Tekapo Scientific Reserve: ecological restoration

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Published by
Department of Conservation
Head Office, PO Box 10-420
Wellington, New Zealand

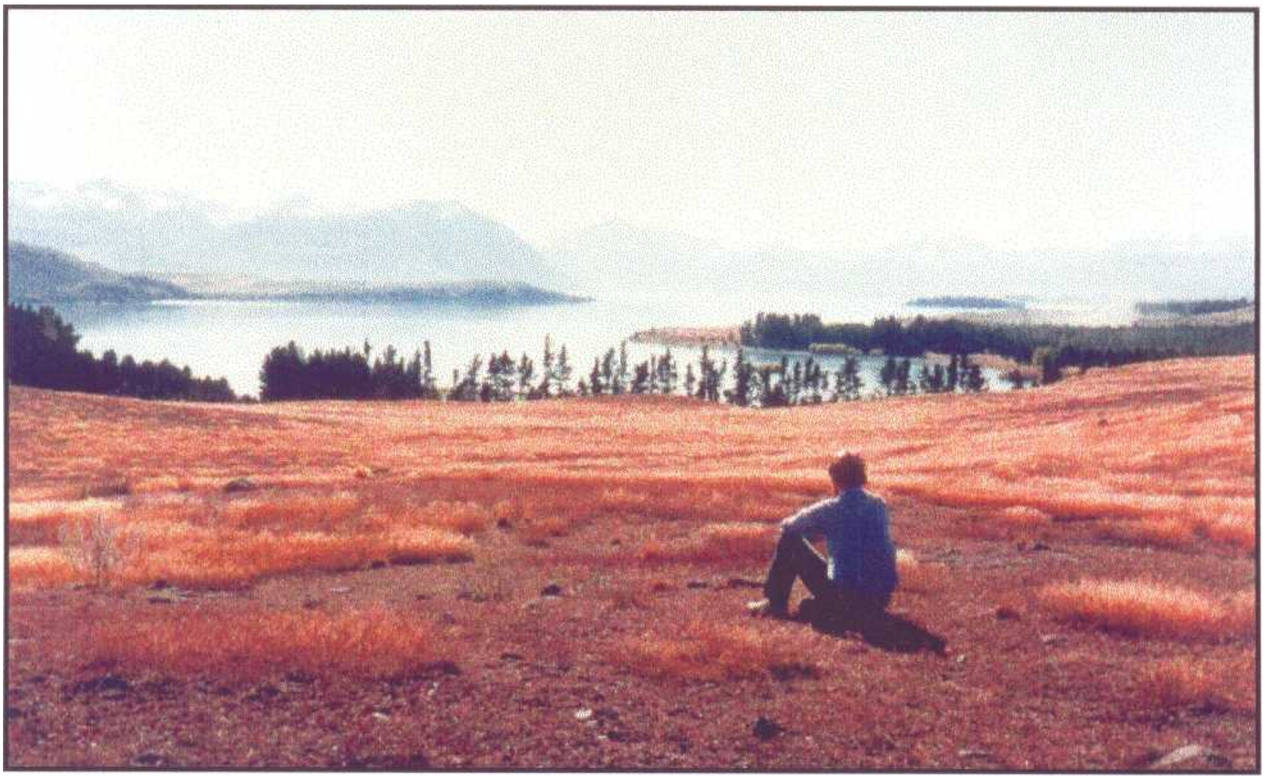
This report was commissioned by Canterbury Conservancy

ISSN 1171-9834

Reference to material in this report should be cited thus:

Espie, P.R., 1997.
Tekapo Scientific Reserve : ecological restoration.
Conservation Advisory Science Notes No. 149, Department of Conservation, Wellington.

Keywords: Tussock grassland, ecological restoration, Mackenzie Ecological Region, rabbit, grazing.



Tekapo Scientific Reserve, moraine ridge, view North.

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1. Summary

1.1 PROJECT

This report for the Science and Research Directorate of the Department of Conservation (DoC), was commissioned by Mark Davis, Senior Conservation Officer, Canterbury Conservancy, to investigate ecological restoration of depleted short tussock grassland in the Tekapo Scientific Reserve, Mackenzie Ecological Region as part of an ongoing research project.

1.2 OBJECTIVES

- To provide quantitative information on soils and the cover and floristic composition of vegetation communities in the Tekapo Scientific reserve for assessing long term ecological change.
- To determine short-term (2 yr.) change in tussock grassland cover and composition of vegetation communities in the reserve following reduction in sheep and rabbit herbivory.
- To find optimum techniques for cost-effective re-establishment of native species in degraded short tussock grasslands by investigating transplanting and conservation tillage drilling as restoration techniques for re-introduction of tussocks and native grasses in degraded grasslands.

