

The Impact of Fire on Tasmanian Alpine Vegetation and Soils

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Abstract

Observations were made across 11-40-year-old fire boundaries in Tasmanian alpine areas of varying macroenvironment and flora. Surface soil organic matter and total nitrogen were significantly less where the vegetation had been recently burned. There were no significant differences between recently burned and recently unburned plots for phosphorus, potassium, calcium, sodium and pH. The burned plots contained few or no gymnosperms or deciduous shrubs, the most frequent dominants of the unburned vegetation. Most other shrubs were markedly less important in the burned than in the unburned plots, although most species of bolster form were little affected by fire, and some composite shrubs were most abundant on the burned plots. Most herbaceous species had equal or higher cover on the burned plots than on the unburned plots. The burned vegetation of the eastern mountains appeared to regenerate more quickly than that of the more oligotrophic western mountains.

Introduction

The combination of fire and stock grazing has had well documented deleterious effects on the soils, vegetation and economic values of the Australian alpine zone (e.g. Edwards 1973; Jackson 1973; Wimbush and Costin 1979). However, there are few published data quantifying the effects of fire in the absence of grazing for the Australian mainland (Good 1973), and none for Tasmania, which has a far more varied alpine flora and vegetation than the northern island (Kirkpatrick 1982, 1983).

Previous descriptive studies of Tasmanian alpine vegetation (Jackson 1973; Kirkpatrick 1977, 1980, 1983, 1984a; Kirkpatrick and Harwood 1980) and palynological work (Macphail 1981) have suggested that the local extinction of species and long-term vegetation changes have resulted from one or more fires. Yet, 16.1% of the area of alpine vegetation of Tasmania was burned in the period 1960-80 (Brown *et al.* 1983a). To assess the significance of this datum, we use quantitative soil and vegetation data from recently burned (10-40 years ago) and adjacent long unburned (*c.* 100 years-? since the last fire) areas to answer the following questions. What are the fire regeneration characteristics and relative speeds of recovery of the major alpine higher plant taxa? What post-fire changes occur in dominance, community cover, community heterogeneity and species richness? What medium-term changes to soils result from firing of long unburned alpine vegetation? Do the soil, species and community changes vary along the major environmental gradients? We also review the evidence relating to fire-caused long-term changes to alpine soils and vegetation and discuss the management implications of our major conclusions.

0067-1924/84/060613\$02.00

Methods

Selection of Study Sites

Mt Field and Mt Read were selected as the major study areas because their alpine areas contained burns of known age (Table 2) adjacent to vegetation with no evidence of previous fire, because no more than a 3 h walk was required to reach the most remote of these fire boundaries and because their flora and vegetation were well separated on the gradient related to precipitation and parent material (Kirkpatrick 1982, 1983). Quantitative information on vegetation change across fire boundaries was available from four other mountains, indicated in Fig. 1. Details of data collection from these latter mountains are given in Table 4.

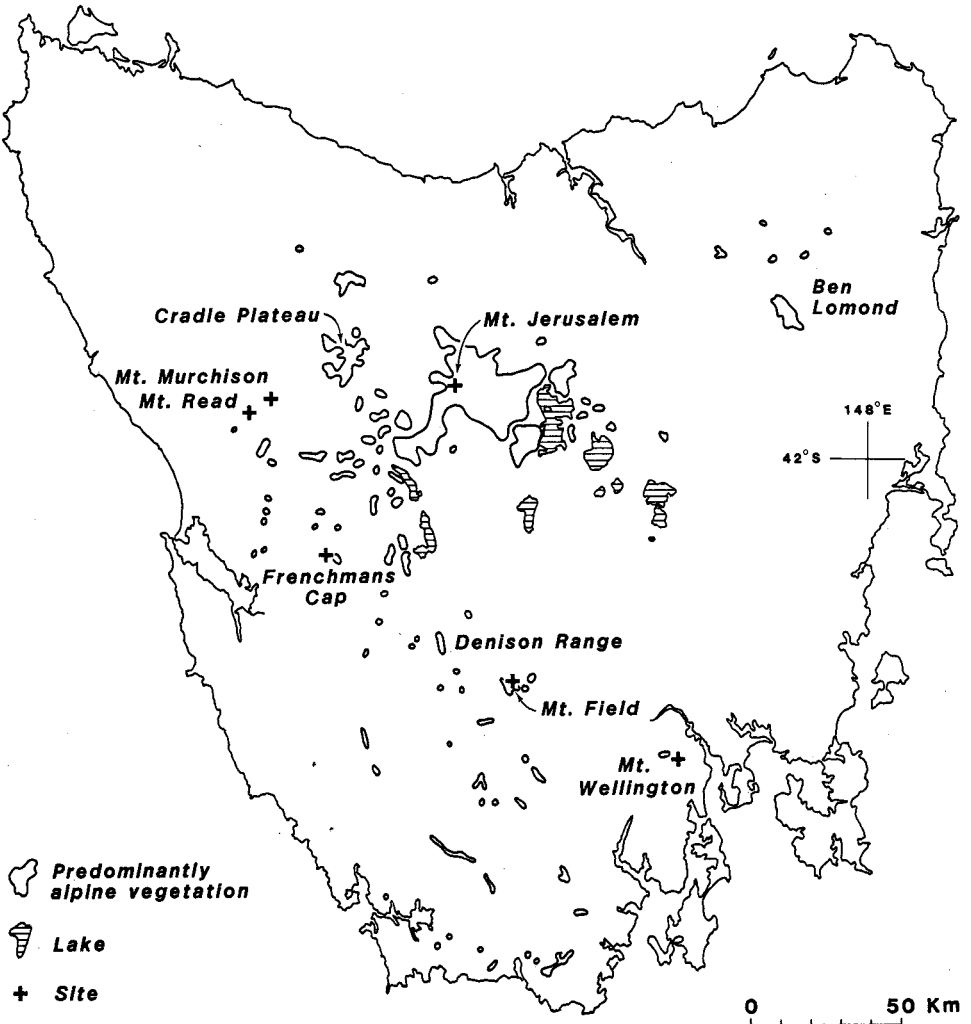


Fig. 1. Map of the distribution of treeless high mountain vegetation in Tasmania showing the locations mentioned in the text. Areas from which fire boundary data were obtained are marked by a plus sign.

