Monitoring vegetation changes at Treble Cone Ski Field, New Zealand

SCIENCE FOR CONSERVATION 192

Kate Wardle and Barry Fahey

Published by
Department of Conservation
P.O. Box 10-420
Wellington, New Zealand

Science for Conservation is a scientific monograph series presenting research funded by New Zealand Department of Conservation (DOC). Manuscripts are internally and externally peer-reviewed; resulting publications are considered part of the formal international scientific literature.
Titles are listed in the DOC Science Publishing catalogue on the departmental website http://www.doc.govt.nz and printed copies can be purchased from science.publications@doc.govt.nz

ISSN 1173-2946
ISBN 0-478-22237-8

This report was prepared for publication by DOC Science Publishing, Science & Research Unit; editing by Lynette Clelland and layout by Geoff Gregory. Publication was approved by the Manager, Science & Research Unit, Science Technology and Information Services, Department of Conservation, Wellington.

CONTENTS

Monitoring vegetation changes at Treble Cone Ski Field, New Zealand

Kate Wardle and Barry Fahey

Landcare Research, P.O. Box 69, Lincoln 8152, New Zealand

ABSTRACT

A vegetation monitoring programme based on 30 transects was initiated at Treble Cone Ski Field in 1997 to determine the nature and extent of damage to cushionfields resulting from grooming and skiing. These transects were resurveyed in 2000 to determine temporal changes in groundcover classes, species frequency, and biomass of selected tall species in response to snow grooming and skiing over three winters (1997–99). In addition, the soil temperatures regime on a groomed and a non-groomed slope were compared to determine whether snow compaction on groomed sites may inhibit soil microbial activity. Direct damage by groomer blades and tracks to cushion plants substantially reduced total vegetation cover and cover of live cushion plants. There were, however, no significant differences in total species occurrences for any of the vegetation life-form categories among groomed, skied, and undisturbed sites in either 1997 or 2000. Moss cover had significantly increased across all transects between 1997 and 2000, with the greatest increase taking place on groomed transects; occurrences of lichen, live dicotyledon herbs, and dead cushion plant species had increased across all sites. There was a significant decrease in the occurrences of dead woody dicotyledons and monocotyledons. Those areas along the transects which had been damaged through grooming or skiing in 1997 had not increased in extent in 2000. No significant changes in species composition of cushionfields were attributed to grooming or skiing.

Keywords: snow grooming, skiing, environmental effects, vegetation change, alpine vegetation, Treble Cone Ski Field, New Zealand.

This paper may be cited as:
Wardle, K.; Fahey, B. 2002. Monitoring vegetation changes at Treble Cone Ski Field, New Zealand. *Science for Conservation 192*. 50 p.

1. Introduction

1.1 SKI FIELD IMPACTS ON VEGETATION

In 1995, the Department of Conservation (DOC) commissioned Landcare Research to conduct a literature review of the likely impacts of snow grooming and skiing on alpine vegetation and soils on DOC Recreational Reserve land in west Otago. The review, which was based mainly on overseas experience, showed that physical damage to plant communites is particularly common on exposed crests and hummocks (Fahey & Wardle 1998). Subsequent visits to Coronet Peak, the Remarkables, and Treble Cone ski areas showed that cushionfield vegetation and wetland communities were more vulnerable to damage from snow grooming than tussock grasslands. Since cushionfields are more widespread than wetland communities (which tend to prefer areas of deeper snow accumulation and are thus less susceptible to damage), and are common where the expansion of cat skiing[1] operations is likely to occur, this vegetation type was considered the highest priority for study.

1.2 CUSHIONFIELD DESCRIPTION AND SITE SELECTION

Treble Cone Ski Field, situated in the Harris Mountains 23 km north of Wanaka, west Otago, was chosen as the study area. Here, cushionfields are dominated by low-growing tundra-like cushion and mat plants, such as *Dracophyllum muscoides*, *Hectorella caespitosa*, and *Raoulia hectori*, and are associated with mountain daisy (*Celmisia viscosa*), slim-leaved snow tussock grassland (*Chionochloa macra*), and snowbank and fellfield vegetation. Permanent vegetation transects were established in cushionfield areas that were groomed and skied, and in undisturbed areas that served as controls (Part 1, Wardle & Fahey 1999).

In 1997, a monitoring programme was established at Treble Cone Ski Field. Data were collected on percentage vegetation cover, species composition, soil bulk density, and penetration resistance of cushionfields which are groomed, skied, or undisturbed (control treatment). There were statistically significant differences in cover of live vegetation among the three treatments (groomed and skied, skied, and control), with transects on both groomed and skied areas showing a significant reduction in total live vegetation cover at cushionfield sample points. However, there was no significant difference in soil bulk density, penetration resistance, species richness or species composition between treatments.

The impact of snow grooming on snow pack properties was also investigated at Treble Cone Ski Field (Part 2, Fahey et al. 1999). The results showed a substantial increase in snow density, penetration resistance, and equivalent

---

[1] Cat skiing involves the repeated use of a tracked over-snow vehicle, usually a snow groomer, in the back country to transport skiers from the bottom of a ski run to the top (in place of a ski lift).

water content at groomed sites. These increases may be sufficient to inhibit soil bacterial activity and subsequent litter decomposition.

The monitoring programme established at Treble Cone Ski Field in 1997 confirmed that snow grooming reduced live vegetation cover at cushionfields. Since workers elsewhere have found that changes in species composition resulting from direct disturbance or indirect effects of snow compaction can be cumulative (e.g. Bayfield 1979; Grabherr 1985), the transects at Treble Cone Ski Field were resurveyed in February 2000. This report discusses the results of this survey and highlights the changes that have occurred since the previous survey was made in January 1997. The report also briefly discusses an investigation made of ground pressure to see whether a minimum snow depth can be identified below which the passage of snow groomers is likely to cause vegetation damage (Appendix 1). The results of a study of soil temperatures beneath a natural and a compacted snow cover are summarised in Appendix 2.

1.3 OBJECTIVES

- To determine any temporal changes in the nature and extent of damage to penalpine and alpine cushionfield communities from snow grooming and skiing based on observations made in January 1997 and February 2000.
- To make recommendations on the future of the vegetation monitoring programme at Treble Cone Ski Field.
- To produce guidelines for minimising surface disturbance at the west Otago ski fields.

2. Methods

2.1 VEGETATION SAMPLING PROCEDURES

Thirty cushionfields were sampled across the ski field in January 1997 and in February 2000 (Fig. 1). Ten sites are in areas that are groomed (Groom + ski), 10 are in skied areas that are not groomed (Ski), and a further 10 are in areas which are virtually never groomed or skied (Control). Details of the sampling procedures are given in Wardle & Fahey (1999).

Most transects had 100 sample points, although two transects (Transects 40S and 42S) had fewer sample points due to the small size of the cushionfields. At each sample point, percentage ground cover was estimated for each of the following six classes: live vascular vegetation; live moss; live lichen; dead vegetation and litter; bare ground (with or without filmy lichens growing on it); and rock and gravel. The presence of all live plant species rooted into the quadrat was recorded to give an estimate of percentage frequency for each plant species. Identifiable dead species were also recorded.

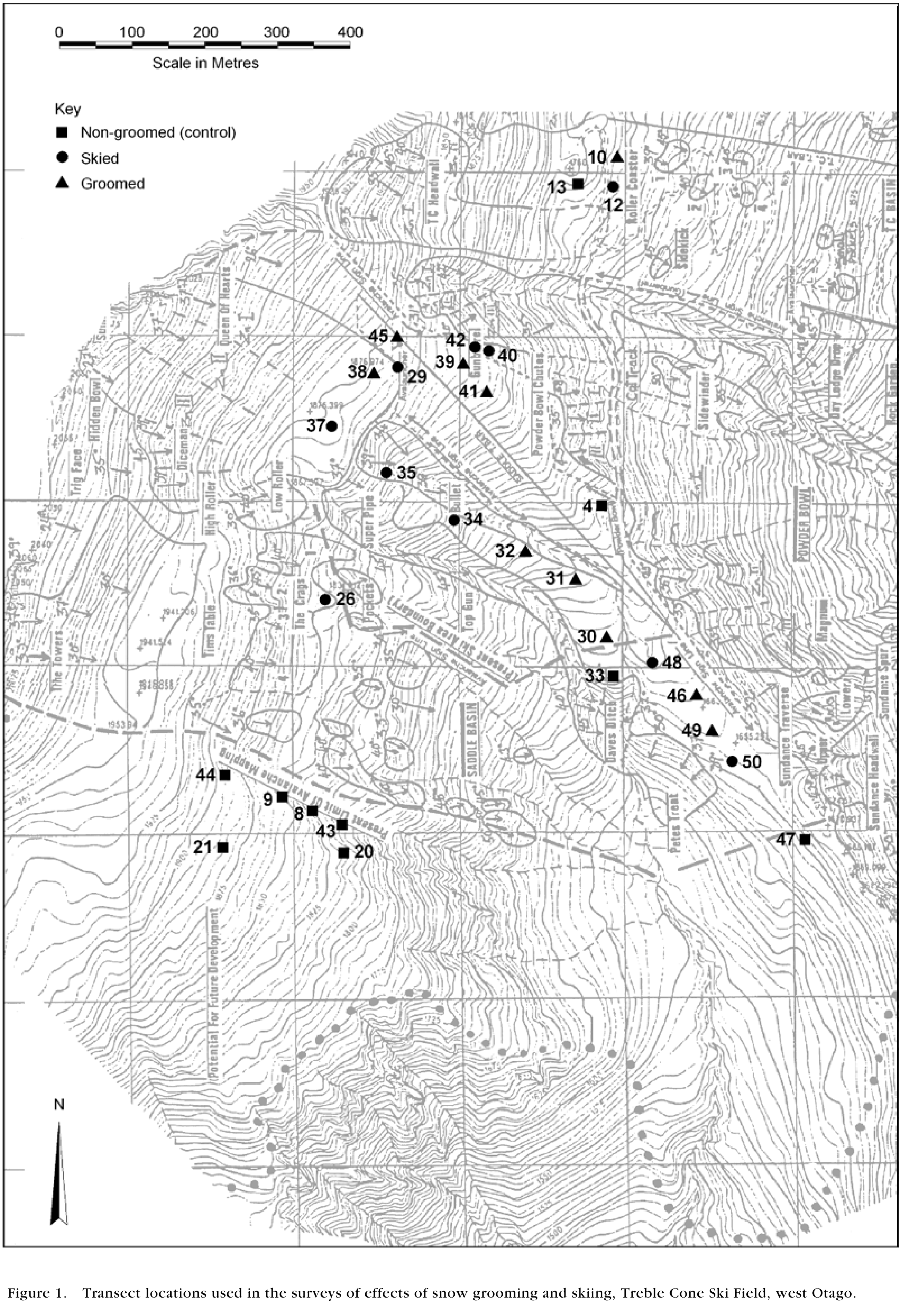

Figure 1. Transect locations used in the surveys of effects of snow grooming and skiing, Treble Cone Ski Field, west Otago.

