Environmental effects associated with snow grooming and skiing at Treble Cone Ski Field

Part 2. Snow properties on groomed and non-groomed slopes

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ABSTRACT

The effect of snow grooming on snow properties at Treble Cone Ski Field and possible impacts on plants and soil were investigated by Landcare Research, Lincoln, for the Department of Conservation in the winter of 1997.

Snow depth, density, equivalent water content, and hardness were monitored along transects at five non-groomed, and four groomed slopes in late July, late August, and late September 1997. Average densities measured for transects on groomed slopes were 36% higher than those on non-groomed slopes. There was 45% more water available on average from the snowpack on groomed slopes than on non-groomed slopes. Snow hardness was 400% times higher across groomed transects in late July, but only 40% higher in late September.

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. They are probably sufficient to inhibit or delay soil bacterial activity and subsequent litter decomposition.

Keywords: snow grooming, skiing, environmental effects, snow properties, Treble Cone Ski Field, Lakes Ecological Region.

Fahey, B.; 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 120B*: 49–62.

1. Introduction

The rapid growth in the New Zealand ski industry in recent years has increased the likelihood that environmentally sensitive alpine ecosystems may suffer irreparable damage from snow grooming and related ski field activities. When snow cover is thin or absent, snow grooming can damage the vegetation and cause the soil to become compacted. Studies in Europe have assessed the impacts of skiing and grooming on vegetation and soil (e.g. Bayfield 1971, 1980; Grabherr 1985; Ries 1996; Watson et al. 1970). The impacts of ski-related activities have also been documented in North America (e.g. Hamilton 1981; Price 1985).

In West Otago, three of the four main downhill ski fields (Coronet Peak, The Remarkables, and Treble Cone) are located on land administered by the Department of Conservation (DOC). In 1995, DOC commissioned Landcare Research to conduct a literature review of the likely impacts of snow grooming and skiing on alpine vegetation and soils. The review drew mainly on overseas experience, and concluded that physical damage to plant communities is likely, particularly on exposed crests and hummocks (Fahey & Wardle 1998). Woody and herbaceous plants as well as tussock species are also vulnerable to damage, especially where the snow pack is thin.

Visits to all three fields in the summer of 1995/96 showed that cushionfield vegetation and wetland communities were more vulnerable to damage from snow grooming than tussock grassland communities. However, wetlands tend to be in areas of deep snow accumulation, and are therefore less likely to be susceptible to damage than cushion vegetation. In addition, cushionfield vegetation is more widespread than wetland communities, and occurs in areas where ski field extension and proposals for cat-skiing ventures are likely to take place. Thus the impact of snow grooming and skiing on cushionfields was considered to be the highest priority for study. Treble Cone Ski Field, situated in the Harris Mountains 23 km west of Wanaka, was chosen as the study area as it has many cushionfields present, and the ski field staff were amenable to providing management information.

To determine the nature and extent of damage to cushionfield vegetation at Treble Cone, 30 permanent 30 m long transects were established across cushionfields in areas that were groomed and skied, and in undisturbed areas that served as a control (Part 1 - Wardle & Fahey 1999). Although 10% of groomed transects were first used in 1976, 70% were not developed until 1989, and the remainder not until 1996. Data were collected on percentage vegetation cover and species composition. Measurements were also made of soil bulk density and penetration resistance. Statistically significant differences in the cover of live vegetation were noted among the three treatments, with both grooming and skiing substantially reducing the total live vegetation cover. However, there were no significant differences in species richness and composition between the two treatments and the control. Nor were there any statistical differences in soil bulk densities and penetration resistance. It was concluded, however, that damage to cushionfields from snow grooming and skiing at Treble Cone is widespread and may be ongoing.

The foregoing investigation dealt only with direct physical damage and changes to vegetation based on field observations in the summer. However, the literature review (Fahey & Wardle 1998) clearly showed that of all the ski-field management processes, snow compaction from grooming has the greatest influence on the plant and soil environment. Price (1985), for example, claims that indirect damage associated with snow compaction may occur over larger areas and for longer periods than direct damage from snow grooming. This present investigation sought to establish the extent to which snow properties at Treble Cone Ski Field are altered by compaction from snow grooming and whether these changes are sufficient to have an impact on the plant and soil environment.