Field Methods

At each of the two main study sites, paired quadrats, 5×5 m, were located 1 m on either side of and parallel to the fire boundaries during the summer and autumn of 1980–81. Care was taken

to distribute paired plots over a wide range of drainage conditions, and to locate each pair where the fire had ceased as a result of wind change or rain rather than where it was stopped by a natural barrier such as a stream, rocky slope or bog. These conditions ensured that the quadrats were adjacent to each other across slope rather than upslope or downslope. Thus the results were not influenced by the erosional transport of propagules from the recently unburned vegetation or vice versa. The proximity of the quadrats to the burn boundary made selection of similar sites in a highly heterogeneous landscape much easier than it would have been had the quadrats been located further from the fire boundary, and ensured that lack of dispersal ability could not account for the absence of species from the burned plots. There was no indication in the field of any differences in fire intensity between the edges and centres of burns (e.g. Fig. 7). The quadrat size was larger than the minimal area for the vegetation types, as indicated by the fact that the mean species richness of the Mt Field quadrats was not significantly different (at $P = 0.05$) from the mean species richness of another 18 quadrats 10×10 m, located in the same vegetation.

The canopy cover of all vascular plant species, moss and lichen and the cover of rocks, wood and bare ground were measured within nine quadrats, 1×1 m, arranged as an X within the larger quadrat. Shrub and large herb species canopy cover and density were measured for the 5×5 m quadrat as a whole, and the presence of any herb species absent from the 1×1 m subsamples was noted. These latter species were given a notional percentage cover of 0.1 for all analyses. All cover measurements were undertaken with the aid of rings and squares of known area. Slope, slope aspect, altitude, topographic location and geographic location were noted. A bulked sample of the top 5 cm of the soil profile was collected from each of the quadrats and pH measured to half a unit using a CSIRO soil-testing kit.

Laboratory Analysis of Vegetation Data

Mean cover of all taxa and other attributes of the quadrats were calculated for recently burned and recently unburned plots on each mountain and *in toto*. The number of quadrat pairs in which the cover of a particular taxon or attribute in the burned plot was lower than its cover in the unburned plot was expressed as a percentage of the number of quadrat pairs in which that taxon or attribute occurred (index A). Discriminant function analysis was used to test whether recency of burning influenced the position of alpine vegetation on the floristic continua related to geographic position and drainage conditions (Kirkpatrick 1983). Thus, there were two discriminant analyses with two groups in each. The two defined groups for the east-west analysis were Mt Field, Mt Jerusalem and Mt Wellington (east) and Mt Read, Frenchmans Cap and Mt Murchison (west), as the first three mountains were in groups 3 and 4 and the last three were in groups 1 and 2 of the floristic classification of Kirkpatrick (1982). All quadrats were also used for the calculation of the discriminant function for the extremes of the drainage gradient. The two groups were defined by the presence or absence of a bolster species cover of greater than 1%, because the bolster species are good indicators of poorly drained ground and are little affected in their cover by fire. Cover data were used in all discriminant function calculations. For these analyses, species of low percentage cover were grouped into 'other shrubs', 'other monocotyledonous herbs', 'other dicotyledonous herbs' and 'other bolster plants', the last category having precedence in allocation. The closely similar small gymnosperms, *Diselma archeri*, *Microstrobis niphophilus* and *Microcachrys tetragona*, were also grouped as were *Richea gunnii* and *R. scoparia*.

Species nomenclature follows Curtis (1963, 1967) and Curtis and Morris (1975) for gymnosperms and dicotyledons, and Willis (1970) and Curtis and Stones (1978) for pteridophytes and monocotyledons. The terms heath, open-heath, shrubland, hermland and open-grassland follow Specht (1972).

Laboratory Analysis of Soils

Roots were removed from soil samples which were milled and air-dried before further analysis. Percentage organic matter was indicated by weight loss on ignition. Total nitrogen was determined by Kjeldahl digestion. Analysis of phosphorus was by the vanado-molybdate method on a digest of 1 g of sample with $\text{HNO}_3/\text{HClO}_4$. Absorption was read at 400 nm on a Varian Superscan spectrophotometer. Potassium and sodium were determined by flame emission measurement of the above digest, on an EEL flame photometer. Calcium was measured photometrically as for potassium and sodium, by dilution (1:1) of the digest with LaCl_3 solution. The two-tailed Mann-Whitney U test was used to test the null hypothesis that there were no differences in soil properties between mountains and between burned and unburned plots within mountains.

Asteraceae													
<i>Abrotanella forsteroides</i>	5	80	—	—	—	—	—	—	—	0.5	0.5	1.1	0.9
<i>Olearia algida</i>	4	71	—	—	—	—	—	—	—	—	—	1.3	0.6
<i>Helichrysum ledifolium</i>	4	67	—	—	—	—	—	—	—	—	—	0.7	6.4
<i>Olearia ledifolia</i>	4	45	1.0	5.0	—	0.1	0.2	0.7	—	2.5	1.2	0.9	0.1
<i>Helichrysum hookeri</i>	4	38	—	—	—	—	—	—	—	—	—	1.7	0.9
<i>Helichrysum backhousii</i>	4	36	6.0	14.2	0.8	7.5	—	—	—	1.0	3.6	3.7	1.3
Other families													
<i>Drimys lanceolata</i>	2	56	6.0	5.2	1.4	1.7	0.1	0.2	—	1.7	0.8	—	—
<i>Pimelea sericea</i>	2	75	—	—	—	—	—	—	—	2.0	1.2	—	—
<i>Donatia novae-zelandiae</i>	5	56	—	—	1.4	—	2.1	5.4	—	2.2	0.1	—	—
<i>Bauera rubrioides</i>	4	43	—	—	4.5	4.3	2.4	11.6	—	—	—	—	—
<i>Coprosma nitida</i>	2	27	—	0.2	—	0.1	—	0.1	—	0.2	0.1	0.1	0.1
<i>Gaultheria hispida</i>	4	0	—	0.2	0.1	1.1	—	—	—	—	—	—	—
Poaceae													
<i>Hierochloa redolens</i>	4	50	—	—	—	—	—	—	—	0.5	0.5	1.5	1.5
<i>Danthonia</i> spp.	4	33	—	0.2	0.1	0.2	0.1	0.3	—	0.1	0.9	—	—
<i>Poa gunnii</i>	5	26	1.0	—	0.2	0.3	0.1	0.9	—	1.3	2.8	28.0	28.0
<i>Deyeuxia</i> spp.	4	14	—	—	—	0.1	—	—	—	0.1	0.6	—	—
<i>Hierochloa fraseri</i>	4	0	—	—	—	—	—	—	—	—	—	—	—
<i>Microlaena tasmanica</i>	5	0	—	—	—	0.1	0.1	3.6	—	—	—	—	—
<i>Agrostis</i> spp.	4	0	—	—	—	0.1	—	—	—	—	—	—	—
Cyperaceae													
<i>Oreobolus pumilio</i>	3	53	—	—	1.0	0.3	4.5	0.9	—	0.8	0.5	—	—
<i>Carpha</i> spp.	4	39	0.2	5.0	2.6	1.0	3.5	4.1	—	0.9	2.5	—	—
<i>Uncinia compacta</i>	4	34	1.0	1.2	0.6	0.6	0.1	0.2	—	0.4	1.5	1.0	1.0
<i>Oreobolus acutifolius</i>	5	31	5.0	1.0	0.1	—	0.1	1.1	—	0.1	0.4	—	—
<i>Oreobolus distichus</i>	5	20	—	—	—	—	—	—	—	—	0.2	—	—
<i>Schoenus calypttratus</i>	4	18	—	—	0.4	1.1	—	0.3	—	—	0.3	—	—
Other Monocotyledonae													
<i>Empodisma minus</i>	3	67	—	—	8.0	1.0	9.3	4.1	—	5.2	0.9	1.0	1.5
<i>Milligania densiflora</i>	5	57	5.2	1.2	0.7	1.2	—	—	—	—	—	—	—
<i>Diplarrhena latifolia</i>	5	43	1.0	1.0	4.3	6.2	—	—	—	—	—	—	—
<i>Campynema lineare</i>	5	43	—	—	0.02	0.01	0.03	0.04	—	—	—	—	—
<i>Astelia alpina</i>	5	36	21.8	25.8	6.6	2.5	3.4	13.9	—	31.9	25.1	31.5	—
<i>Luzula</i> spp.	4	25	—	0.2	0.1	2.0	—	—	—	—	0.1	0.1	0.2