For those sample points occurring in taller vegetation, such as *Chionochloa macra* tussock grassland, or where the more common taller species (i.e. blue tussock (*Poa colensoi*), *Celmisia viscosa*, or *Marsippospermum gracile*) occur along the transect, a height-frequency method (Scott 1965) was used to determine stature and biomass. Where tillers of *Chionochloa macra* were rooted in the lowest height interval, the longest leaf was extended up the height pole to determine its maximum length. The data collected in 1997 were compared with those collected in 2000 to indicate how grooming or skiing has affected the biomass and height of taller vegetation.

2.2 SITE INFORMATION

At each transect, general observations were made regarding the extent and type of damage, patterns in vegetation, and presence of any weed species. Photos were taken looking along each transect to compare with those taken from the same locations in January 1997, and also of adjacent damaged areas to assist in establishing how ground cover and species composition may have changed through time. Some examples are included in Appendix 6 (Figs A6.1–A6.9)). These show the same areas photographed in January 1997 (Wardle & Fahey 1999; Appendix 3). The rest are kept at Landcare Research, Lincoln. The altitude, slope, aspect, and year the area was first groomed or skied were also recorded for each transect (Table 1).

2.3 DATA ANALYSIS

Statistical analyses were conducted on ground cover and species frequency data using the SAS programme (1989).

2.3.1 Plant communities

As many of the transects traversed patches of other plant communities in addition to cushionfield vegetation, it was necessary to classify the dominant plant community at each sample point. Four main plant communities were identified: cushionfield vegetation, *Celmisia viscosa* matfield, tussock grassland, or *Marsippospermum gracile* snowbank vegetation. The plant community classifications assigned to sample points in 1997 were applicable to the 2000 data. The number of sample points with ‘cushionfield vegetation’ at each transect are outlined in Appendix 3.

2.3.2 Ground cover

To determine whether the ground cover characteristics of ‘cushionfield vegetation’ have changed as a result of grooming and skiing, only groundcover class data collected from sample points dominated by cushionfield vegetation were analysed. The results were converted into percentage data to facilitate comparison among transects.

TABLE 1. GENERAL TRANSECT DETAILS, TREBLE CONE SKI FIELD.

TRANSECT NO.	ALTITUDE (m a.s.l.)	SLOPE (deg.)	ASPECT (deg.)	YEAR FIRST GROOMED/SKIED
Control				
33	1655	13	158	n/a
47	1660	27	212	n/a
4	1705	12	145	n/a
13	1765	22	125	n/a
43	1800	20	108	n/a
20	1810	17	119	n/a
8	1825	20	100	n/a
9	1830	17	67	n/a
21	1880	13	116	n/a
44	1880	18	90	n/a
Ski				
48	1650	15	165	1996
50	1650	17	189	1996
34	1755	21	140	1989
12	1760	23	110	1976
26	1800	2	100	1989
35	1815	26	105	1989
40	1815	12	90	1989
42	1825	27	56	1989
29	1860	25	104	1989
37	187	17	119	1989
Groom + ski				
46	1640	4	135	1996
49	1655	15	158	1996
30	1680	14	174	1989
31	1700	20	170	1989
32	1720	21	152	1989
10	1765	17	107	1976
41	1815	14	84	1989
39	1825	23	276	1989
45	1865	23	125	1989
38	1870	11	300	1989

Transect 30 (a Groom + ski treatment) was removed from the analysis of ground cover classes. It was originally thought to be a degraded cushionfield, but is in fact located on severely degraded *Celmisia viscosa*.

For the remaining 29 transects, the average percentage ground cover was calculated for each of the six ground cover classes for 1997 and 2000 (see Section 2.1).

Using these data, the statistical significance of the following relationships were investigated:

Ground cover classes and environmental variables (2000)

The average percentage ground cover data for 2000 were log-transformed to improve the normality of the data. Pearson correlation was used to investigate the relationships between the ground cover classes and the environmental variables (altitude, aspect, and slope).

Ground cover classes and management variables (2000)

The average percentage ground cover data for 2000 were log-transformed to improve the normality of the data. A one-way analysis of variance (ANOVA), which had an unbalanced design due to the removal of transect 30 from the analysis, was used to investigate the relationship of ground cover classes with management treatment (i.e. Groom + ski, Ski, and Control) in 2000.

To determine whether differences in ground cover classes between transects were still significant after controlling for environmental variables (i.e. altitude, aspect, slope, and duration of treatment, representing the number of years since treatment was first applied), a one-way analysis of covariance (ANCOVA) was used. This analysis was unbalanced due to the removal of transect 30 from the analysis.

The results were robust with respect to the type of analysis used, and the same results were obtained using a non-parametric Kruskal-Wallis test. This repeats the analyses performed on the 1997 cover classes (Wardle & Fahey 1999).

Changes in average ground cover from 1997 to 2000

The relationship between change in average ground cover from 1997 to 2000 and the environmental variables was determined using correlation variables and tested using the *t*-test. The relationship between change in average ground cover and management treatment was analysed using a one-way unbalanced ANOVA.

2.3.3 Species frequency and richness

Life-form classification of plant species

Cushionfields at Treble Cone Ski Field exhibit a natural variability in species present from site to site. To determine any management effects on species frequency, it was therefore necessary to classify each species into one of six life-form categories prior to analysis: cushion plants, woody dicotyledon herbs (non-cushion habit), other dicotyledon herbs, grasses and other monocotyledons, lichens, and mosses. These are listed in Table 2.

Clarification of 1997 analysis procedure

A programming error has been identified in the analysis of the species frequency data for 1997. While it was intended to express the total number of occurrences for each species within a particular life-form category as a percentage, which would give an average percentage per species (Wardle & Fahey 1999), the analysis was done on the percentage of points along a transect with at least one species of that life-form category present.

However, percentage frequency is not useful when assessing whether a change in species composition is significant through time, as the percentage frequency could remain the same or go down, even though the total number of occurrences of, for example, species of grasses and other monocotyledons went up.

TABLE 2. PLANT SPECIES RECORDED IN SAMPLING AND THE LIFE-FORM CATEGORIES USED IN TREBLE CONE SURVEY.

Cushion plants
Abrotanella inconspicua
Anisotome imbricata
Chionohebe thompsonii
Colobanthus buchananii
Dracophyllum muscoides
Hectorella caespitosa
Phyllachne colensoi
Phyllachne rubra
Raoulia hectorii

Other dicotyledon herbs
Anisotome flexuosa
Anisotome languinosa
Brachycome sinclairii
Cardamine bilobata
Epilobium tasmanicum
Euphrasia zelandica
Gentiana divisa
Hieracium lepidulum
Leptinella goyenii
Ourisia glandulosa
Schizeilema exiguum
Viola cunninghamii

Woody dicotyledons (non-cushion habit)
Aciphylla kirkii
Celmisia haastii
Celmisia laricifolia
Celmisia lyallii
Celmisia viscosa
Chionohebe densifolia
Coprosma perpusilla
Dracophyllum pronum
Hebe lycopodioides
Melicytus alpinus
Raoulia grandiflora

Grasses and monocotyledons
Agrostis magellanica
Agrostis muelleriana
Carex pterocarpa
Carex pyrenaica
Chionochloa macra
Koeleria sp.
Luzula pumila
Marsippospermum gracile
Poa colensoi
Rytidosperma pumilum

Lichens
Alectoria nigricans
Cetraria islandica var. *antarctica*
Siphula dissoluta
Thamnolia vermicularis

Mosses
Mosses not identified

Analysis procedure in 2000

To provide a more meaningful statistical analysis of change in species composition from 1997 to 2000, the data have been analysed in a slightly different way. The total number of species occurrences in sample points along each transect were summed for each life-form category. This provides a 'total' of, for example, occurrences of grasses and monocotyledons rather than an average per species. If total occurrences of a life-form category go up between 1997 and 2000, that category must have increased along the transect.

Sample points on 'cushionfield vegetation' only

To determine any change in species frequency on cushionfield vegetation through time, only those sample points in the 30 transects which had been classified as 'cushionfield vegetation' were analysed. The occurrences of live and dead species in each life-form category were summed. A *t*-test was used establish whether any change in occurrence of life-form categories from 1997 to 2000 is greater or less than 0.

A balanced ANOVA was used to test whether each of the following relationships was significant: between management treatments (i.e. Groom + ski, Ski, and Control) and total species occurrence in any life-form category in 1997 and 2000, and the change in occurrence of life-form category due to management treatment through time (1997–2000).

Biomass

Diagrammatic representation of height-frequency values for the taller species present on each transect in 1997 and 2000 provides a visual record of how their biomass changes through time (Appendix 4).

The following information was extracted for *Chionochloa macra*, *Poa colensoi*, and *Celmisia viscosa*:

- height of maximum frequency: for each transect, this is the height-above-ground interval most frequently recorded along that transect;
- mean tiller height: averaged over the points along a transect at which a species is present (calculated for *Chionochloa macra* only);
- total height frequency: total number of height-frequency intervals in which a species is recorded at all points along the transect;
- change (%) in total height frequency

$$= \frac{\text{(total height freq. in 1997 – total height freq. in 2000)}}{\text{total height frequency in 1997}} \times 100$$

Because the primary focus of the monitoring programme is on cushionfield vegetation, relatively few sample points were present on tussock grassland. Therefore, no statistical analysis was done on these data.