1.1 OBJECTIVES

To determine the impacts of snow grooming and skiing on snow pack characteristics and highlight the implications for the biotic environment at the soil–snow interface by:

- establishing depth of snow cover along previously monitored transects,
- determining degree of snow pack compaction and density changes associated with snow grooming and associated skiing,
- comparing these characteristics with those of snow cover not subjected to intensive grooming and skiing.

2. Methods

The snow pack was monitored at nine of the original 30m transects established in the summer of 1997/98 at Treble Cone (Fig. 1). Transect details are provided in Appendix 12.1 of Part 1 (Wardle & Fahey 1999). Four were regularly groomed and skied (10G, 39G, 46G, and 49G), while five served as control sites in relatively undisturbed areas (4C, 13C, 33C, 44C, and 47C). Parameters determining which transects were monitored for snow pack characteristics included ease of relocation, safety (away from avalanche paths), and similarity of site characteristics (e.g. aspect and slope) between groomed and control sites.

At each transect the following snow properties were measured: snow depth, density, equivalent water content, and hardness. Monitoring was conducted three times during the season: 21–22 July (early season), 25–29 Aug (mid-season), and 30 Sept–1 Oct (late season).

2.1 SNOW DEPTH

A snow depth probe marked off at 1 cm intervals was driven through the snow to ground level at 2 m intervals along the approximate location of each transect. Fifteen records of snow depth were made at each transect.

2.2 SNOW DENSITY AND EQUIVALENT WATER CONTENT

Mt Rose sampler

A Mt Rose sampler was used to determine the overall density of snow at three points along each transect. The sampler was driven through the snow with a constant twisting motion, until ground level was reached. The snow pack depth was noted prior to removal of the sampler tube. The length of the snow core inside the sampler tube was also noted, and then weighed to determine the water equivalent reading (cm water). Finally, the sampler was weighed empty. A minimum snow depth of 40 cm is required for accurate measurements to be made with the Mt Rose Sampler. Thus, wherever possible, the sampler was used in snow close to the transect that exceeded this depth. In low-density new snow, the snow core often became compacted, reducing the accuracy of the measurements. The equivalent water content of the snow pack was calculated as the product of the average snow depth and average snow density, as measured along the transect.

Density scale

Where the snow pack was <40 cm, a density scale was used in place of the Mt Rose sampler. A snow pit was dug, and the thickness of each of the snow layers