Herbs

<i>Hierochloa redolens</i>	4	50	—	—	—	—	—	—	—	0.5	0.5	1.5	1.5
<i>Danthonia</i> spp.	4	33	—	0.2	0.1	0.2	0.1	0.3	—	0.1	0.9	—	—
<i>Poa gunnii</i>	5	26	1.0	—	0.2	0.3	0.1	0.9	—	1.3	2.8	28.0	28.0
<i>Deyeuxia</i> spp.	4	14	—	—	—	0.1	—	—	—	0.1	0.6	—	—
<i>Hierochloa fraseri</i>	4	0	—	—	—	—	—	—	—	—	—	—	—
<i>Microlaena tasmanica</i>	5	0	—	—	—	0.1	0.1	3.6	—	—	—	—	—
<i>Agrostis</i> spp.	4	0	—	—	—	0.1	—	—	—	—	—	—	—
Cyperaceae													
<i>Oreobolus pumilio</i>	3	53	—	—	1.0	0.3	4.5	0.9	—	0.8	0.5	—	—
<i>Carpha</i> spp.	4	39	0.2	5.0	2.6	1.0	3.5	4.1	—	0.9	2.5	—	—
<i>Uncinia compacta</i>	4	34	1.0	1.2	0.6	0.6	0.1	0.2	—	0.4	1.5	1.0	1.0
<i>Oreobolus acutifolius</i>	5	31	5.0	1.0	0.1	—	0.1	1.1	—	0.1	0.4	—	—
<i>Oreobolus distichus</i>	5	20	—	—	—	—	—	—	—	—	0.2	—	—
<i>Schoenus calypttratus</i>	4	18	—	—	0.4	1.1	—	0.3	—	—	0.3	—	—
Other Monocotyledonae													
<i>Empodisma minus</i>	3	67	—	—	8.0	1.0	9.3	4.1	—	5.2	0.9	1.0	1.5
<i>Milligania densiflora</i>	5	57	5.2	1.2	0.7	1.2	—	—	—	—	—	—	—
<i>Diplarrhena latifolia</i>	5	43	1.0	1.0	4.3	6.2	—	—	—	—	—	—	—
<i>Campynema lineare</i>	5	43	—	—	0.02	0.01	0.03	0.04	—	—	—	—	—
<i>Astelia alpina</i>	5	36	21.8	25.8	6.6	2.5	3.4	13.9	—	31.9	25.1	31.5	—
<i>Luzula</i> spp.	4	25	—	0.2	0.1	2.0	—	—	—	—	0.1	0.1	0.2

Table 1 (Continued)

No. of quadrats:	RC		A		Frenchmans Cap		Mt Murchison		Mt Read		Mt Field		Mt Jerusalem		Mt Wellington	
			U	B	U	B	U	B	U	B	U	B	U	B	U	B
Herbs																
Asteraceae																
	2		75									0.1	0.1	0.5		
<i>Craspedia alpina</i>												0.1	0.2	0.1		
<i>Celmisia saxifraga</i>	3		62		0.2							0.1	0.2	0.1		0.3
<i>Celmisia longifolia</i>	2		46		0.2	1.0			1.0		0.5	0.1			5.6	4.1
<i>Abrotanella scapigera</i>	5		44		1.2	1.7			1.2	1.7	0.1	0.2				
<i>Senecio pectinatus</i>	5		43								0.01	0.04		0.1	0.1	
<i>Erigeron stellatus</i>	4		38				0.9	0.4	0.1	2.0	0.4	0.1				
<i>Brachycome</i> spp.	4		29								0.1	1.7	0.3			0.2
<i>Ewarria meredithiae</i>	4		20				0.1	0.1	0.1	0.2		0.1				
<i>Gnaphalium</i> spp.	4		20			0.01	0.02			0.1		0.1			0.1	0.1
<i>Ewarria planchonii</i>	4		17								0.03	0.1				0.8
<i>Helichrysum milliganii</i>	5		10				0.2	0.1		0.5						
<i>Senecio leptocarpus</i>	4		9		1.0	5.2	0.3	3.1		0.1						
<i>Senecio gunnii</i>	4		0										0.4			
Other herbs																
<i>Drosera arcturi</i>	3		53			1.0	0.1	0.1	0.1	0.1	0.8	0.1				
<i>Lycopodium fastigiatum</i>	5		50		0.2						0.1	0.3		0.5	0.2	0.1
<i>Diplazis cordifolia</i>	5		43		2.0	2.0	0.3	1.3						0.1		0.7
<i>Euphrasia</i> spp.	4		40			0.3	0.2		0.1	0.1						2.1
<i>Acaena montana</i>	4		33								0.5	0.5		0.1		0.3
<i>Mitrasacme montana</i>	4		22					0.6		0.1				0.1		0.9
<i>Gonocarpus montanus</i>	4		20								0.2	3.8		0.1	0.2	
<i>Gentianella diemensis</i>	4		19						0.02	0.06	0.01			0.1		
<i>Acaena novae-zelandiae</i>	4		14					0.13			0.3	0.9		2.5	3.2	
<i>Anemone crassifolia</i>	4		10						0.3	3.1						
<i>Histiopteris incisae</i>	4		0				0.01	0.03								
<i>Rubus gunnianus</i>	5		0				0.2	1.1		0.1	0.1	0.9		0.2	1.2	0.7
<i>Epilobium</i> spp.	4		0									0.2			0.3	
Bare ground	7				n.a.		0.5	6.7	0.7	32.0	2.8	18.2	1.4	7.6		n.a.
Rocks	8				n.a.		5.1	6.6	0.8	3.7	4.5	14.1	6.6	9.4		n.a.
Dead wood	25				n.a.		0.9	3.3	n.a.			6.2	n.a.			n.a.
Total plant cover					n.a.		117.7	52.5	116.6	65.4	136.2	62.72	153.0	89.6		n.a.
Species richness					n.a.		21.2	25.9	17.6	23.5	22.9	28.1	n.a.			n.a.