3. Results

3.1 GROUND COVER

Percentage data for ground cover classes at each transect in 2000 are presented in Appendix 5.

3.1.1 Ground cover classes and environmental variables (2000)

The cover of dead vegetation is significantly negatively correlated with elevation ($r = -0.46$, $P = 0.012$, $n = 29$) and positively correlated with aspect ($r = 0.37$, $P = 0.047$, $n = 29$), i.e. there is a higher cover of dead vegetation at lower elevation and on shadier sites. This relationship is similar to that found in 1997 (Wardle & Fahey 1999), when there was a greater cover of dead vegetation at lower elevations ($r = 0.48$, $P = 0.007$, $n = 30$) and on shadier sites ($r = 0.45$, $P = 0.012$, $n = 30$).

In 2000, both moss ($r = 0.41$, $P = 0.027$, $n = 29$) and rock ($r = 0.38$, $P = 0.039$, $n = 29$) were also positively correlated with elevation.

3.1.2 Ground cover classes and management variables (2000)

There was a lower cover of live vegetation on the Groom + ski transects than on transects of the other two treatments (Table 3). Live vegetation was the only cover class that differed significantly among the three management treatments (ANOVA, $F_{2,26} = 4.90$, $P = 0.02$).

The difference in ground cover classes among management treatments was still significant after controlling for differences among transects in altitude, aspect, and slope (ANCOVA, $F = 4.92$, $P = 0.016$).

Contrary to the results in 1997, live vegetation cover did not show a strong, significant relationship with the number of years that a transect had been skied or groomed (regression $F = 4.09$, $P = 0.06$).

TABLE 3. AVERAGE PERCENTAGE GROUND COVER (± STANDARD ERROR) FOR EACH 2000 COVER CLASS BY MANAGEMENT TREATMENT.

Number of transects are given in brackets. The results of ANOVA (*F* and *P* values) testing for differences in average cover among management treatments in each of the cover classes are shown in the last two columns. 'Cushionfield vegetation' sample points only.

	GROOM + SKI (9)	SKI (10)	CONTROL (10)		
Cover class	Average % cover ± S.E.	Average % cover ± S.E.	Average % cover ± S.E.	$F_{2,26}$	P
Live veg	32 ± 2	38 ± 1	41 ± 2	4.9	0.02
Dead veg	30 ± 3	32 ± 2	25 ± 2	2.11	0.14
Bare + Rock	18 ± 3	14 ± 1	12 ± 2	2.04	0.15
Moss	7 ± 1	4 ± 1	4 ± 1	1.63	0.22
Lichen	13 ± 3	13 ± 1	17 ± 2	1.38	0.27

3.1.3 Change in average cover from 1997 to 2000

Irrespective of management treatment, the following changes in ground cover are significant: a negative change in cover of dead vegetation, and bare+rock cover classes, and a positive change in moss and lichen cover have taken place since 1997 (Table 4), i.e. there is less dead vegetation and bare+rock, and more moss and lichen in 2000 than in 1997. The cover of live vegetation shows no significant tendency to increase or decrease.

TABLE 4. THE MEAN CHANGE IN AVERAGE PERCENTAGE COVER FROM 1997 TO 2000 ACROSS ALL TRANSECTS.

The results of a *t*-test to determine whether the mean change in cover differs significantly from 0 are shown. 'Cushionfield vegetation' sample points only.

COVER CLASS	NUMBER OF TRANSECTS	MEAN CHANGE IN % COVER	*t*-VALUE	*P*
Live	29	–1.1	1.4	0.17
Dead	29	–3.5	4.3	< 0.001
Bare + Rock	29	–1.6	2.5	0.02
Moss	29	2.3	6.8	< 0.001
Lichen	29	2.2	2.2	0.004

There is no significant correlation between the change in average cover and any of the environmental variables (elevation, aspect, slope, year of first skiing).

3.1.4 Change in cover in relation to management treatments

The results of a one-way unbalanced ANOVA show little difference in change in cover between management treatments (Table 5). The change in moss cover shows a significant difference at $P < 0.05$, and has increased more on the Groom + ski transects. The change in live vegetation cover shows a less significant difference ($P = 0.06$), and has decreased more on Ski transects. Although the cover of dead vegetation has decreased across all the transects since 1997 ($P = 0.08$), the smallest decrease has occurred on Ski transects, while the greatest reduction in cover of dead vegetation since 1997 has taken place at Control transects.

TABLE 5. AVERAGE CHANGE IN PERCENTAGE COVER (1997–2000) BY MANAGEMENT TREATMENT.

Number of transects are given in brackets. The results of ANOVA (*F* and *P* values) testing for differences in average change in cover among management treatments in each of the cover classes are shown in the last two columns. 'Cushionfield vegetation' sample points only.

Cover class	GROOM + SKI (9) Average change % cover ± S.E.	SKI (10) Average change % cover ± S.E.	CONTROL (10) Average change % cover ± S.E.	$F_{2,26}$	P
Live veg	–0.1 ± 1.6	–3.5 ± 1.1	0.5 ± 0.9	3.15	0.06
Dead veg	–4.7 ± 1.7	–1.0 ± 1.5	–5.0 ± 0.7	2.84	0.08
Bare + Rock	–2.1 ± 1.6	–0.7 ± 0.9	–2.1 ± 0.8	0.53	0.60
Moss	3.5 ± 0.7	1.9 ± 0.4	1.5 ± 0.5	3.99	0.03
Lichen	2.7 ± 0.7	0.9 ± 1.7	2.9 ± 0.8	0.91	0.42

3.2 SPECIES FREQUENCY

Data for total species occurrences for each transect in 1997 and 2000 are presented in Appendix 3. The number of sample points classed as 'cushionfield vegetation' has not changed since 1997.

3.2.1 'Cushionfield vegetation' only

A summary of the average number of occurrences per transect of species in each life-form category by management treatment (for cushion vegetation only) is given in Table 6.

There was no significant difference (balanced one-way ANOVA, $P > 0.05$) in total species occurrences for any of the life-form categories by management treatment in either 1997 or 2000.

Irrespective of management treatment, there is a significant increase in the occurrence of dead cushion plant species and live dicotyledon herb and lichen species, and a significant decrease in the occurrence of dead woody dicotyledon and dead monocotyledon species across all transects since 1997 (Table 7). However, there was no significant difference (balanced one-way ANOVA, $P > 0.05$) in the mean change in any of the life-form categories by management treatment between 1997 and 2000.

TABLE 6. TOTAL NUMBER OF SPECIES OCCURRENCES FOR EACH LIFE-FORM CATEGORY ALONG A TRANSECT.

Averaged over the 10 transects for each management treatment in 1997 and 2000 (e.g. live cushion plants had an average of 52.6 occurrences along control transects in 1997, where one occurrence = a live cushion plant species being recorded at one point along the transect). The degree of change is given in brackets. 'Cushionfield vegetation' sample points only.

	GROOM + SKI (10)			SKI (10)			CONTROL (10)		
Life-form category	1997	2000	(Change)	1997	2000	(Change)	1997	2000	(Change)
Live cushion plants	42.5	40.9	(–1.6)	66.2	64.2	(+2.0)	52.6	54.0	(+1.4)
Dead cushion plants	23.5	26.1	(+2.6)	35.8	44.2	(+8.4)	24.4	26.2	(+1.8)
Live woody dicot	19.3	16.6	(–2.7)	19.9	25.1	(+5.2)	24.3	21.4	(–2.9)
Dead woody dicot	11.7	10.2	(–1.5)	8.5	7.9	(–0.6)	13.4	8.9	(–4.5)
Live dicot herb	3.6	6.6	(+3.0)	3.8	7.7	(+3.9)	3.9	4.6	(+0.7)
Dead dicot herb	0.8	0.8	(0.0)	0.5	0.3	(–0.2)	0.0	0.2	(–0.2)
Live monocot	46.5	45.6	(–0.9)	37.2	35.4	(–1.8)	41.4	36.4	(–5.0)
Dead monocot	15.2	9.0	(–6.2)	11.6	6.4	(–5.2)	11.4	6.7	(–4.7)
Live moss	33.0	40.7	(+7.7)	36.9	31.1	(–5.8)	36.6	30.6	(–6.0)
Live lichen	53.6	64.2	(+10.6)	71.5	71.8	(+0.3)	78.1	82.9	(+4.8)

TABLE 7. AVERAGE CHANGE IN SPECIES OCCURRENCE BY LIFE-FORM CATEGORY.

All 30 transects, for 'cushion vegetation' sample points only (1997–2000). The results of a *t*-test (*t* and *P* values) for differences in average change in species occurrence by life-form category are shown.

LIFE-FORM CATEGORY	MEAN CHANGE IN OCCURRENCE	SE	*t*-VALUE	*P*
Live cushion plants	–0.73	1.80	0.41	0.69
Dead cushion plants	4.27	1.43	2.99	0.006
Live woody dicot	–0.13	1.84	0.07	0.94
Dead woody dicot	–2.2	1.04	2.11	0.04
Live dicot herb	2.53	1.07	2.37	0.02
Dead dicot herb	0.0	0.14	0.0	1.00
Live monocot	–2.57	1.77	1.44	0.16
Dead monocot	–5.37	1.20	4.47	0.0
Live moss	–1.37	3.03	0.45	0.66
Live lichen	5.23	1.91	2.74	0.01

3.2.2 Biomass

Biomass data for *Chionochloa macra*, *Poa colensoi* and *Celmisia viscosa* are summarised in Table 8.

Mean tiller height of *Chionochloa macra* has increased across all transects from 1997 to 2000. Total height frequency of *Chionochloa macra*, as an indicator of plant biomass, however, has either remained the same or increased only slightly across all transects.

There has been a 7–27% decline in total height frequency of *Poa colensoi* across all transects, the largest reduction occurring on control sites (27%).

The total height-frequency of *Celmisia viscosa* has decreased by 30% on Control sites, while on Ski and gGroom + ski sites it has increased slightly (0.5–4%).

TABLE 8. COMPARISON OF HEIGHT-FREQUENCY DATA FOR THREE SPECIES BY MANAGEMENT TREATMENT.

