses of different capsule types and their seed, and determination of genetic differences between New Zealand and Australian populations of *Leptospermum scoparium*.

6.4 AWARUA PLAIN PEATLANDS

An unanswered question that keeps arising in relation to conservation management of the Awarua peatlands is: what was the original vegetation? This could be refined to asking: what was the prehuman vegetation; and what native vegetation types might potentially still occupy the area in relation to soils and present climate?

Given the large extent of the present-day manuka scrub, fernland, sedgeland, and rushland cover of the Waituna, Seaward Moss, and Toetoes peatlands, it is easy to regard this as being something close to the 'original' plant cover. Yet there is good evidence for a former forest cover. Wood of former forest trees is often exposed by drains dug in the peat (see fig. 129 in Johnson & Gerbeaux 2004). Johnson (2001) records the identity of wood samples (rimu, totara, manuka and, possibly, kanuka) buried in peat near the present edge of Awarua Bay, some kilometres distant from any surviving forest remnants. Much of that wood is charred, indicating that the former forest was destroyed by fire. What we do not know is the age of that deforestation, and nor do we know what the long-term history has been of fires across these peatlands, especially in relation to human influences. There is thus a need for studies of environmental history of these peatlands, based on peat corings, analysis of macrofossils, pollen, spores, and charcoals, and radiocarbon-dating.

Another approach that could be used towards reconstructing a model of former and potential vegetation cover would be to understand the sequences of peat types that occur across the slightly undulating landforms, in relation to those which still support a native forest cover, e.g. in parts of the Toetoes peatlands. My general conclusion is that much of the Awarua Plain margin would have had some form of podocarp-broadleaved forest, probably upon any surface which today holds manuka, and that such forest would have formed a mosaic pattern, closely surrounding those numerous peat pools and patches of cushion bog which still survive upon the slight crests of land, and intersected by stream channels which would have had relatively narrow margins of flax swamp and red tussock fen.

One further clue to the type of vegetation that would be present if fires had been less frequent still exists on those tiny islands within peat pools that have escaped fires. One example, having kamahi and other broadleaved tree and shrub species, is described by Johnson (2001). Other such islands are also present across the peatland complex, and it would be an informative exercise to document the vegetation of each. Aside from the challenge of locating the sites and gaining access, this would be a straightforward descriptive project that could be undertaken by conservancy staff or as a student project.

This question as to what was the original vegetation of these burnt landscapes may seem somewhat academic, but without some better answers to it, as a contribution to long-term conservation goals, then management of the peatlands can only continue on a short-term cycle of trying to minimise the extent of inevitable future fires, and controlling the weeds, such as gorse, that benefit from every burn.

6.5 POST-FIRE VEGETATION OF SOUTHERN INLAND LAKE BASINS

The extent to which fire has removed and reduced tall forest and other woody communities in the rainshadow basins of the great southern lakes is exemplified by the situation in the upper Clutha district, documented by Wardle (2001a, b). Using evidence from soil charcoals, field studies of remnant stands of forest and scrub, and early surveyors' records, Wardle describes a pattern of past and present vegetation sequences along the steep rainfall gradient. His broad story is one of prehuman fire, especially of former celery pine but also of kanuka and manuka, contraction of podocarp forests and fragmentation of beech forests especially within the period of Maori presence, then post-1850s fires that burned up to previous forest boundaries. He briefly describes the ability of kohuhu and other broadleaved trees to invade bracken and form a continuous canopy if they escape fire long enough.

The data presented in sections 5.4 and 5.5 provide a brief and simplified picture of some of the early stages of post-fire recolonisation of bracken country in southern lake basins. The courses of succession are considerably more complex, depending on position along the overall rainfall gradients, altitude, aspect, soil parent materials, fire frequency, soil seed banks, and proximity to seed sources. Examples of various woody communities that have developed over relatively long fire-free periods are present on islands within lakes such as Wanaka and Hawea (e.g. those described in Scenic Reserve surveys in Allen 1978, Ward & Munro 1989). These habitats offer much prospect for further study of fire ecology and regeneration of woody vegetation in inland Southland and Otago. Such further understanding is especially relevant for any future conservation management aimed at long-term restoration of native woody vegetation, as has been proposed for Central Otago by Walker et al. (2003).