^A Includes *Microcachrys tetragona*.

^B Includes *Richea gunnii* at Mt Field.

Results and Discussion

Species Regeneration Characteristics

Table 1 gives mean percentage cover in the unburned and burned quadrats on each mountain for all taxa occurring in three or more quadrat pairs, and places each of these taxa in one of five classes.

(1) Those that are most often absent from recently burned areas in which they were present before fire. Adults are readily killed by fire and have seeds which seldom survive its incidence. Given the experimental design, their general absence from the burned plots cannot be attributed to a lack of dispersal ability, although many of these species have no apparent adaptations for long-distance dispersal. All the gymnosperms, the winter deciduous shrub *Nothofagus gunnii* and *Orites milliganii* fall within this class which fits within class III of Gill (1981).

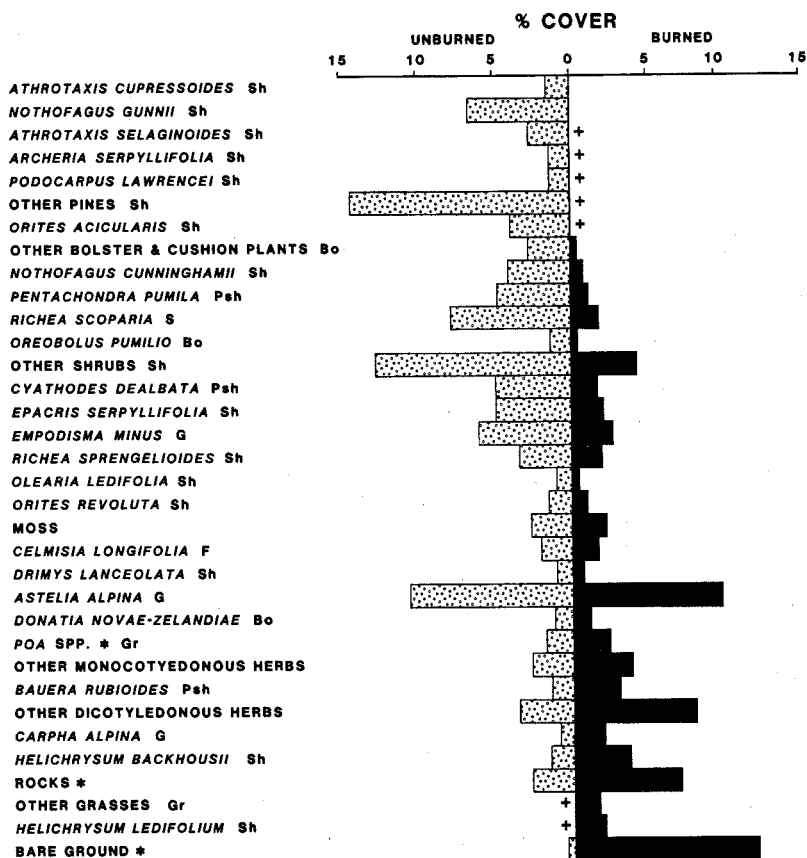


Fig. 2. Mean percentage cover of species, species groups, rocks and bare ground for all burned and unburned plots. The plus sign indicates presence with cover too low to be depictable on the diagram. *Sh*, shrub; *Psh*, prostrate shrub; *Bo*, bolster plant; *G*, graminoid; *Gr*, grass; *F*, forb. * No values available for Mt Wellington.

(2) Those that are found in recently burned areas with a much lower cover than they possess in adjacent long unburned areas, and that have regenerated from seed. This category contains a large number of the alpine shrub species including such widespread dominants as *Orites acicularis* and *Richea scoparia*. This class includes species from classes II and III of Gill (1981).

(3) Those that recover vegetatively from fire and yet fail to attain the cover they exhibit in the long unburned areas. This class includes both shrubs and herbs, and includes species from classes IV and V of Gill (1981).

(4) Those that exhibit a greater cover in recently burned than in long unburned areas and that have established from seed in the recently burned areas. The shrubby *Olearia* and *Helichrysum* species largely belong to this class as do many of the herbaceous species. The shrub species in this class belong to classes II and III of Gill (1981).

(5) Those that exhibit an equal or greater cover in recently burned areas than in recently unburned areas and that recover vegetatively from fire. A few shrubs, the two bolster species in Table 1 (*Donatia novae-zelandiae* and *Abrotanella forsteroides*) and a large number of herbaceous species belong to this category. Many of these species also establish from seed after fire. The shrub species in this class belong to classes IV and V of Gill (1981).

Few alpine species lack all of the ability to: recover vegetatively from fire; store viable seeds in the soil; and disperse rapidly into burned areas. However, those which do lack all these attributes are major dominants of the coniferous heath and deciduous heath that covers much of the alpine zone wherever there is no evidence of fire. Some indication of the limited dispersal ability of the *Athrotaxis* species is given in Fig. 3. *Nothofagus gunnii*, *Diselma archeri* and *Microstrobus niphophilus* are similarly poorly dispersed wherever dispersal from a fire boundary is apparent. The last two species are absent from most recent burns but do occur as occasional seedlings on the burned ground at Mt Field, where these seedlings are closely associated with the remains of fire-killed individuals of the same species. *Microcachrys tetragona* and *Podocarpus lawrencii*, the two other dominants of coniferous heath, are category 1 species but are dispersed widely by means of the regurgitate of the black currawong (*Strepera fuliginosa*). They both possess fleshy and sweet arils.