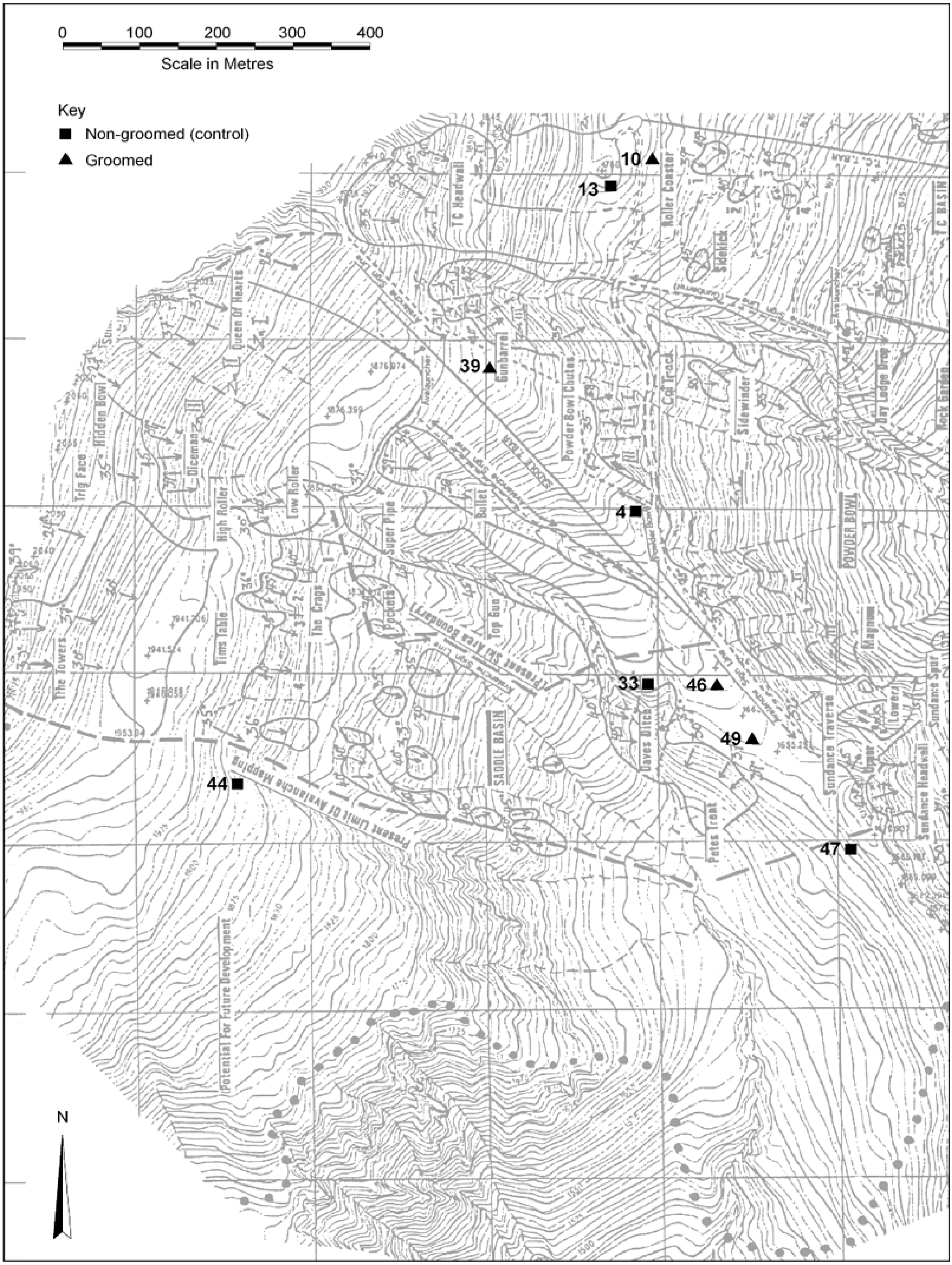

FIGURE 1. TRANSECT LOCATIONS USED IN THE 1997 SNOW SURVEY, TREBLE CONE SKI FIELD.

determined. The total depth of the snow pack was also noted. The 4 cm diameter by 8.6 cm long stainless steel cylinder was then driven into the exposed face of each snow layer. The cylinder with snow core was placed on the density scale, from which a density measurement was recorded.

2.3 RELATIVE HARDNESS OF SNOW LAYERS

The relative hardness of snow layers at sites along the transect was measured using a ram penetrometer. Ram hardness is measured by the force that must be applied in order to make the instrument's conical tip penetrate the snow pack. The weight of the tubes, hammer, and a dynamic load from the falling hammer produce this force.

The weight of penetrometer and hammer used were noted, and converted to newtons. The ram penetrometer was then held in a vertical position on the snow. The depth to which it sank into the snow under its own weight (without the hammer) was noted. The hammer was then gently placed on the penetrometer, and the new penetration was recorded. The hammer was then dropped from a height of 5 cm, and the penetration noted. The number of blows, fall height, and depth of penetration into the snow were recorded up to the point before the rate of penetration changed. This procedure was continued, with the aim of achieving a penetration rate of about 1 cm per blow. Finally, calculations were made to determine the ram hardness versus depth of snow.