Species are *Chionochloa macra*, *Poa colensoi*, and *Celmisia viscosa* in 1997 and 2000. Ten transects for each treatment.

	GROOM + SKI		SKI		CONTROL	
	1997	2000	1997	2000	1997	2000
Chionochloa macra						
Height of maximum frequency (cm)	16	20	17	20	16	20
Total height frequency	687	687	687	693	932	944
Change (%)		0		< 1		1
Mean tiller height (cm)	39	43	43	47	40	43
Poa colensoi						
Height of maximum frequency (cm)	5	5	5	5	5	5
Total height frequency	361	301	236	219	283	207
Change (%)		-17		-7		-27
Celmisia viscosa						
Height of maximum frequency (cm)	6.1	6.1	5.0	5.8	5.5	6.5
Total height frequency	189	197	115	121	213	149
Change (%)		4		0.5		-30

3.2.3 General observations

Vegetation changes

In general, the extent of groomer and/or skier damage does not appear to have changed much in the vicinity of the established transects. However, in some cases exposed woody stems and roots, usually of dead cushion vegetation, have been broken, revealing bare ground (e.g. at transect 48G), or bare ground has been removed to expose rock beneath (e.g. at transect 10G). On some cushionfields that are skied and groomed (especially at high altitude), moss and filmy lichens appear to be colonising bare ground. On a few groomed transects, blue tussock and *Luzula pumila* also appear to be increasing.

The only area where groomers have caused a major increase in vegetation damage and earth disturbance is above the ski field on a steep slope used to gain access to an area known as Tim's Table. Groomers are used towards the end of the ski season to take skiers up to the ridgeline above the ski field. Here, large areas of *Celmisia viscosa* and cushionfield have been totally removed, exposing the soil, which is now subject to erosion associated with frost heave and needle ice. Some damage was evident here in 1997, but the area affected has increased markedly (Appendix 6, Fig. A6.9, upper). A more extensive area of damage is now apparent further upslope where groomers travel over a steep cushionfield lip towards the ridge (Appendix 6, Fig. A6.9, lower).

Of concern is the presence of *Hieracium lepidulum* seedlings above 1800 m. Some plants were found on Groom + ski transect 41G on Saddle Ridge and near 45G on Side Saddle. No other exotic species were seen in the vicinity of the transects, although browntop (*Agrostis capillaris*) has been sown in areas of major earth disturbance.

Changes in management treatment

A change in the distribution of skiers and snowboarders and a thin snow pack at Treble Cone Ski Field since the vegetation monitoring programme was first established in 1997, have led to some of the transects experiencing a change in management treatment. Several of the Control transects are now being disturbed by skiers. For example, while Control transect 47C is disturbed relatively infrequently, skiers have been seen on it, and several pegs had been dislodged as a result.

There is increasing use by snowboarders and skiers of off-field areas, such as that south of the New Boundary line, possibly due to the recent construction of a ‘bridge’ across a gully enabling access back to the Saddle chairlift. Control transects 8C, 9C, and 43C are therefore likely to be receiving low levels of skier traffic. In addition, transect 37S (Ski) at the top of the Saddle area has been cut by groomer tracks since 1997.

The long-term average snow fall for Treble Cone is 248 cm (Tom Elworthy, pers comm.). The total snow base for 1997, 1998, and 1999 was 175, 119, and 131 cm, respectively, with the figure of 119 cm for 1998 being the lowest in 10 years. Temperatures have been 1.5–2.0°C above average over the last few years, and there has been more rainfall than usual on the ski area in winter.

As a direct consequence of there being little snow in recent years, ‘groom + ski’ transect 10G, at the top of the six-seater chairlift, has received no grooming since 1997.

4. Discussion

4.1 MONITORING ASSESSMENT

All the transects were successfully re-located in 2000, although some pegs had been removed by skier/groomer activity. Resurveying at intervals of 10 years is considered adequate for monitoring the impacts of snow grooming activity on ground cover and species frequency, unless there are major changes in disturbance intensity in the interim. However, it will be necessary to check and replace lost pegs at more frequent intervals to ensure that transects are not lost.

The inconsistent pattern of skier and groomer use through time at transect sites is a factor that could have a bearing on the results of the vegetation monitoring programme. Of most concern is the increased skier traffic on control sites located around the New Boundary area. Any expansion of grooming activities on to areas previously only skied (as has happened at transect 37S) may also yield confusing results in the future.

4.2 DIRECT DAMAGE TO VEGETATION BY GROOMING AND SKIING

Cushionfields occupy sites that experience many freeze–thaw cycles during the short growing season and have moist frost-active soils (Bliss & Mark 1974). They are commonly found on convex slopes and solifluction hummocks, where exposure to strong winds often results in a thin snow pack, which readily melts (Korner & de Moreas 1979; Talbot et al. 1992). When snow-grooming machinery is used in such locations, the treads and blades of the moving vehicle scalp areas of cushion vegetation, revealing patches of bare ground, or leaving areas of dead vegetation and cushion plant litter.

4.2.1 Spatial variation in vegetation characteristics in 2000

At 'cushionfield vegetation' sample points at Treble Cone Ski Field, the total live vegetation cover is significantly less at sites which are groomed, than those that are only skied or undisturbed (Table 3). There were many visual signs of physical damage on groomed cushionfields, e.g. scalped hummocks, broken woody stems, sheared-off vegetation and areas of exposed bare ground. Cushion plants such as *Dracophyllum muscoides* and *Chionohebe thompsonii* appeared to be particularly prone to stem breakage. Some cushion plants showed signs of scraping from ski edges. However, areas of extensive bare ground or rock resulting from severe scalping were mostly confined to steep slopes where skiers traverse the hillside or scrape the snow cover away at the base of moguls (e.g. transect 29S).

This type of direct damage has been observed in Germany (Ries 1996), western North America (Price 1985; Hamilton 1981), and Alaska (Felix & Raynolds 1989; Felix et al. 1992). In Colorado, Greller et al. (1974) found that where snow was lacking in alpine tundra communities, the treads of snowmobiles scraped the soil away, removed the lichen and damaged prominent rigid cushion plants.

However, at Treble Cone Ski Field management treatment does not have a significant effect on species composition in terms of summed total number of species occurrences for each life-form category along each transect (Table 6).

4.2.2 Vegetation changes between 1997 and 2000

Irrespective of management treatment, there has been a significant decrease in cover of dead vegetation, and bare ground + rock, and an increase in moss and lichen at cushionfield transects since 1997. While total vegetation cover of live cushion plant species (in relation to 'cushionfield vegetation' sample points) has been significantly reduced at sites which have been groomed, in both 1997 (Wardle & Fahey 1999) and 2000 (Table 3), it is notable that the cover of live vegetation has, however, remained stable through time (Table 4). Certainly, field observations indicated that, after the initial scalping episode, the level of damage, in most instances, does not appear to increase (Appendix 3). The greatest increase in moss cover has occurred on groomed transects. The cover of live vegetation has declined on disturbed sites, with the greatest decline occurring on skied transects.

The total species occurrence in any of the life-form categories is not significantly affected by grooming, skiing, or control treatments in either 1997 or 2000, and no significant change in total species occurrence has taken place in that time.

In terms of species frequency, on groomed transects at Treble Cone Ski Field the percentage of points along a transect with at least one cushion plant species present was significantly lower than at either skied or control sites in 1997

(Wardle & Fahey 1999). However, when the 1997 data were reanalysed (see Section 2.3.2) to determine the total number of species occurrences for each life-form category along a transect, it was found that all transects, irrespective of whether they have been groomed, or skied, or are control sites, have a similar number of total occurrences of cushion plant species. This indicates that, at least in 1997, occurrences of cushion plants tended to be more clumped along groomed transects than ski or control transects, so that there were fewer sample points with live cushion plants along a groomed transect. Since species frequency data for 2000 were not analysed in the same way as the 1997 data were originally (Wardle & Fahey 1999), it cannot be assumed that this conclusion still holds for the 2000 data set. However, field observations in 1997 and 2000 confirmed that groomed transects had large patches with no cushion plants growing on them.

In 1997, a significant relationship was observed between the number of years a transect had been skied or groomed, and live vegetation cover (Wardle & Fahey 1999). This relationship was no longer apparent in 2000. One reason for this could be that most of the damage had been done when the sites were first disturbed, with no further significant decline in live vegetation cover taking place. Other workers (e.g. Bell & Bliss 1973; Wanek 1971, 1974) have noted that the impact on vegetation is greatest in the first season and that plants appear to recover in subsequent seasons. Alternatively, the inconsistent management at some transects (see Section 3.2.4) may explain this relationship no longer being apparent in 2000.

The results from this study indicate that ongoing management is not actually causing increased bare ground or major changes in vegetation. However, field observations suggest that some cushionfields at Treble Cone Ski Field appear to be in a state of initial recovery, with minor changes in ground cover taking place, e.g. bare ground being colonised by moss. Field observations at Treble Cone Ski Field suggest that when a cushionfield is disturbed by grooming and/or skiing, live vegetation is initially damaged or scraped off, revealing an area of bare ground, and brittle lichens such as *Cetraria islandica* var. *antarctica* are crushed. With time, further bare ground may be exposed as the exposed stems of dead vegetation are broken off to form a cushionfield litter. This litter may or may not remain in situ. If no further disturbance takes place, the area of exposed bare ground can be colonised by lichens and *Polytrichum juniperinum* moss and, subsequently, by monocotyledons such as blue tussock (*Poa colensoi*) and *Luzula pumila*. Remaining dead vegetation may also be colonised by lichens, until the original species is difficult to identify. However, if a damaged area is repeatedly scraped, this succession does not appear to take place. Colonisation of bare ground by moss, lichens, blue tussock, and *Luzula pumila* appears to be taking place at some transects (e.g. transects 39G, 45G and 41G), but not at recently disturbed transects such as those in the Saddle Valley area. Secondary succession of a severely disturbed *Dracophyllum muscoides* cushionfield site on the Old Man Range in Central Otago resulted in an increase in blue tussock, and a notable absence of *Cetraria islandica* var. *antarctica*, 11 years after the initial roadworks (Roxburgh et al. 1988).