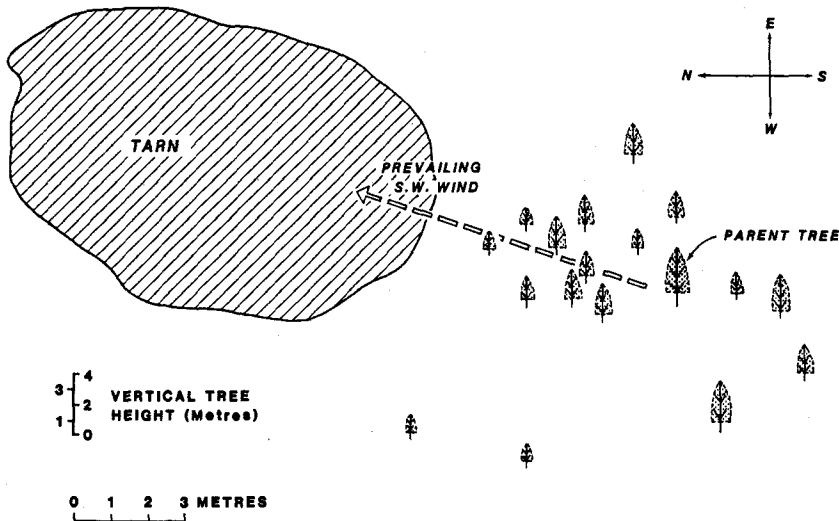


Fig. 3. The location of individuals of *Athrotaxis cupressoides* around a single survivor of a fire of unknown age in subalpine vegetation at Mt Field, Tasmania.

The Impact of Fire on Community Characteristics

There are dramatic differences in dominance and structure between recently burned and unburned alpine vegetation (Fig. 7; Table 2). Where bolster plants have high cover in coniferous heath or other heath communities in the unburned vegetation, they are generally dominant in the burned areas, although *Dracophyllum minimum* is less successful in both vegetative and seedling recovery from fire than are *Abrotanella forsteroides*, *Donatia novae-zelandiae* and *Phyllachne colensoi* (N. Gibson, personal communication).

Table 2. A comparison of the burned and unburned paired plots

Plots	Years since fire	Species cover in common ^A	No. of species in common	Percentage of species in common ^B	Species only in unburned quadrat	Species only in burned quadrat	Unburned vegetation	Burned vegetation
Mt Read								
53/54	20	15.1	18	52.9	8	8	Donatia bolster heath	Donatia bolster heath
59/60	20	20.4	15	42.9	10	10	Diselma archeri coniferous heath	Microlaena tasmanica grassland
45/46	20	23.2	12	40.0	10	8	Diselma archeri coniferous heath	Donatia bolster heath
43/44	20	15.7	10	33.3	11	9	Diselma archeri coniferous heath	Donatia bolster heath
41/42	20	6.3	5	15.6	8	19	Nothofagus gunnii deciduous heath	Bauera rubioides open-heath
50/51	20	10.2	8	26.7	8	14	Nothofagus gunnii deciduous heath	Bauera rubioides open-heath
47/48	20	7.8	9	28.1	8	15	Nothofagus gunnii deciduous heath	Astelma alpina herbland
49/50	20	7.8	12	38.7	4	15	Nothofagus gunnii deciduous heath	Bauera rubioides open-heath
55/56	c. 40	5.9	5	19.2	4	17	Nothofagus gunnii deciduous heath	Richea scoparia open-heath
57/58	c. 40	5.1	6	20.7	5	18	Nothofagus gunnii deciduous heath	Astelma alpina herbland
Mt Field								
73/74	15	45.8	24	58.5	4	13	Diselma archeri coniferous heath	Astelma alpina herbland
69/70	15	24.9	20	46.5	9	14	Diselma archeri coniferous heath	Astelma alpina herbland
67/68	15	14.7	16	37.2	19	8	Microstrobos niphophilus coniferous heath	Helichrysum backhousii shrubland
77/78	15	59.5	11	44.0	0	14	Richea scoparia open-heath	Astelma alpina herbland
65/66	15	17.7	12	32.4	8	17	Diselma archeri coniferous heath	Gonocarpus montanus herbland
61/62	15	27.2	19	48.8	4	16	Microstrobos niphophilus coniferous heath	Helichrysum backhousii shrubland
71/72	15	53.7	8	25.9	7	16	Diselma archeri coniferous heath	Astelma alpina herbland
75/76	15	38.4	11	29.7	12	14	Athrotaxis cupressoides coniferous heath	Astelma alpina herbland
63/64	15	11.6	11	35.5	11	9	Podocarpus lawrencii coniferous heath	Astelma alpina herbland

^ATotal of coincident cover values. ^BNo. of spp. in common divided by total No. of spp. in both quadrats and multiplied by 100.

Where bolsters are absent, grassland, herbland or shrubland replaces coniferous and deciduous heath 10–20 years after fire, with *Astelia alpina* and *Helichrysum backhousii* being the most frequent dominants of herbland and shrubland respectively (Table 2). *Poa gunnii* is a widespread dominant of 10–20-year-old burns on the Central Plateau and other eastern mountains (Fig. 8), where shrub composites other than *H. backhousii* dominate the shrubland of burned areas: these other species are *Helichrysum hookeri*, *H. ledifolium* and *Olearia algida*. There was little difference between the burned and unburned plots in the proportional dominance of the individual species with the greatest cover in each quadrat. At Mt Field the species with the greatest cover in each quadrat accounted for an average of 36.4% of the total plant cover of the unburned quadrats and 42.2% of the total plant cover of the burned quadrats. The equivalent figures for Mt Read were 40.8% and 43.2% respectively.

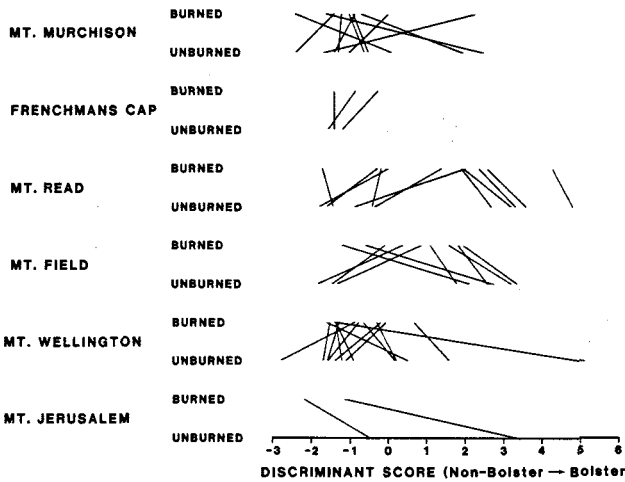


Fig. 4. Discriminant scores of unburned and burned plots by mountain for the bolster to non-bolster analysis. Each line joins the values for adjacent burned and unburned plots.