2.4 STATISTICAL TESTS

The Shapiro-Wilk test for normality (Shapiro & Wilk 1965) was used to establish whether the snow density, equivalent water content, and ram penetration resistance data conformed to a normal distribution. Since there were no major departures from the rankit plot provided by the Shapiro-Wilk test, normality was assumed. A 2-sample 't' test was then applied to the sets of data from non-groomed and groomed transects collected during each visit to test for differences between means. The effects of the two management treatments were also tested on the average values per transect (i.e. where $n = 5$ for non-groomed transects, and $n = 4$ for groomed transects) using repeated measures analysis of variance.

2.5 BACKGROUND INFORMATION

A summary of weather conditions during the 1997 ski season was kindly supplied by the management at Treble Cone Ski Field. It notes that June was dry and cold, with little or no snow except in the vicinity of the summit. The first major snow fall of the season occurred on 10–11 July. It provided a 25 cm base, and up to 45 cm in the northwest area of the ski field. On 18 July another storm added 26–30 cm to this base, and more storms occurred between 10–16 August, bringing the base to 105 cm at the top of the T-2 lift (1750 m) and 170 cm closer to the summit. There was some rain to 1800 m on 19 August, followed by additional snow on 27 and 28 August. September was very dry and clear with mild days and cool (below freezing) nights.

The total snow base for 1997 was 175 cm, which was the second lowest for the last 7 years (mean snow base thickness = 287 cm).

2.6 CONDITIONS DURING VISITS

Early season (late July)

The first monitoring was done in late July, after the first main snowfall of the year.

Mid season (late August)

The weather was very unsettled during this visit. Between 25 and 29 Aug 1997, most of the transects had received about 50 cm of new snow. Snow coverage was good all over the ski field.

Transects 33C, 39G, 44C and 46G were all monitored (25 Aug) prior to the new snowfall (25 Aug), 13C and 10G were monitored during the snowfall (26 Aug), and 4C, 47C, and 49G were monitored after this snowfall (29 Aug)

Late season (late September/early October)

It had rained the day before the visit and on 30 Sept 1997 the snow pack was typically spring-like. However, there were still some obvious snow layers in the snowpack. The following transects were measured: 4C, 13C, 10G, 33C, 39G, and 44C. A clear night on 1 Oct promoted strong radiative cooling in the upper snowpack. Transects 46G, 47C, and 49G were measured that day.

3. Results

3.1 SNOW DEPTH

Average snow depths recorded across the five transects located on non-groomed slopes ranged from 11 to 40 cm in late July, 40 to 81 cm in late August, and 25 to 68 cm in September/October (Table 1). There was a similar range of snow depths across the four groomed transects in July (12 –41 cm). At the time of the August and September visits, the depths ranged from 41 to 172 cm, and 49 to 131 cm respectively. Thus in late July, mean snow depths for the non-groomed transects were comparable with those associated with groomed transects, but in late August and late September the mean depths for groomed transects were greater. This could be a consequence of local topographic differences. Once compacted, the snow is also less susceptible to redistribution by wind.

TABLE 1. AVERAGE SNOW DEPTHS (cm) FOR TRANSECTS ON NON-GROOMED (CONTROL) AND GROOMED SLOPES AT TREBLE CONE SKI FIELD IN LATE JULY, LATE AUGUST, AND LATE SEPTEMBER/EARLY OCTOBER 1997. FIGURES IN BRACKETS ARE STANDARD ERRORS.

NON-GROOMED TRANSECTS				GROOMED TRANSECTS			
Transect	July	Aug.	Sept.	Transect	July	Aug.	Sept.
4C	27	81	60	10G	12	41	49
13C	30	67	57	39G	29	102	82
33C	40	64	68	46G	22	67	75
44C	11	40	44	49G	41	172	131
47C	19	79	25				
mean(SE)	25.4(±11.0)	66.2(±16.4)	50.7(±16.8)	mean(SE)	26.0(±12.2)	95.5(±56.8)	84.4(±34.2)