Many of the naturalised woody species recorded from around Lakes Te Anau, Wakatipu, and Wanaka are relatively localised in their present distribution, yet, like most weeds, are poised to spread further, a process that for many of them will be encouraged by fire creating opportunities to establish in well-lit and freshly disturbed habitats. The threats posed by wilding trees (especially conifers and eucalypts) and by legume shrubs (gorse, broom, tree lupin) are already well known. Among other wind-distributed weeds, Spanish heath and buddleia are two shrubs that appear to be on the increase in the Wakatipu Basin, and both are capable of invading ground bared by fire. Fleshy-fruited shrub weeds that are already familiar foes in conservation lands include blackberry, sweet brier, Himalayan honeysuckle, elder, and hawthorn. Attention is drawn, however, to species that are less well known as environmental weeds, but which appear to be on the increase in these lake basin seral communities, notably rowan, spindle tree, flowering currant, cotoneasters, and (at Te Anau) Darwin's barberry.

6.6 WETLANDS AND FIRE IN WESTLAND

Much has been written, and conjectured, about the origins and processes of West Coast wetlands, vegetation, and soils, and the degree to which fire is an important factor. 'Pakihi' is a frequent and readily recognisable vegetation / habitat type, but is hard to define. Pakihi vegetation in its various forms and stages has been described from many sites by Rigg (1962) and Williams et al. (1990). Mew (1983) discusses pakihi in terms of the various soil sets associated with different landforms, and summarises hypotheses that have been advanced to explain their distribution, including natural and man-induced fires, changes in soil physical and chemical characteristics, and regional climatic variation.

Typical pakihi vegetation (stunted manuka and other shrubs with wire rush and tangle fern) falls within the general umbrella of heathland (Burrows et al. 1979). Such vegetation can occur not only on highly infertile extreme gley podzol soils, but also on sites where forest has been logged or burnt, and again in wetlands, with or without a fire history. Wardle (1977) notes the similar assemblage of species between his 'infertile swamp' and that of 'natural pakihi'. His diagram showing primary succession of lowland plant communities illustrates the complex relationships and trends in relation to age of surface and topography (Wardle 1980b).

In their outline of New Zealand wetland classification, Johnson & Gerbeaux (2004) recognise the wetland class 'pakihi and gumland' as being characterised by mature or skeletal soils of very low fertility and low pH, wholly mineral or sometimes with peat, rain-fed and with poor ability to transport water, frequently saturated but seasonally dry. Following this circumscription, most of the Westland study sites described in Section 5.6 are not pakihi, but instead are complexes of bog, fen, and swamp upon peat substrates. Nevertheless they display various degrees of fire-affected vegetation that demonstrate stages towards the heathland cover typical of frequently burned pakihi vegetation upon mineral soils, such as that of German Terrace (site 12).

In those Westland study sites that have no recent history or evidence of fire, e.g. Waitangiroto River (site 15) and Waita River (site 18), the wetlands have a pattern of a broad marginal zone of scrub that rises gently in height towards the surrounding forest margins, the presence of manuka but also of several other shrub species, and an occurrence of shrubs as small clumps within the body of the wetland. *Baumea* sedges and *Gahnia* tussocks are common, and although wire rush and tangle fern may be present, they are not necessarily dominant. In wetlands in a similar setting but with a history of recent fires, e.g. Doughboy (site 14), Okarito (site 16), and Dismal Swamp (site 19), the scrub ecotones against forest margins are much more abrupt, manuka is much the most common shrub species and often forms apparently even-aged stands, and the herbaceous vegetation of the main wetland body is predominantly wire rush and tangle fern.