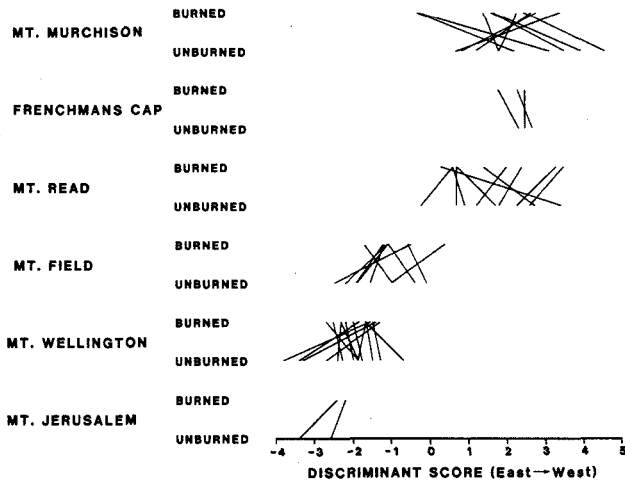


Fig. 5. Discriminant scores of unburned and burned plots by mountain for the eastern mountain-western mountain analysis. Each line joins the values for adjacent burned and unburned plots.

Much bare ground remained in the burned areas 10–20 years after fire whereas little or no bare ground was found in adjacent unburned plots (Figs 2 and 6–8; Table 1) or in the 40-year-old burn plots on Mt Read. A consistently higher rock cover was recorded for the burned in comparison with the unburned plots (Fig. 2; Table 1). Total plant cover in the burned plots was approximately half of that in the unburned plots for all mountains

Table 3. Means, standard deviations and comparisons of significance for measured soil properties of burned and unburned sites
 * Significant at 0.05%. ** Significant at 0.02%. n.s., Not significant at 0.05%

Mountain	pH		Organic matter (%)		N (%)		P (ppm)		K (ppm)		Ca (ppm)		Na (ppm)	
	\bar{x}	s	\bar{x}	s	\bar{x}	s	\bar{x}	s	\bar{x}	s	\bar{x}	s	\bar{x}	s
Mt Field Burned	5.42	0.363	41.87	18.71	0.922	0.245	290	126.5	175	33.1	837.5	485.3	142.5	38.9
P	n.s.		n.s.		*		n.s.		n.s.		n.s.		n.s.	
Unburned	5.40	0.514	55.06	15.07	1.285	0.391	356.9	72.1	225	97.6	1356.3	1428.4	172.8	79.9
Index A ^a	67		89		89		67		89		67		67	
Mt Read Burned	3.93	0.28	6.22	1.26	0.142	0.038	118	23.7	780	359.8	345	101.1	75.4	14.8
P	n.s.		**		*		n.s.		n.s.		n.s.		n.s.	
Unburned	3.80	0.15	10.66	4.61	0.207	0.084	108.5	23.7	550	209.2	320	81.2	77.8	20.0
Index A ^a	40		80		90		50		10		60		50	

^a Percentage of paired plots in which the burned plot had a lesser value than the unburned plot.

except Mt Jerusalem, where it was considerably more than half (Table 1). Mean species richness was higher in the burned plots than in the unburned plots for all mountains and for most pairs of quadrats within any mountain (Tables 1 and 2).

At both Mt Read and Mt Field the burned quadrats were much more similar in species abundances to each other than were the unburned quadrats. This phenomenon resulted from the virtual elimination of large shrub species cover from the burned quadrats and a concomitant increase in abundance of species with wide environmental ranges. For example, at Mt Read, *Athrotaxis selaginoides* and *Nothofagus gunnii* accounted for a large proportion of the total plant cover in 6 of the 10 unburned quadrats but were almost completely absent from the other four unburned quadrats where drainage was poor. In contrast, the species which dominated the burned quadrats at Mt Read (Table 2) were found almost ubiquitously in both burned and unburned quadrats. This decrease in spatial vegetational heterogeneity resulting from recent fire is evident within individual mountains in the results of the discriminant function analyses (Figs 4 and 5), where there is a strong tendency within each mountain for the unburned quadrats to have a wider dispersal of values than the burned quadrats. Douglas and Ballard (1971) found a similar reduced heterogeneity in burned alpine vegetation of the North Cascades in the U.S.A.

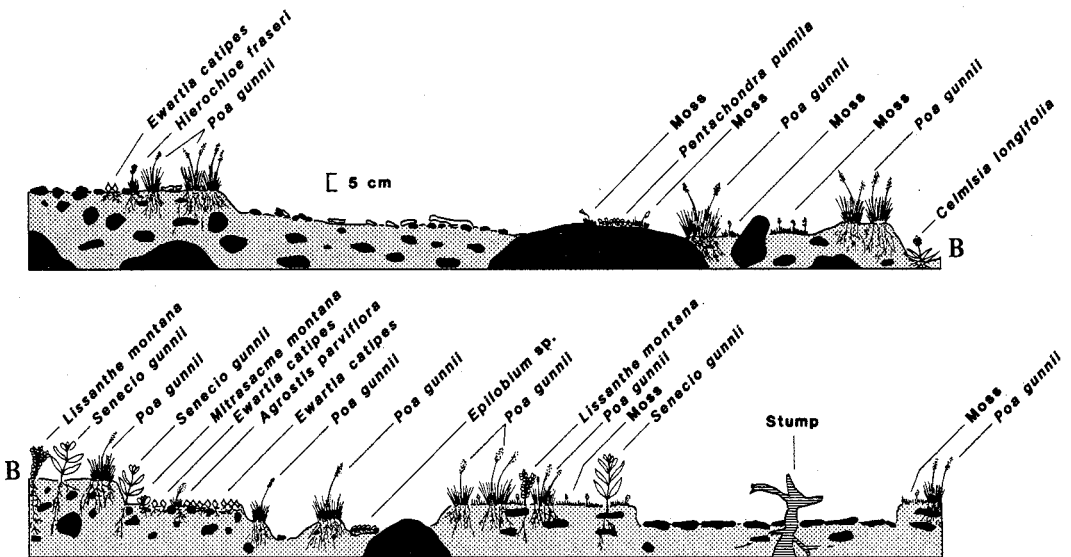


Fig. 6. Surveyed cross section of part of the 18-year-old burn at Mt Jerusalem at 1350 m. The black areas are dolerite rocks. The unlabelled white features on the surface are pieces of dead wood.