3.2 SNOW DENSITIES

The mean of the snow densities recorded at the control transects increased from 265 kg/m^3 in late July to 378 kg/m^3 in late September (Table 2). The lower snow densities noted along the control transects in late August were a consequence of new snow accumulating on top of a shallow snowpack. For the groomed sites the mean ranged from 364 kg/m^3 in late July to 459 kg/m^3 in late September. They were consistently higher than those recorded at the non-groomed transects (by 99 kg/m^3 or 37% in late July, 134 kg/m^3 or 55% in late August, and 81 kg/m^3 or 21% in late September.) The 2-sample ‘t’ test showed a statistically significant difference between the means of the data collected from transects across non-groomed and groomed slopes for all three visits

TABLE 2. AVERAGE SNOW DENSITIES (kg/m^3) CALCULATED FROM SAMPLES TAKEN WITH THE MT ROSE SNOW SAMPLER ALONG SELECTED TRANSECTS ON NON-GROOMED (CONTROL) AND GROOMED SLOPES AT TREBLE CONE SKI FIELD IN LATE JULY, LATE AUGUST, AND LATE SEPTEMBER/EARLY OCTOBER 1997. Figures in brackets (light) are the numbers of samples taken per transect. Figures in bold in the last two rows are means and standard errors for each visit.

NON-GROOMED TRANSECTS							GROOMED TRANSECTS						
Transect	July		August		September		Transect	July		August		September	
	density	depth	density	depth	density	depth		density	depth	density	depth	density	depth
4C	244 (4)	36 (4)	196 (4)	80 (4)	335 (3)	52 (3)	**10G**	337 (6)	49 (3)	410 (4)	47 (4)	446 (3)	96
13C	298 (4)	32 (5)	284 (4)	60 (4)	434 (3)	57 (4)	**39G**	329 (4)	49 (4)	294 (4)	79 (4)	454 (3)	86
33C	265 (6)	41 (5)	259 (5)	64 (5)	335 (3)	70 (3)	**46G**	401 (4)	65 (4)	484 (3)	53 (3)	569 (4)	65
44C	258 (4)	25 (4)	260 (4)	43 (4)	413 (3)	57 (4)	**49G**	390 (4)	45 (3)	315 (3)	153 (3)	368 (3)	132
47C	262 (4)	29 (4)	212 (4)	91 (4)	373 (4)	57 (4)							
mean	**265**	**33**	**242**	**68**	**378**	**59**	**mean**	**364**	**52**	**376**	**83**	**459**	**95**
(SE)	**(±20)**	**(±6)**	**(±37)**	**(±19)**	**(±45)**	**(±7)**	**(SE)**	**(±37)**	**(±3)**	**(±108)**	**(±49)**	**(±83)**	**(±28)**

($p<0.0007$). Analysis of variance also showed transects across groomed slopes to have significantly higher densities than their counterparts located on non-groomed slopes ($p=0.0124$).

3.3 EQUIVALENT WATER CONTENTS

Using analysis of variance, mean equivalent water contents for groomed transects were significantly higher than those calculated for non-groomed transects for all visits ($p \leq 0.00025$). In late July, for example, there was on average 60 mm (62%) more water in the profile at the groomed transects, in late August 140 mm (84%), and in late September 198 mm (89%) (Table 3).

TABLE 3. AVERAGE EQUIVALENT WATER CONTENTS (mm) CALCULATED FROM THE MEAN DEPTHS AND DENSITIES MEASURED WITH THE MT ROSE SNOW SAMPLER ALONG TRANSECTS ON NON-GROOMED (CONTROL) AND GROOMED SLOPES AT TREBLE CONE SKI FIELD IN WINTER 1997.

NON-GROOMED TRANSECTS				GROOMED TRANSECTS			
Transect	July	Aug.	Sept.	Transect	July	Aug.	Sept.
4C	88	157	174	10G	134	193	429
13C	95	170	248	39G	161	232	390
33C	109	166	235	46G	158	256	370
44C	85	112	235	49G	176	482	486
47C	76	192	213				
mean(SE)	97(±12)	159(±29)	221(±29)	mean(SE)	157(±66)	292(±132)	419(±198)

Equivalent water contents also increased significantly over the 3 months for both groomed and non-groomed transects ($p \leq 0.0001$). The higher equivalent water contents noted for groomed slopes are a function of the higher densities and greater depths compared with non-groomed areas (Table 2), and again are thought to reflect the tendency for snow groomers to pile extra snow on to ski runs before smoothing and compacting it.