The perceived role of moss in revegetating areas of bare ground is supported by the results of the monitoring programme which revealed a significant increase in the cover of moss across all transects since 1997, with the greatest increase taking place on Groom + ski transects. This result is contrary to that noted by Forbes (1992) who found that mosses and lichens are especially slow in regenerating after the passage of summer seismic vehicles in Alaska.

While loss of 'brittle' lichen appears to be an indicator of loss of cushionfield condition, the colonisation of bare ground by other lichens may be a first step in revegetation of damaged areas. However, no statistically significant relationship could be found between change in lichen cover and management treatment. There are a number of possible reasons for this. First, transects within a management treatment are at different stages of revegetation. Therefore, a long period of time may be required to detect the changes in ground cover. Secondly, the vegetation monitoring programme design is insensitive to the role of lichen in vegetation succession in disturbed cushionfields. For example:

- The 'lichen' ground cover class lumps together the brittle lichens which grow on top of healthy cushionfield vegetation with other lichens that are more associated with colonising bare ground and dead vegetation.
- The species composition assessment identifies only one lichen at the species level, i.e. the 'brittle' lichen *Cetraria islandica* var. *antarctica*; all other lichens are lumped together as 'other lichen'.

All transects at Treble Cone Ski Field exhibit significant increases in the occurrence of lichen, live dicot herbs and dead cushion plant species, and a decrease in frequency of dead woody dicotyledons and monocotyledons between 1997 and 2000. In similar alpine environments on the Old Man Range in Central Otago, changes in species composition of cushionfields have taken 11 years to become apparent after disturbance (Roxburgh et al.1988). It would thus be instructive to resurvey the vegetation transects at Treble Cone at intervals of 10 years over a 30-year period.

4.2.3 Confounding factors

It is possible that management effects are confounded with other factors related to spatial variation, but which have not been controlled for during the analysis (e.g. microtopography characteristics, frequency and intensity of grooming or skiing disturbance, presence of ski training gates which influence the pattern of skier usage, etc.). Such factors may mask any management effect on this data set. Unknown factors are causing natural change at Control sites, such as an increase in dead vegetation cover, which presumably are also affecting the ecology of cushionfields at Groom + ski sites. In addition, some transects (see Section 3.2.4) have received inconsistent management treatments, at least since 1997, which may again mask management effects.

4.2.4 Tussock species

While overseas workers have found that erect woody plants are most vulnerable to damage by oversnow vehicles (e.g. Forbes 1992), Greller et al. (1974) also found that the passage of snowmobiles in the Front Range of the Colorado Rocky Mountains resulted in the scalping of *Kobresia* tussocks where the canopy was open. However, at Treble Cone Ski Field, damage to *Chionochloa macra* tussocks on transects was rarely observed. On the contrary, there has been an increase in tiller height and biomass across all transects since 1997.

This can be explained in terms of the design of the monitoring programme wherein cushionfields were the main focus. Thus only tussocks growing immediately adjacent to cushionfields were monitored. Cushionfields grow on convex slopes and solifluction lobes whereas tussocks tend to occupy hollows at the edge of the humps, which attract a deeper snow pack. Therefore, when a snow groomer passes over an area of cushionfield, the groomer tracks or blade are more likely to catch on the cushionfield hump than shear the tussocks, which are protected by the topography and deeper snow pack. However, where an even, gentle slope is present (e.g. transect 30G), tussocks have been sheared.

The observed increase in tiller height and biomass since 1997 is therefore likely to be in response to climatic factors that have favoured tussock growth, including the production of inflorescence, which extends above the height of tussock leaves.

There has been a reduction in biomass of *Poa colensoi* across all transects and of *Celmisia viscosa* at control sites since 1997. There is no obvious explanation for this, although it is possible that browsing by sheep and/or insects may have contributed to this reduction.

4.3 INDIRECT EFFECTS OF GROOMING AND SKIING ON VEGETATION

Although direct damage associated with shearing of vegetation is the most obvious impact of snow grooming and skiing, a change in species composition can occur in response to snow compaction, resulting in changes in length of growing season and soil moisture availability (Price 1985; Baiderin 1980; Grabherr 1985; Emers et al. 1995).

Snow compaction leads to changes in thermal and hydrological properties of the snow pack. Snow density, thermal conductivity and length of snow retention have been found to increase, while porosity, permeability and water-holding capacity are decreased (Neumann & Merriam 1972). Changes in snow pack characteristics as a result of over-snow vehicle use, including increases in density, have been noted by Baiderin (1980), Kattelmann (1985), and Pesant (1987). At Treble Cone Ski Field, increases in snow density and hardness attributed to snow grooming are similar to those observed overseas, but lie at the low end of the range (Fahey et al. 1999). Since snow thermal conductivity increases in proportion to the square of the increase in density (Yen 1969), the increases observed at Treble Cone Ski Field have the potential to alter the thermal regime of the underlying soil, and certainly are sufficient to cause deeper frost penetration (Appendix 2). This may delay soil bacterial activity and subsequent litter decomposition (Meyer 1993). In addition, changes in soil temperature can result in changes in timing of snow melt, with compacted snow tending to lie longer on groomed ski slopes. Hamilton (1981) and Price (1985) suggest that over a period of years it is probable that retarded snow melt will cause a change in species composition through changes in the length of growing season, soil moisture distribution and soil erosion by wind, water and needle ice. A comparison of soil temperatures monitored at a Groom + ski transect (46G), and a Control transect (4C) showed no retardation in snow melt (Appendix 2) but, because measurements were taken at only one site, we do not know whether this result is more widely applicable.

Plants have different levels of vulnerability and ability to recover from the effects of snow compaction. The characteristics that determine their vulnerability are the timing of flowering, and growth form and size. Prolonged snow-lie adversely affects early-spring-flowering perennials and ephemeral plants as they have a shorter growing season. Baiderin (1980, 1983) observed in Russia that the colder temperatures under compacted areas retarded growth and flowering of early spring flowers and reduced their seed productivity and viability, resulting in changes in plant species composition. Plants flowering in early spring dropped out of the plant community and were replaced by later-flowering species.

No significant change in species composition of cushionfields at Treble Cone Ski Field has been observed. However, such changes take place over a long time, and prolonged snow melt may be offset by a trend towards warmer winters. Indeed, as already noted, snow melt was not delayed by compaction at one groomed transect monitored during winter 1999 at Treble Cone (Appendix 2). In a similar alpine environment on the Old Man Range in Central Otago, changes in species composition of cushionfields in response to a change in snow pack characteristics have taken 32 years to become apparent (Smith et al. 1995). At Treble Cone Ski Field, the species composition of cushionfields has only been monitored since 1997, yet cushionfields have been experiencing grooming and skiing disturbance for between 3 and 23 years. It is therefore unlikely that the transects all exhibit the same pattern of change in species composition, as the length of time available for recovery to take place has varied greatly. For statistically significant changes in species composition, in response to changes in snow compaction, to become evident, it will be necessary to resurvey the transects over a long period of time. As previously mentioned, management effects may be confounded with other factors which have not been controlled for during analyses.

Other vegetation monitoring programmes established at Treble Cone (Jensen et al. 1997) and the Remarkables (Knight Frank 1994) Ski Fields reported that up to 73% of transects were lost as a result of major disturbances such as track building and terrain modification. Similar problems were encountered at Turoa Ski Field due to transect loss (Rogers & Kimberley 1990). It is important that the full set of cushionfield transect sites remain unmodified during the life of this study, and this condition should be included as part of the ski field's licence to operate on land managed by the Department of Conservation.

4.4 MINIMUM SNOW PACK THICKNESS FOR VEGETATION PROTECTION

Ries (1996) concluded that a snow depth of at least 30 cm is necessary to limit damage to plant communities. However, few data are offered to support this conclusion. The US Federal Government requires a minimum average snow depth of 15 cm in order for vehicles to be permitted on the arctic tundra for seismic exploration (US Department of Interior 1983). An investigation into the the relationship between snow cover and degree of disturbance in the arctic by Felix & Raynolds (1989) showed that vegetation disturbance across tussock tundra was lower on vehicle trails where snow depths exceed 25 cm. Snow depths of 15 cm prevented impact on the soil from vehicle tracks, but did not prevent vegetation disturbance. The threshold for disturbance in moist sedge-shrub tundra was 20 cm. However, Felix & Raynolds (1989) concluded that a snow cover of 50 cm would be necessary to prevent any disturbance.

5. Conclusions

Grooming damages cushionfields by scalping off localised areas of protruding cushion vegetation. This significant loss of cushionfield vegetation is replaced by areas of dead vegetation, cushion plant litter, or bare ground (Tables 3 and 5).

Areas exhibiting vegetation damage from grooming and skiing have not increased since 1997 (Table 4). Once the initial physical damage is done, the actual extent of bare ground is unlikely to increase unless new patterns of groomer or skier use occur. The only large area of bare soil that has shown a substantial increase is on a steep slope below Tim's Table. It is currently experiencing erosion from frost heave and needle-ice activity.

The rate of vegetation succession on areas exposed by groomer blades or skiers will depend on whether the area of bare ground is repeatedly scalped each winter, thereby removing newly established plants.

The species composition of damaged areas where recovery takes place may depend on:

- the resilience of species to levels of disturbance. Monocotyledons such as *Poa colensoi* and *Luzula pumila* are likely to be more resilient than plants that are brittle and have slow rates of growth (e.g. *Dracophyllum muscoides* cushion plant, *Cetraria islandica* var. *antarctica* lichen);
- the frequency and intensity of ongoing physical disturbance;
- environmental factors affecting plant recolonisation, e.g. moss appears to colonise areas at high altitudes faster than those at lower altitudes at Treble Cone;
- the species present in the vicinity of the damaged area, and the characteristics of those species. Cushionfields that naturally have a greater diversity of species present have a wider 'selection' of species available to recolonise damaged areas. The ease with which a plant colonises bare ground will depend on various factors, such as methods of seed dispersal, rate of vegetative growth, and flowering rates;
- the presence of exotic plant species in the vicinity of damaged areas, which have faster growth rates, or are readily spread by seed, e.g. *Hieracium lepidulum* was first recorded in 2000, and poses a threat to the disturbed cushionfield communities at Treble Cone Ski Field.