Many of these wetland sites can be classified as fens: peatlands that are on slightly sloping ground, which receive inputs of groundwater from adjacent forest slopes. They are therefore somewhat more fertile than bogs (which receive water only from rain), and less fertile and less watery than swamps. Nevertheless, such fen surfaces can develop surface vegetation that has a bog character, as peat accumulates to a dome that is raised above groundwater influence (as at Lake Kini 'Pakihi'). One effect of fire is to retard this process, by consuming the deep, soft layer of *Sphagnum* cushions and associated perched bog plants, as seen at Lake Haupiri (site 13). An advanced stage of this process is seen at Okarito Road (site 16), where repeated fires have reduced the wetland surface to the level of compacted peat.

In one sense, these frequently burned Westland wetlands have a certain resilience to fire in that recolonisation is almost wholly by native plants (although there is a tendency for a few weeds, notably gorse, to establish on the margins of burnt areas). But in the long term, say over forthcoming centuries, repeated fire will impact upon peat accumulation and the ongoing natural process of wetland growth. From another perspective, that of recognising some strictly pakihi sites as having originated and been maintained by natural (non-human) fire, then, as discussed by Williams et al. (1990), such areas may need fire as a management tool in order to retain their distinctive biota and dynamic nature.

7. Conclusions

At all the sites visited for this study, regrowth following fire has been principally by native plants, but the frequency of fire is such that at most sites the vegetation does not have the opportunity to proceed through a full successional course back to forest or to wetland vegetation having an 'original' or potential composition and pattern. Fire has the general impact of reducing diversity of native woody species. Although manuka often plays a rapid and useful role in re-establishing a native plant cover after fire, it is likely that repeated fire encourages manuka to become more abundant after each fire event, and that this response may be accentuated by selection, perhaps even over a few generations, of manuka populations exhibiting enhanced degrees of serotiny. On the Awarua peatlands, Southland Conservancy staff are undertaking experimental treatments on the effectiveness of removing manuka that is invading cushion bogs. This is an appropriate research exercise that will help in understanding the dynamics of these lowland cushion bog communities.

Fire does not confer any benefits to the conservation values, ecological processes, or biota at any of the study sites. Nor do any of the sites suggest themselves as candidates for controlled burning. From a management perspective, fire should continue to be guarded against in all these ecosystems, using the established approaches of fire contingency plans, fire-fighting, education for community awareness and, where possible, prosecution of offenders known to have caused deliberate fires. None of the study sites would seem amenable to fire protection by the use of firebreaks or grazing regimes.

The possibility of accidental fires is always present, of course, though this risk may now have diminished in areas such as the Awarua Plain and the Te Anau Basin where fires associated with development of agricultural land adjoining conservation land are probably less frequent than they were several decades ago. In the Wakatipu, Wanaka, and Hawea basins, the risk of accidental fires may increase with growing population and tourist pressures, while the burning of pastoral land is an ongoing tradition. Fires in bracken country inevitably affect regenerating scrub and forest, including that on conservation land. Any future prospects for reducing fire frequency and fire impacts in this country will require a much increased awareness of fire risks to regenerating vegetation, increased advocacy of conservation and landscape values, and much cooperation between conservation agencies and landowners.

Invasion of fire-prone vegetation by woody weeds is an ongoing issue, and one which will become more of a problem in the future, as existing weeds become more widespread, and as new ones make their presence felt. On the peatlands of the Awarua Plain, and in some of the Westland wetlands, gorse poses a considerable threat. It is readily able to resprout and expand its margins after fire. One strategy that should be put into action is to control gorse populations that occur close to fire-prone wetland sites. Another is to have contingency plans in place for control of gorse regrowth and seedling establishment on wetland and peatland sites within 2 years of any fire. Such timing takes advantage of the relatively easy access across wetland surfaces soon after fire, as well as aiming to prevent post-fire gorse from producing further seed.

A large number of woody weed species are present in the southern lakes basins. Their spread is inevitable, especially in the wake of repeated fires creating open habitats, and the need for their control will be on-going. Management of woody environmental weeds on conservation land cannot be effectively done in isolation. Effective weed management strategies are needed, involving DOC and regional and district councils. The author's view is that DOC should play a lead role in this matter. One of the biggest problems with weeds is that their phases of establishment, quiescence, and spread so often go unnoticed or unattended. The establishment phase is a critical one, when control action is most likely to be effective and inexpensive, yet when attention is drawn to a newly establishing weed species there is seldom any urgent control action taken, a situation which is in contrast to the rapid response that can be made to an outbreak of fire or the escape of an animal pest. The author also believes that, as an agency having a high awareness of environmental weeds, DOC should be proactive in developing policies and contingency plans for immediate action on newly discovered weeds.