The Impact of Fire on Soils

At several of the burned plots on Mt Read the organic-rich horizon had been totally removed by burning and consequent erosion, giving a significant difference between the organic content of surface soil in the burned area and that in the unburned area (Table 3). There was no significant difference between the organic content of the surface soils of the burned and unburned plots at Mt Field. Total P, total K, total Ca, total Na and pH did not differ significantly between burned and unburned plots on either mountain, whereas percentage N was lower in the surface soils of the burned areas on both mountains (Table 3). If nitrogen is limiting to Tasmanian alpine plant species, as has been suggested for tundra species at Barrow by Ulrich and Gersper (1978), the medium-term fire-lowered nitrogen content of the Tasmanian soils could have a marked ecological impact. At Mt Field and Mt Read there is little opportunity for biological fixation through higher plants as

leguminous shrubs and herbs are virtually absent, and other Australian alpine taxa that are known nitrogen-fixers (Carr *et al.* 1980) are also absent or of extremely low cover values. However, nitrogen-fixers such as *Poa* spp., *Sphagnum cristatum* and Fabaceae spp. are more common on the drier mountains such as Mt Wellington and the Central Plateau.

We have not directly quantified the impact of fire on the rate of soil erosion but general observation and the higher values for rock cover in burned than in unburned plots suggest that it is substantial. Even on relatively gentle slopes, the combination of prolonged soil exposure (Table 1), heavy precipitation, strong winds and frequent formation of needle ice is unconducive to soil stability (Figs 6 and 8).

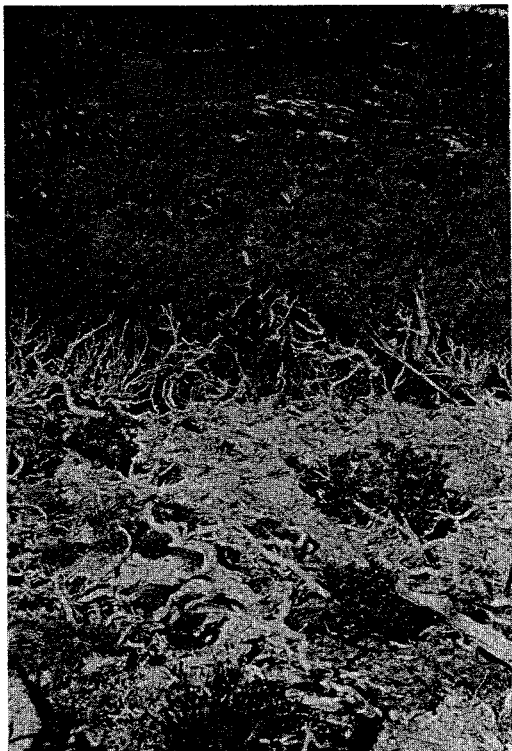


Fig. 7. The 20-year-old fire boundary on Mt Read. Closed-heath dominated by *Athrotaxis selaginoides* and *Nothofagus gunnii* has been replaced by a sparse community dominated by *Helichrysum backhousii*.

Environmental Variation of Fire Impact

The surface soils of Mt Field and Mt Read were significantly different at the $P=0.01$ level for all measured attributes, with Mt Read having higher values than Mt Field for K only. As well as being considerably more fertile per unit volume, the soils of Mt Field are generally much deeper than those of Mt Read. Thus, the nutrients available to plants per unit area are likely to be considerably higher at most sites on Mt Field than on Mt Read. This difference is reflected in the rate of recolonization following fire with almost twice as much ground being bare at Mt Read 20 years after a fire than at Mt Field 15 years after a fire, and with total plant cover in the burned plots being similar despite the lesser time elapsed at Mt Field. The data from Mt Murchison and Mt Jerusalem (Table 1) substantiate a quicker recovery rate for the eastern mountains, except for the low value for bare ground for Mt Murchison. However, the long unburned plots on Mt Murchison mostly lacked the group 1 species and had high cover values for vegetative recoverers. Soil nutrient data for the Mt Murchison plots (Kirkpatrick 1984b) show it to be as infertile

as Mt Read. No soil data are available for the Mt Jerusalem plots but, since these plots are on dolerite like those at Mt Field and are in a similar climate to Mt Field, they are likely to possess similar characteristics.

There is a weak tendency for the burned and unburned plots to be more similar in species composition and abundance as drainage becomes more impeded (Fig. 4; Table 2). This tendency is most apparent in the data from Mt Read, where *Diselma archeri* coniferous heath and *Donatia novae-zelandiae* bolster heath occupied the more poorly drained sites before fire, and where there is no overlap between percentage of species cover in common between the paired plots on poorly drained ground and those on better drained ground and only a slight overlap in the percentage of species in common between the two sets of plots (Table 2). The prominence of vegetative recoverers, and the relative paucity of groups 1 and 2 species on poorly drained sites, could account for this tendency. On Mt Murchison and Mt Wellington (Fig. 4), where group 1 species were largely absent from the long unburned plots, the tendency was least apparent.

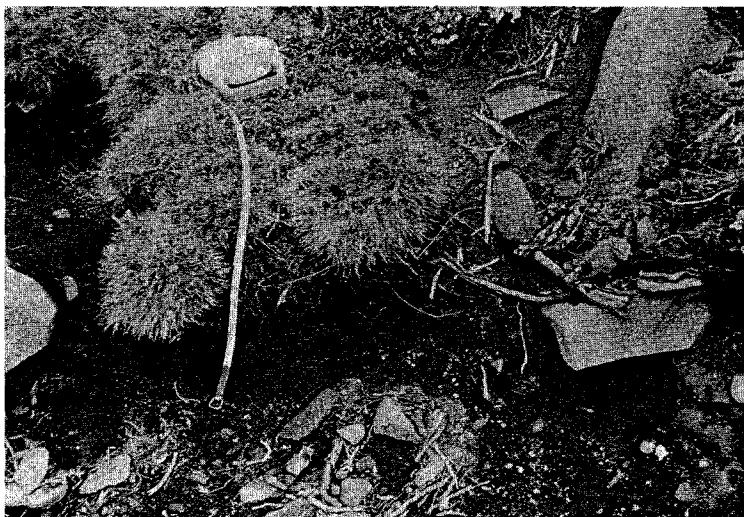


Fig. 8. Accelerated erosion in the 18-year-old burn at Mt Jerusalem. *Poa gunnii* is dominant.