No significant changes in species composition at cushionfields can be attributed to grooming or skiing activity. However, it is possible that changes in species composition in terms of live cushion plants and live moss may be significant if a larger sample size had been used. Studies in other alpine areas of New Zealand suggest that changes in species composition due to disturbance may take a decade or more to become apparent (e.g. Roxburgh et al. 1988; Smith et al. 1995). A commitment to continued monitoring is considered necessary if patterns of plant succession following disturbance by grooming and ski activity (i.e. either direct damage or indirect effects resulting from increased snow compaction) are to be understood in the long term.

In summary, the vegetation monitoring programme has revealed that:

- cushion plants are sensitive indicators of grooming- and skiing-related impacts;
- snow grooming has had more impact on total live vegetation cover than skiing alone;
- there was no significant difference in species composition among skied, groomed, and undisturbed sites.

Between 1997 and 2000 the monitoring programme has shown that:

- the cover of moss has significantly increased across all transects, with the greatest increase taking place on Groom + ski transects;
- there are significant increases in the occurrence of lichen, live dicotyledon herbs and dead cushion plant species across all sites;
- there is a significant decrease in the frequency of dead woody dicotyledons and monocotyledons across all sites;
- grooming and skiing does not have an impact on the biomass and height of *Chionochloa macra* tussocks associated with the cushionfield transects, primarily because they are more likely to be located in hollows and are thus protected by a deeper snow cover;
- the invasive weed, *Hieracium lepidulum*, is starting to colonise cushionfield vegetation above 1800 m;
- natural changes in ground cover are taking place at Control transects (e.g. less dead vegetation and more moss since 1997);
- the largest decline in height frequency of *Poa colensoi* (27%) and *Celmisia viscosa* (30%) has occurred at Control sites.

Compaction of the snow pack by snow groomers reduces the snow's insulating qualities leading to substantial soil freezing in groomed areas, whereas non-groomed sites with a snow cover > 20 cm may not experience any freezing (Appendix 2).

A snow cover of at least 20 cm appears necessary to prevent vegetation disturbance by over-snow vehicles, including snow groomers.

It is recommended that the transects be revisited every 3 years to replace lost pegs, and to re-photograph points of damaged areas on transects. It is desirable that the vegetation transects should be resurveyed within the next 10 years to assess changes in ground cover and species frequency for cushion vegetation, changes in the biomass of adjacent taller plant communities, the state of damaged areas recorded as photo points, and future monitoring needs; and similar surveys could usefully be continued for 30 years. To assist monitoring, an ongoing commitment from Treble Cone Ski Field management not to modify any of the cushionfield transect sites (nor to remove any of the transect pegs during the life of the monitoring programme) should be sought and formalised in the Operator's licence/lease agreement. The managers should be provided with a map of the transect sites, and be familiar with their locations.

Several management actions would assist the protection of the vegetation of the ski areas. Where new areas for skiing are being developed, especially where these areas are on exposed convex slopes, over-snow vehicles should only be used when the snow is continuous or exceeds 20 cm depth. In practical terms this means the avoidance of cushionfield vegetation, as this occupies convex slopes. Consideration could be given to oversowing earthwork areas with blue tussock, rather than exotic browntop, as it is suited to the alpine conditions, and may reduce the risk of further hawkweed invasion through contamination of seed.

6. Acknowledgements

This report originated from work carried out under Department of Conservation research investigation 2104.

We thank Richard Duncan for providing assistance with data analysis; Dale Norbury for assistance in the field; Claire Newell and Rob Wardle for commenting on an earlier draft; Christine Bezar for editing the report; Wendy Weller for wordprocessing; and the management of Treble Cone Ski Field for allowing access to field sites.

7. References

Baiderin, V.V. 1980: Experimental modelling of ecological consequences of winter. *Soviet Journal of Ecology 11 (3)*: 140–146.

Baiderin, V.V. 1983: Winter recreation and subnival plant development. *Soviet Journal of Ecology 13(5)*: 287–291.

Bayfield, N.G. 1979: Recovery of four montane heath communities on Cairngorm, Scotland, from disturbance by trampling. *Biological Conservation 15*: 165–179.

Bell, K.L.; Bliss, L.C. 1973: Alpine disturbance studies: Olympia National Park, USA. *Biological Conservation 5*: 25–32.

Bliss, L.C.; Mark, A.F. 1974: High-alpine environments and primary production in the Rock and Pillar Range, Central Otago, New Zealand. *New Zealand Journal of Botany 12*: 445–483.

Emers, M.; Jorgenson, J.C.; Raynolds, M.K. 1995: Response of arctic tundra plant communities to winter vehicle disturbance. *Canadian Journal of Botany 73*: 905–917.

Fahey, B.D.; Wardle, K. 1998: Likely impacts of snow grooming and related activities in the West Otago ski fields. *Science for Conservation 85*. Department of Conservation, Wellington.

Fahey, B.D.; Wardle, K.; Weir, P. 1999: Environmental effects associated with snow grooming and skiing at Treble Cone Ski Field. Part 2. Snow properties on groomed and non-groomed slopes. *Science for Conservation 120*: 49–62. Department of Conservation, Wellington.

Felix N.A.; Raynolds, M.K. 1989: The effects of winter seismic trails on tundra vegetation in NE Alaska, USA. *Arctic and Alpine Research 21(2)*: 188–202.

Felix, N.A.; Raynolds, M.K.; Jorgenson, J.C.; DuBois, K.E. 1992: Resistance and resilience of tundra plant communities to disturbance by winter seismic vehicles. *Arctic and Alpine Research 24 (1)*: 69–77.

Forbes, B.C. 1992: Tundra disturbance studies: long term effects of vehicles on species richness and biomass. *Environmental Conservation 19 (1)*: 48–58.

Grabherr, G. 1985: Damage to vegetation by recreation in the Austrian and German Alps. *In*: Bayfield, N.G.; Barrow, G.C. (Eds): The ecological impacts of outdoor recreation on mountain areas in Europe and North America. *Recreational Ecology Research Group Report 9*.

Greller, A.M.; Goldstein, M.; Marcus, L. 1974: Snowmobile impact on three alpine tundra plant communities. *Environmental Conservation 1(2)*: 101–110.

Hammitt, W.E.; Cole, D.N. 1987: Wildland recreation: ecology and management. Wiley, New York. 341 p.

Hamilton, E.H. 1981: The alpine vegetation of Marmot Basin, Jasper National Park, Alberta, and the impact of ski activities upon it. MSc thesis, Department of Botany, Edmonton, Alberta.

Jensen, C.; Webster, B.; Carter, D.; Treskonova, M. 1997: Succession in tussock grasslands: its implications for conservation management. *Science for Conservation 61*. Department of Conservation, Wellington. 43 p.

Kattelmann, R. 1985: Snow management at ski areas: hydrological effects. *In*: Watershed management in the eighties. Proceedings of the symposium sponsored by the committee on watershed management of the irrigation and drainage division of the American Society of Civil Engineers in conjunction with the ASCE Convention in Denver, Colorado.

Knight Frank, 1994: Vegetation monitoring at the Remarkables Ski Field. Unpublished report, Knight Frank (NZ) Limited, Land Resources Division, Christchurch, New Zealand.

Korner, Ch.; de Moreas, J.A.P.V. 1979: Water potential and diffusion resistance in alpine cushion plants on clear summer days. *Oecologia Plantarum 4*: 109–120.

Mark, A.F.; Bliss, L.C. 1970: The high-alpine vegetation of Central Otago, New Zealand. *New Zealand Journal of Botany 8*: 381–451.

Meyer, E. 1993: The impact of summer and winter tourism on the fauna of alpine soils in western Austria (Oetztal Alps, Ratikon). *Revue Suisse de Zoologie 100(3)*: 519–527.

Neumann, P.W.; Merriam, H.G. 1972: Ecological effects of snowmobiles. *Canadian Field Naturalist 86*: 207–212.

Pesant, A.R. 1987: Snowmobiling impact on soil properties and winter cereal crops. *Canadian Field Naturalist 101*: 22–32.

Price, M.F. 1985: Impacts of recreational activities on alpine vegetation in Western North America. *Mountain Research and Development 5*: 263–277.

Ries, J.B. 1996: Landscape damage by skiing at the Schauinsland in the Black Forest, Germany. *Mountain Research and Development 16(1)*: 27–40.

Rogers, G.; Kimberley, M. 1990: Turoa ski field, Tongariro national Park. Vegetation monitoring programme. Unpublished report prepared for the Dept of Conservation by the Forest and Wildland Ecosystems Division of the Forest Research Institute, Rotorua.

Roxburgh, S.H.; Wilson, J.B.; Mark, A.F. 1988: Succession after disturbance of a New Zealand high-alpine cushionfield. *Arctic and Alpine Research 20(2)*: 230–236.

SAS Institute Inc. 1989: SAS/STAT User's Guide, Version 6, Fourth Edition, Volume 1, Cary NC: SAS Institute Incorporated. 943 p.

Scott, D. 1965: A height-frequency method for sampling tussock and scrub vegetation. *New Zealand Journal of Botany 3*: 253–260.

Smith, B.; Mark, A.F.; Wilson, J.B. 1995: A functional analysis of New Zealand alpine vegetation: variation in canopy roughness and functional diversity in response to an experimental wind barrier. *Functional Ecology 9*: 904–912.

Talbot, J.M.; Mark, A.F.; Wilson, J.B. 1992: Vegetation-environment relations in snowbanks on the Rock and Pillar Range, Central Otago, New Zealand. *New Zealand Journal of Botany 30*: 271–301.

US Department of the Interior. 1983: Geological and geophysical exploration of the coastal plain, Arctic National Wildlife Refuge, Alaska; final rule. *Federal Register 48(76)*: 16838–16870.

Wanek, W.J. 1971: Snowmobile impacts on vegetation, temperature and soil microbes. Pp. 16–129 *in*: Chubb, M. (ed.) Proceedings of the 1971 snowmobile and off-road vehicle research symposium. *Department of Parks and Recreation Resources Technical Report 8*. Michigan State University, East Lansing.