3.4 SNOW PENETRATION RESISTANCE (HARDNESS)

To facilitate the comparison of data collected at different times, snow-penetration-resistance measurements were standardised by dividing the summed penetration resistance for the profile by the depth of snow. This produced a figure in units of N/cm of snow depth. The data listed in Table 4 are based on measurements taken with the ram penetrometer across the five transects on non-groomed (control) and four groomed slopes (1 to 4 profiles per transect).

TABLE 4. MEAN "STANDARDISED" SNOW PENETRATION RESISTANCE DATA (N/cm) AND ASSOCIATED SNOW DEPTHS (cm) MEASURED BY THE RAM PENETROMETER FOR EACH OF THE FIVE CONTROL AND THE FOUR GROOMED TRANSECTS (3–4 PROFILES PER TRANSECT) ON TREBLE CONE SKI FIELD FOR WINTER 1997. Figures in bold in the last row are means and standard errors (SE).

NON-GROOMED							GROOMED						
Transect	July		Aug.		Sept.		Transect	July		Aug.		Sept.	
	N/cm	d	N/cm	d	N/cm	d		N/cm	d	N/cm	d	N/cm	d
4C	6	29	33	45	60	49	10G	65	12	41	50	17	36
4C	42	34	48	90	89	63	10G	26	17	55	53	25	88
4C	7	20	61	106	117	60	10G	35	19	78	74	-	-
13C	17	46	42	66	83	56	10G	29	18	-	-	-	-
13C	-	-	91	79	41	50	39G	144	12	43	64	44	31
13C	-	-	14	46	52	64	39G	33	4	66	95	105	118
33C	35	31	45	75	129	85	39G	58	64	121	119	-	-
33C	36	49	50	77	100	86	46G	137	41	203	57	81	76
33C	18	51	47	69	65	66	46G	108	24	279	62	113	73
44C	26	20	57	57	42	21	46G	284	15	113	53	-	-
44C	29	30	42	45	76	36	46G	89	18	-	-	-	-
44C	73	27	30	40	37	57	49G	53	48	175	187	103	114
44C	7	10	-	-	-	-	49G	145	40	65	195	93	126
47C	10	14	35	90	85	19							
47C	12	25	95	91	21	17							
47C	7	33	25	59	52	20							
mean	**23**	**30**	**48**	**70**	**70**	**50**	**mean**	**93**	**28**	**112**	**96**	**98**	**81**
(SE)	**(±19)**		**(±22)**		**(±31)**		**(SE)**	**(±73)**		**(±79)**		**(±70)**	

Mean standardised resistance values showed a 3-fold increase through the season at the control transects (23 N/cm in late July to 70 N/cm in late September). At the groomed sites the standardised values were higher than their non-groomed counterparts during all three visits, but the maximum (112 N/cm) was reached in August rather than September. The biggest contrast in resistance to penetration between the non-groomed and groomed transects was observed in July, with the latter averaging almost 400% that of the former. By September there was less of a difference between the two sets of data (70 N/cm for the non-groomed and 98 N/cm for the groomed slopes, a 40% increase). Based on the results of the 2-sample 't' test, there was a statistically significant difference between the means of the resistance measurements for those transects on non-groomed slopes and those on groomed slopes for data collected during the late July and late August visits ($p < 0.009$) but not for the September visit ($p < 0.2591$). Analysis of variance revealed a significant interaction between the effects of treatment and time ($p = 0.00035$). Grooming significantly increased snow penetration resistance in early season ($p = 0.005$) to mid-season ($p = 0.015$) snow packs. However, no statistically significant differences between groomed and non-groomed areas occurred late in the season ($p = 0.985$).