Several topics for future research are mentioned in the discussion sections above, and can be summarised as follows:

- It is desirable to record precise locations of post-fire vegetation study sites, such as those on the Awarua peatlands, using GPS methods, which were not available when the studies were initiated.
- A fuller understanding of the original (and potential) vegetation of the Awarua peatlands should be sought via studies on peat history, identification and distribution of wood in the peatlands, modelled reconstruction of likely former vegetation by comparing soils and hydrological factors with those under surviving forest, and a documentation of forest remnants on peat pool islands that have escaped fires.
- Many aspects of fire-adaptive characteristics of manuka remain to be studied in more detail.
- The patterns and sequences of post-fire successions towards native scrub and forest in southern inland lake basins have yet to be studied in any detail. Studies in relation to fire history, seed sources, and weed invasion would be informative, not only for managing habitats in these basins, but also in developing long-term strategies for woody plant re-establishment on conservation lands in the drier parts of inland Otago.

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Appendix 1

BOTANICAL NAMES OF PLANTS REFERRED TO IN TEXT BY COMMON OR ABBREVIATED NAMES

blackberry	*Rubus fruticosus*
bog pine	*Halocarpus bidwillii*
bracken	*Pteridium esculentum*
broadleaf	*Griselinia littoralis*
broom	*Cytisus scoparius*
buddleia	*Buddleja davidii*
cabbage tree	*Cordyline australis*
celery pine	*Phyllocladus alpinus*
cotoneaster	*Cotoneaster* spp.
creeping buttercup	*Ranunculus repens*
Darwin's barberry	*Berberis darwinii*
donatia	*Donatia novae-zelandiae*
elder	*Sambucus nigra*
epacris	*Epacris pauciflora*
flax	*Phormium tenax*
flowering currant	*Ribes sanguineum*
forked sundew	*Drosera binata*
gorse	*Ulex europaeus*
Hall's totara	*Podocarpus hallii*
hard beech	*Nothofagus truncata*
hawthorn	*Crataegus monogyna*
Himalayan honeysuckle	*Leycesteria formosa*
inaka	*Dracophyllum longifolium*
kahikatea	*Dacrycarpus dacrydioides*
kamahi	*Weinmannia racemosa*
kanuka	*Kunzea ericoides*
karamu	*Coprosma lucida*
kohuhu	*Pittosporum tenuifolium*
koromiko	*Hebe salicifolia*
lancewood	*Pseudopanax crassifolius*
lotus	*Lotus pedunculatus*
manuka	*Leptospermum scoparium*
marble leaf	*Carpodetus serratus*
matagouri	*Discaria toumatou*
matai	*Prumnopitys taxifolia*
mingimingi	*Coprosma propinqua*
mountain akeake	*Olearia avicenniifolia*
mountain beech	*Nothofagus solandri* var. *cliffortioides*
mountain wineberry	*Aristotelia fruticosa*
pink pine	*Halocarpus biformis*
red tussock	*Chionochloa rubra*
rimu	*Dacrydium cupressinum*
rowan	*Sorbus aucuparia*
silver pine	*Lagarostrobus colensoi*
southern rata	*Metrosideros umbellata*
Spanish heath	*Erica lusitanica*
spindle tree	*Euonymus europaeus*

Appendix 1 continued:

square sedge	*Lepidosperma australe*
sundews	*Drosera* spp.
sweet brier	*Rosa rubiginosa*
tangle fern	*Gleichenia dicarpa*
tetraria	*Tetraria capillaris*
three-finger	*Pseudopanax colensoi*
tree lupin	*Lupinus arboreus*
tree tutu	*Coriaria arborea*
wire rush	*Empodisma minus*
yellow silver pine	*Lepidothamnus intermedius*