Wanek, W.J. 1974: A continuing study of the ecological impacts of snowmobiling in northern Minnesota. Final report for 1973/74. Center for Environmental Studies, Bemidji State College, Bemidji, Minnesota, USA. 54 p.

Wardle, K.; Wardle, R. 1992: The impact of a snow groomer on the vegetation and ground cover of Broken River ski basin. Unpublished report, Dept of Conservation.

Wardle, K.; Fahey, B. 1999: Environmental effects associated with snow grooming and skiing at Treble Cone Ski Field. Part I. Vegetation and soil disturbance. *Science for Conservation 120*: 1–48. Department of Conservation, Wellington.

Wardle, P. 1991: Vegetation of New Zealand. Cambridge Press, Cambridge.

Yen, Y-C. 1969: Recent studies on snow properties. Pp. 173–213 *in*: Chow, V.T. (ed.) *Advances in Hydroscience 5*.

Appendix 1

MEASUREMENT OF BEARING CAPACITY UNDER COMPACTED SNOW

Natural snow is an efficient attenuator of load. Its network of ice crystals spreads the load over a large area very quickly, thus greatly reducing contact pressure. However, compacting snow severely inhibits its ability to absorb loads and it begins to behave much more like other mostly elastic engineering materials in response to pre-catastrophic failure loads. We know that snow becomes compacted from grooming and skiing at Treble Cone Ski Field (Fahey et al. 1999). Average snow densities measured on groomed slopes were, for example, 36% higher, and had hardnesses up to 4 times those on non-groomed slopes.

Groomers used at Treble Cone Ski Field are manufactured in Germany by Kassbohrer. The model currently in use is the Pisten Bully 260. It has a blade at the front for redistributing the snow, and a rotary tiller at the rear for roughing up the snow surface (Figure A1.1). With these two attachments it has an overall length of 10 m and a width of 5 m. Its deadweight is 6.2 t. The quoted specific surface pressure is 0.0441 kg/cm^2 (4.2 kPa). In comparison, a Hitachi 20 t excavator, depending on track width, has a ground pressure of 43 kPa, 10 times that of the Kassborhrer; by comparison, a Caterpiller D7 bulldozer has a ground pressure of 70 kPa.

A device to measure pressure changes generated by the movement of snow groomers was installed at the learners' slope just north of the ski base at Treble Cone Ski Field in March 1999. It consisted of a 4-m-long oil-filled rubber hose connected to a transducer. The lead from the transducer was attached to a fence post on the perimeter of the slope (Fig. A1.2). The hose was buried just below the grassed surface, and parallel to the slope contour across the path the groomers take in the winter (Fig. A1.3).

Figure A1.1 One of the three Kassbohrer snow groomers used at Treble Cone Ski Field with attached blade at front and rotary tiller at rear.

Figure A1.2. Oil-filled rubber hose in position to measure bearing capacity of snow groomers at the learners' slope, Treble Cone Ski Field.

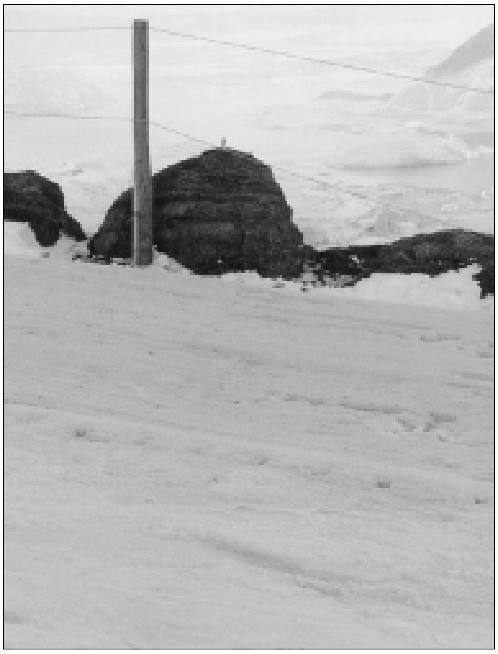

Figure A1.3. Late winter view of location of buried rubber tube designed to measure bearing capacity of snow groomers on learners' slope, Treble Cone Ski Field.

The equipment was left unattended until late in the season. Then, on three consecutive days in late September, a logger with a small internal battery was attached to the lead from the transducer while the slope was being groomed. It was set to record voltage changes at 2-second intervals, which could be converted into pressure. Given the short interval between readings, it was only possible to run the loggers continuously for about 2 hours before the memory capacity of the logger was exceeded. The snow pack in the vicinity of the buried hose was 10–15 cm deep at the time the first tests were run. It consisted mostly of coarse granular snow crystals with an ice base of 2–3 cm. In the first run on 20 September, the groomer made a series of passes across the buried hose. A very small increase in voltage was noted each time the groomer passed over the hose. Only when the groomer remained stationary across the hose for 30 seconds was there any notable increase in voltage output from the logger. On the final evening of measurements (22 September), four runs were made on a slightly thinner snow pack (7–10 cm). Again, the increase in voltage output was barely detectable. Thus the results suggest that, even with a thin snow cover subjected to increased compaction through groomer activity, there does not appear to be any major increase in loading at the soil surface.

A word of caution is in order here, however. While the technique used to measure pressure differences across the soil–snow interface is theoretically sound, the measured pressure changes during groomer passes were not truly representative of what was happening at the actual surface. This was because it was necessary to bury the oil-filled hose 2–3 cm below the surface to ensure that it was hidden from inquisitive keas. It is also noteworthy that increases in pressure at the ground surface were only detected after the groomer remained stationary over the site. It is difficult to translate the results of this exercise into a meaningful statement on the physical impact of groomer traffic at Treble Cone

Ski Field. About all we can conclude is that the increase in load associated with the passage of groomers over 10–15 cm of granular snow is apparently minimal. Thus a snow pack with its network of ice crystals can spread the load over a large area, although continued compaction of the snow may reduce the number of contacts, and its ability to absorb loads. Here the rotary tiller at the rear of the groomer may have more of a role to play by physically stirring up the upper 5–10 cm of the snow pack, and thus preventing it from compacting further. However, this situation is probably dependent on the thickness of the protective snow cover. When it is less than 10 cm thick, the disturbance associated with rotary tilling may extend to the ground surface, causing direct damage to the underlying vegetation.

The observations made here into the relationship between pressure and surface disturbance are unfortunately inconclusive. We are not aware of any similar study undertaken here or overseas that has tackled the difficult task of monitoring load changes associated with groomer activity on ski slopes. From this perspective the work was really more of an attempt to test whether the technique was capable of detecting pressure changes below a thin snow pack during groomer passes. We have shown that it is feasible, but that refinements are required for it to yield positive results. These would include the use of appropriately placed load cells or the introduction of more sensitive pressure transducers closer to the surface (with adequate protection from kea attack), and the use of loggers with adequate memory capacity and access to ample battery power.

Appendix 2

SOIL TEMPERATURE DIFFERENCES BETWEEN GROOMED AND NON-GROOMED SLOPES

In March 1999, three stand-alone temperature sensors were installed at 5 cm depth in the soil at one of the groomed transects (46G) (Fig. A2.1) and another set of three at a control transect (4C) (Fig. A2.2). Transect 46G is located about 50 m east of the Saddle chair station at an altitude of 1640 m on a slope of 4° and with an aspect of 135°. It is groomed nightly, which could amount to as many as 90 times during a ski season, and may have as many as 500 skiers per hour. Transect 4C is located further upslope and approximately 300 m to the north-west. It is on a slope of 12° and has an aspect of 145°. Thus, apart from the slightly higher elevation (1705 m) and relatively undisturbed condition, it resembles transect 46G. The two sets of sensors were installed within a 1 m radius and close to the line of the respective transects. The sensors were pre-programmed to begin recording on 1 May, and were removed with the loggers still operating on 13 December. Snow depths and densities were measured at both transects on 29 July, 21 August, and 23 September (Table A2.1).

In all cases, mean depths at the control transect exceeded those at the groomed transect. On 21 August, for example, the snow pack at the control transect was almost three times thicker than that at the groomed transect. Similarly, densities across the groomed transect were in most cases almost double those measured across the non-groomed transect. Maximum densities of 560 and 330 kg/m^3 were observed at the groomed and the control transects, respectively, in late September.

Figure A2.1. View of cushionfield transect 46G (Groom + ski), showing temperature sensor inserted at 5 cm depth, just before burial, March 1999.

Figure A2.2. View of cushionfield transect 4C (Control), showing temperature sensor inserted at 5 cm depth, just before burial, March 1999.

TABLE A2.1. MEAN SNOW DEPTHS AND DENSITY.

Measured at Groom + ski transect 46G and Control transect 4C during the 1999 ski season. Standard deviations for snow depths are given in brackets.

DATE	46G (GROOM + SKI)		4C (CONTROL)	
	depth (cm)	density (kg/m^3)	depth (cm)	density (kg/m^3)
29 Jul 99	29.7 (± 5.3)	400	32.4 (± 4.9)	244
21 Aug 99	21.8 (± 2.8)	490	57.3 (± 5.1)	200
23 Sep 99	18.1 (± 3.1)	560	23.1 (± 6.6)	330

The average and the minimum soil temperatures for the groomed and control transects in May were quite similar (Table A2.2). With the onset of colder weather in June, however, both the average and minimum temperatures were lower on the groomed slope than they were at the control. At the height of the ski season (July through August), average and minimum soil temperatures beneath the groomed slope were all below freezing, with the temperature falling to a minimum of –5.3°C on 10 August. On the same date at the control site the minimum temperature was 0.4°C. Indeed, at no time during the period of record did soil temperatures at 5 cm depth at the control site fall below 0°C, indicating that if any soil freezing occurred it was confined to the upper few centimetres. A minimum temperature of –5.3°C at the groomed transect suggests that freezing conditions probably extended to a depth of 10 cm and perhaps as much as 20 cm. In September, average temperatures at 5 cm depth remained slightly colder at the groomed transect, and minimum temperatures on occasion still fell below freezing, whereas those in the non-groomed control area remained around 1°C. Following the cessation of grooming with the closure of the ski season in late September, and the subsequent melting of the snow pack at both sites, average and minimum temperatures for October became similar. Soil freezing observed at the groomed transect may in time cause perennial herbs such as *Anisotome imbricata*, which have large below-ground storage organs, to die because of intracellular ice crystals causing cytolysis (Hammitt & Cole 1987). The same authors noted that colder temperatures under compacted snowmobile trails caused a 100-fold reduction in soil microbial activity, and a 2- to 10-fold reduction in soil fungi.