4. Discussion

Baiderin (1980) observed snow density to increase 1.3 times in response to snow compaction on ski slopes in Russia. Kattelmann (1985) studied the effects of mechanical snow compaction on the snowpack hydrology of ski fields near Donner Summit in the Sierra Nevada of California, and found the density of compacted snow to be 120 kg/m^3 higher than that of uncompacted snow. This is similar to the average difference in density noted at Treble Cone between non-groomed and groomed snow (105 kg/m^3) from the data collected during the three winter visits in 1997. Kattelmann (1985) concluded that the difference in density was the most significant physical difference between compacted and non-compacted snow and accounted for many of the other noted contrasts. Pesant (1987) found that snow compaction by snowmobiles caused density to increase by 58%. Similar increases in density were noted at Treble Cone in 1997 between non-groomed and groomed transects (34% in late July, 55% in late August, and 21% in late September).

Since snow thermal conductivity increases in proportion to the square of the increase in density (Yen 1969), increases of the magnitude observed at Treble Cone have the potential to alter the thermal regime of the underlying soil. In winter, for example, more heat will be extracted from ground overlain by compacted rather than uncompacted snow. Baiderin (1983), for example, found that soil temperatures under snow on ski slopes can be 5–7 times colder and frost penetration 7–11 times higher than under non-skied snow. Wanek (1971) found the O-horizon under snowmobile trails to be 11°C colder than under undisturbed snow; the A-horizon under compacted snow froze approximately 1 month earlier and thawed 2–3 weeks later in the spring. According to Baiderin (1980), the tendency for compacted snow to lie longer on groomed ski slopes can force early spring perennials to bloom later because of the changed conditions at the soil–snow interface. Prolonging the snow cover may also prevent plants from photosynthesising, thereby retarding plant growth. In addition, some species may not be able to complete their life cycle (Wanek 1971; 1974). Thus summer- and autumn-flowering species may tend to prevail on heavily groomed and skied slopes. However, no changes in species composition have been observed at Treble Cone (Part 1 - Wardle & Fahey 1999).

The effect of likely soil temperature differences between groomed and non-groomed sites on the plant and faunal environments at a location like Treble Cone is difficult to assess. The literature suggests that the increases in snow density and hardness recorded at Treble Cone are probably sufficient to affect soil organisms. Wanek (1971) for example noted a 100–fold reduction in soil bacteria and a 2– to 10-fold reduction in soil fungi in soil under compacted snowmobile tracks. Meyer (1993) found that the use of snow groomers on ski runs in Austria reduced the abundance of whole soil fauna by 70%. The slower melt rate of compacted versus non-compacted snow may also reduce bacterial activity near the surface and subsequent litter decomposition (Neumann & Merriam 1972). In addition, snow compaction can lead to the formation of an ice layer at the surface which can cause an oxygen deficiency in the A-horizon (Price 1985).

5. Conclusions

- The changes in snow pack properties observed in the winter of 1997 at Treble Cone Ski Field are substantial, but lie at the low end of the range compared with those recorded in the overseas literature.
- The observed increases in snow density and hardness at Treble Cone could be sufficient to increase heat loss through the snow, thereby reducing soil temperatures, although it is unlikely that this will lead to any marked increase in the depth of soil freezing beneath the snow pack.
- Soil bacterial activity could be inhibited or delayed in the spring and litter decomposition affected accordingly.

6. Recommendations

- Soil temperatures should be measured to 20 cm depth in the soil on heavily groomed and non-groomed slopes to determine the effect snow compaction has on the ambient soil temperature and thus the biotic environment.

- The relationship between snow depth and loading at the snow-soil interface as a consequence of snow grooming should be determined through the installation of load cells at a transect on a frequently groomed slope and at a transect on a lightly groomed slope.
- The 30 original transects established at Treble Cone in 1997 should be resurveyed in the summer of 1999/2000 to determine any temporal trends in plant disturbance and species composition on groomed slopes compared with non-groomed slopes.

7. Acknowledgements

We thank Jim Henderson for his assistance in the field, Wendy Ruscoe for assisting with the statistical analyses, and the management of Treble Cone Ski Field for allowing access to the field sites during the 1997 ski season.

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