The Nature of Succession and Long-term Vegetation Change

The species in groups 3–5 are present in the burned areas within a year after the fire and their relative growth rates and longevities control the nature of succession for at least 20 years. Some observations of 1–5-year-old burns in the central and eastern mountains suggest a relatively rapid ingress of group 2 species. However, their densities are low and seedlings are confined to already stabilized ground (Fig. 6). Two decades are sufficient to allow the recolonization of some group 1 species in some circumstances. The most successful recolonizers are the bird-dispersed prostrate pines, *Podocarpus lawrencii* and *Microcachrys tetragona*. The least successful are *Nothofagus gunnii* and *Athrotaxis cupressoides* (Fig. 2).

There is strong fossil evidence that group 1 species can be eliminated from a site for up to thousands of years by a single fire. The local extinction of gymnosperms and *Nothofagus gunnii* in the Denison Range is associated with a concentration of charcoal in the profile (Macphail 1981). These species have not returned to the site despite their survival only 1 km away and a return to infrequent fire after their elimination (Macphail 1981). The disappearances of *Microstrobis niphophilus* and *Nothofagus gunnii* at 285 cm

in the Adamsons Peak pollen diagram (Macphail 1979) occur in amongst a series of concentrations of fine black particles in the profile (Macphail 1980). These concentrations cease at 220 cm and *Nothofagus gunnii* pollen returns in some numbers by 170 cm. *Microstobus* pollen is only present as two traces for the rest of the profile. In the Beatties Tarn (Mt Field) diagram, *Nothofagus gunnii* is present in traces from the late Pleistocene, becomes abundant for some depth around the date of 7850 B.P., then disappears from the profile for the most recent 100 cm (Macphail 1979). In the Lake Vera (Frenchmans Cap) diagram, *Nothofagus gunnii* pollen numbers plummet at approximately the same time as they become abundant at Beatties Tarn, then resurge to a long-maintained moderate abundance (Macphail 1979). The above changes cannot be interpreted as climatically induced, in that their lack of synchronization cannot be fitted to any theory of advancing altitudinal waves of plant communities. However, they do fit the theory of long-term local elimination by a temporally random and low incidence of fire.

There may have been no fire since some areas were colonized by the group 1 species. The Tarn Shelf (Mt Field) pollen diagram provides strong support for this proposition in that there is not even a concentration of fine black particles in the last 4000 years of the record, and it is only in this time that *Microstobus* pollen occurs as more than a trace (Macphail 1979, 1980).

Table 4. Details of data collected from other mountains

Mountain	No. of quadrat pairs	Age of burn (years)	Sampling details	Information source ^a	Date of data collection
Mt Jerusalem	2	18	25 m line intercepts	Kirkpatrick	1978
Mt Wellington	15	11 (2 pairs), 16 (13 pairs)	5 × 5 m quadrats	Harper, Keage and McCrae	1978
Frenchmans Cap	3	13	10 × 10 m quadrats (5 cover classes only)	Kirkpatrick	1979
Mt Murchison	10	c. 20	5 × 5 m quadrats	Cantle	1982

^aAll personal communications.

The present distributions of the group 1 species also provide strong supporting evidence for the proposition that they are susceptible to long-term elimination by even one fire. *Microstobus niphophilus* is one of the most abundant species in the unburned vegetation at Mt Field yet is absent from most of the other mountains in the State (Brown *et al.* 1983b), while occurring frequently enough in a wide range of climatic and edaphic environments to reject the validity of a hypothesis of limitation by the physical environment. Other group 1 species are apparently randomly absent from the Eastern Arthur Range while being abundant on some of its closest neighbours, yet *Diselma archeri* has survived in low numbers. On Pyramid Mountain, *Microcachrys* is abundant but *Diselma archeri* is absent, despite occupying identical environments only a few kilometres away, and the genus *Athrotaxis*, also present in identical environments on a nearby mountain, is represented by only one individual (Kirkpatrick 1984a).

In some alpine areas burned more than 40 years ago, there is no invasion of the burned area from directly adjacent stands of group 1 species. Such an invasion may require the senescence of at least some of the group 2 species which dominate alpine vegetation 40–50 years after fire, and could only proceed in very short steps for those group 1 species with no adaptations for long-distance dispersal.

Once the group 1 species have been eliminated from an area, fire has a lesser short-term impact on the vegetation and soils, as is apparent in the comparison of the impact of fire on vegetation cover and composition between the mountains lacking group 1 species in the unburned vegetation and those with unburned vegetation dominated by group 1 species (Table 1). Given that it takes 20–40 years for the re-establishment of complete

vegetation cover, even where group 1 species have been previously eliminated, fire cannot attain very high frequencies. Thus, repeated fire is likely to have its main impact on the composition of vegetation through its encouragement of soil erosion and its progressive depletion of nutrient stocks (Bowman and Jackson 1981), rather than through the direct elimination of species in groups 2-5.

General Discussion

Fridriksson (1963), Douglas and Ballard (1971), Bliss and Wein (1972) and Wein and Bliss (1973) all made favourable comment on either the rejuvenating effect of fire or its contribution of a distinctive persistent flora to the northern hemisphere tundra and alpine areas that they studied. However, their conclusions relate only to the short term, and do not take into account any long-term extinction of species or long-term deterioration in soil conditions that might result from firing.

In Tasmania, fire eliminates or reduces much of the high mountain endemic shrub element while favouring more widespread species, reduces vegetation spatial heterogeneity and leads to accelerated erosion of the shallow alpine soils. There is no evidence of a fire-requiring element in the Tasmanian alpine flora (Kirkpatrick 1983), even the most adventitious of the alpine plants being found on ground disturbed by periglacial processes or by the marsupials which abound in much of the high country. Thus, fire substantially reduces the nature conservation value of alpine ecosystems. Some of the effects of fire are also economically deleterious. For example, Edwards (1973) has demonstrated the importance of shrub cover in enhancing precipitation through fog-screening.

The increased accessibility to alpine areas provided by hydro-electric, mining and forestry developments, the widespread use of intense fire as a management tool in montane areas directly adjacent to alpine vegetation, the high propensity to light fires in hot windy weather demonstrated by Tasmanians (Jackson and Bowman 1982) and the recent sharp increases in the recreational usage of the more remote alpine areas (Kirkpatrick 1979) have all contributed to an increased incidence of fire in the alpine zone in the last quarter century. The implementation of the desirable policy of exclusion of fire from the remaining long unburned areas of Tasmanian alpine vegetation thus presents some considerable problems in the management of both land and people.

Acknowledgments

This work was largely supported by a University of Tasmania Special Research Grant. We thank Denis Charlesworth, Terese Hughes, Kathryn Charlesworth, Adrian Bowden, David Bowman and two anonymous referees for their help. The State Government Analyst undertook all chemical analyses.

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