TABLE A2.2. AVERAGE MONTHLY AND MINIMUM SOIL TEMPERATURES.

From the record for three sensors installed at a depth of 5 cm across transect 46G (Groom + ski) and transect 4C (Control), Treble Cone Ski Field, winter 1999.

MONTH	GROOM + SKI						CONTROL					
	Average			Minimum			Average			Minimum		
May 99	2.3	2.4	2.0	0.2	1.1	0.7	2.2	2.0	1.9	2.2	0.9	1.1
Jun 99	1.0	0.5	0.9	–1.0	–2.8	–0.8	1.2	1.2	1.1	0.3	–0.2	0.3
Jul 99	–0.2	–1.0	0.1	–3.3	–4.9	–2.2	0.9	1.0	0.9	0.1	0.4	0.6
Aug 99	–1.6	–2.0	–1.8	–4.2	–5.0	–5.3	0.8	0.8	0.8	0.4	0.4	0.6
Sep 99	0.9	0.5	0.4	–1.1	–1.5	–1.7	1.2	1.2	1.1	1.1	1.1	0.9
Oct 99	5.0	5.0	4.3	0.9	1.0	0.9	4.2	4.1	3.7	1.2	1.1	1.0

The difference in snow depth at the two transects appears to be insufficient to account for the markedly colder ambient soil temperatures between mid-July and early September at the groomed transect (Fig. A2.3). The only other possible explanation is that higher snow densities caused rapid heat loss from the ground through the snow pack at the groomed transect compared with the control. It is noteworthy, however, that increased compaction from grooming and skiing at the groomed transect did not lead to a greater time lag before the onset of melting and the subsequent exposure of the surface to direct heating and cooling. In fact the temperature record suggests that the ground surface at the groomed site became snow-free on 3 October, 5 days before the control site (Fig. A2.3). Thus snow melt was not delayed by compaction, from which we can assume that the length of the growing season was approximately the same for both the groomed and the control transects.

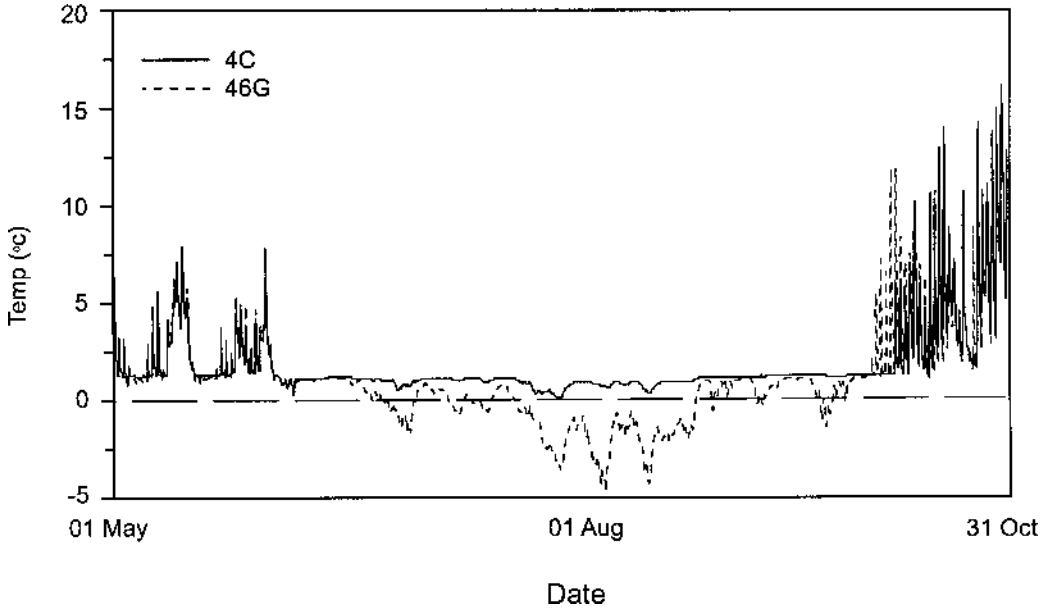

Figure A2.3. Time plot of average soil temperature at 5 cm depth at transects 46G (Groom + ski) and 4C (Control) for period 1 May to 31 Oct 1999.

Appendix 3

TOTAL SPECIES OCCURRENCES

Figures are for each transect in 1997 and 2000 for sample points located in cushionfield vegetation only.

Groom + ski transects 1997	**10G**	**30G**	**31G**	**32G**	**38G**	**39G**	**41G**	**45G**	**46G**	**49G**
No. of sample points	96	-	49	59	68	58	75	77	80	87
Live cushion plants	66	0	25	8	72	25	30	65	84	50
Dead cushion plants	54	0	4	13	16	23	23	168	42	42
Live woody herbs	8	23	20	12	5	29	13	12	34	37
Dead woody herbs	0	40	21	19	12	6	6	3	1	20
Live dicot herbs	0	0	0	0	17	1	3	7	2	6
Dead dicot herbs	0	0	0	0	5	0	0	2	1	0
Live monocots	30	43	38	41	74	9	66	59	56	49
Dead monocots	2	40	22	23	8	8	26	10	5	8
Live moss	29	37	39	14	54	16	62	38	0	41
Live lichen	53	17	21	38	64	9	85	82	51	111
Ski transects 1997	**12S**	**26S**	**29S**	**34S**	**35S**	**37S**	**40S**	**42S**	**48S**	**50S**
No. of sample points	96	66	100	57	71	61	88	80	100	95
Live cushion plants	99	33	114	47	35	70	85	74	48	67
Dead cushion plants	52	15	72	38	13	12	61	28	31	36
Live woody herbs	8	30	21	2	46	18	8	0	32	34
Dead woody herbs	5	9	0	2	20	3	3	0	18	25
Live dicot herbs	0	3	12	1	4	14	1	0	0	3
Dead dicot herbs	0	0	0	0	0	5	0	0	0	0
Live monocots	21	72	23	9	56	50	28	29	31	53
Dead monocots	4	22	1	5	22	20	2	0	22	18
Live moss	28	59	40	11	45	33	37	17	43	56
Live lichen	82	54	132	27	42	56	72	56	113	61
Control transects 1997	**4C**	**8C**	**9C**	**13C**	**20C**	**21C**	**33C**	**43C**	**44C**	**47C**
No. of sample points	90	46	67	90	100	69	55	43	100	84
Live cushion plants	68	49	39	100	54	57	22	22	57	58
Dead cushion plants	36	12	20	52	15	21	13	10	23	42
Live woody herbs	36	39	32	29	28	17	13	13	21	15
Dead woody herbs	20	22	11	6	29	9	11	13	12	11
Live dicot herbs	0	4	0	2	9	12	0	0	12	0
Dead dicot herbs	0	0	0	0	0	0	0	0	0	0
Live monocots	36	48	34	40	61	69	29	14	75	8
Dead monocots	8	9	15	3	14	15	11	4	30	5
Live moss	44	37	35	43	57	52	20	20	44	14
Live lichen	63	33	68	127	127	66	25	34	142	96

Groom + ski transects 2000	**10G**	**30G**	**31G**	**32G**	**38G**	**39G**	**41G**	**45G**	**46G**	**49G**
No. of sample points	96	-	49	59	68	58	75	77	80	87
Live cushion plants	77	0	18	3	75	30	36	82	43	45
Dead cushion plants	70	0	11	6	21	20	23	21	44	45
Live woody herbs	5	16	18	11	2	13	15	19	34	33
Dead woody herbs	0	29	13	13	2	3	5	4	10	23
Live dicot herbs	0	0	0	1	30	0	3	30	0	2
Dead dicot herbs	0	0	0	0	5	0	0	3	0	0
Live monocots	25	38	30	35	69	34	58	69	57	41
Dead monocots	4	15	10	14	9	8	17	3	8	2
Live moss	26	43	37	21	46	29	68	62	47	28
Live lichen	46	15	23	41	73	34	114	89	77	130

Ski transects 2000	**12S**	**26S**	**29S**	**34S**	**35S**	**37S**	**40S**	**42S**	**48S**	**50S**
No. of sample points	96	66	100	57	71	61	88	80	100	95
Live cushion plants	89	50	105	48	28	68	82	68	43	61
Dead cushion plants	73	36	76	40	11	29	67	45	32	33
Live woody herbs	10	75	28	4	48	24	9	3	24	26
Dead woody herbs	4	17	2	0	11	5	1	0	20	19
Live dicot herbs	0	10	27	2	7	26	0	2	0	3
Dead dicot herbs	0	0	1	0	0	2	0	0	0	0
Live monocots	23	46	23	16	71	61	19	23	28	44
Dead monocots	3	9	1	3	10	10	4	1	11	12
Live moss	26	1	36	18	49	46	32	27	31	45
Live lichen	89	50	140	29	48	59	74	66	110	53

Control transects 2000	**4C**	**8C**	**9C**	**13C**	**20C**	**21C**	**33C**	**43C**	**44C**	**47C**
No. of sample points	90	46	67	90	100	69	55	43	100	84
Live cushion plants	69	50	40	102	53	60	24	24	60	58
Dead cushion plants	51	7	18	57	18	14	12	11	27	47
Live woody herbs	33	38	18	28	30	15	9	15	20	8
Dead woody herbs	29	5	6	4	13	2	8	8	6	8
Live dicot herbs	0	3	2	4	10	16	1	0	9	1
Dead dicot herbs	0	0	0	0	0	2	0	0	0	0
Live monocots	29	40	26	38	65	68	25	13	55	5
Dead monocots	8	2	10	5	12	5	5	3	13	4
Live moss	26	33	28	39	43	46	25	15	14	10
Live lichen	71	32	77	136	135	67	32	39	146	94