1.3 RESEARCH HIGHLIGHTS

- Remeasurement of 12 permanent plots, after two years of reduced rabbit numbers and no sheep grazing, showed bare ground decreased by 10%, litter by 1.5% and animal dung by 1%. Adventive species showed the largest increase in cover, mouse-ear hawkweed *(Hieracium pilosella)* by 9%, browntop *(Agrostis capillaris)* by 4.5% and sweet vernal *(Anthoxanthum odoratum)* by 2.3%. Native grasses also increased, fescue tussock *(Festuca novae-zelandiae)* by 1.2%, *Pyrrantbera exigua* by 1%, and blue tussock *(Poa colensoi)* by 0.2%. A few native herbs also increased, notably scabweeds *(Raoulia australis* and *R. parkii)* by 1.3% and 0.6%, *Leucopogon fraserii* by 1%, and the prostrate shrub *Coprosma petrei* by 0.3%.
- Restoration of six native grasses, snow tussock *(Chionochloa rigida)*, red tussock (*C. rubra*), blue tussock, silver tussock *(Poa cita)*, blue wheat grass *(Elymus rectisetus)* and fescue tussock, was trialed by direct drilling seed in four contrasting landforms in spring 1993. *Elymus* had the highest laboratory seed germination 74%, followed by fescue tussock 32%, blue tussock 27%, silver tussock 14%, snow tussock 0.5% and red tussock 0.3%.

- Initial field establishment was excellent for *Elymus*, silver, blue and fescue tussock, ranging from 13 plants/ m to 6 plants/ m, but was very poor for snow and red tussock (< 0.1 plants/ m). *Elymus* had an establishment rate of 14.6% viable seed sown, followed by both blue and silver tussock at 2.7%, fescue tussock at 1.3% and finally snow and red tussock under 0.1%.

- After one and a half years *Elymus*, blue and fescue tussock establishment was 5, 3 and 2 plants/ m respectively. *Elymus* cover averaged 7.0%, blue tussock 3.2%, silver tussock 1.8% and fescue tussock 1.0 %.

- Fertiliser had no statistically significant effect on initial establishment, though, as might be expected, this was best at the highest fertiliser rate. After one and a half years, sown native cover was significantly related to fertiliser supply. *Elymus* differed from blue, silver and fescue tussocks by responding best at lower fertiliser levels and by superior establishment on the drier outwash sites.

- Rabbits browsed up to 78% of transplanted native grasses within a week of introduction and after 10 months had almost completely eliminated *Elymus*, plume grass *(Dichelachne crinita)* and fescue tussock, except for one site where all the fescue plants were browsed but survival was 29%. Transplant survival ranged from 64 to 92% in a rabbit-proof exclosure at an adjacent Tekapo site.

1.4 CONCLUSIONS

- Re-establishment of native short tussocks and grasses by direct drilling appears a feasible option for large scale restoration of degraded grasslands.

- Re-establishment of some species, such as tall tussocks, may be best achieved by transplanting, but requires effective rabbit control.

- Reduced grazing pressure has resulted in a beneficial reduction in bare ground, increased cover of fescue tussock and smaller native grasses, but also with a corresponding increase in adventive grasses, and possibly *Hieracium* cover. Grazing should continue to be held at the lowest possible level.

2. Introduction

The Tekapo Scientific Reserve (Pt. Reserve 3864, New Zealand Gazette 1913/ 454) was allocated to the Department of Conservation (DoC) in 1987. It comprises 1058 ha of fescue tussock grassland and related communities immediately south of Lake Tekapo in the Mackenzie Basin (Mackenzie Protected Natural Areas Survey Ecological Unit 63-1-197 and adjoining units, Espie et al. 1984).

The reserve contains two major landforms, a terminal moraine and extensive fluvioglacial outwash surface, the latter being downcut in a flight of terraces by the Tekapo river, with a corresponding diversity of soils, vegetation and fauna.

The Department's primary management goals for the reserve (Davis 1993) are:

- To retain and enhance natural conservation values present in the reserve;
- To undertake research assisting nature conservation of dry tussock grasslands and intermittent wetlands in the eastern South Island high country.

To achieve these goals DoC poisoned rabbits in 1991 and perimeter fenced the reserve with rabbit netting in 1992. Initial floristic surveys of the wetlands (Johnson 1991) and rangelands (Espie 1992) appraised vegetation in the reserve. Long-term vegetation and invertebrate monitoring programmes commenced in 1993 (Espie 1993, White pers. comm.).

The designation as a conservation area has raised intense local debate concerning the reserve's suitability for conservation and alternative land uses have been suggested. The depleted vegetation condition and weed invasion, principally by mouse-ear and king devil hawkweeds *(Hieracium pilosella* and *H. praealtum)*, are the principal concerns. This highlighted an urgent research requirement to develop technologies for ecological restoration of the indigenous short tussock grasslands as previous revegetation research has largely focused on restoration of eroded high-altitude sites (O'Connor 1979).

Determination of cost-effective revegetation strategies is critical, and of national importance with the impending release of *Hieracium* biological control agents (Scott, pers. comm.). If biocontrol agents are successful to any degree, replacement with native species will be desirable on the conservation estate. Restoration will require active input, as simply removing *Hieracium* or grazing is unlikely to result in rapid reversion to the former vegetation communities. Furthermore it is important for DoC policy makers to be able to contribute to the general discussion concerning the sustainable use of tussock grasslands, supported by solid experimental evidence. Perhaps equally importantly, local credibility requires that DoC is seen to be actively implementing research, for which the reserve has been expressly designated.

2.1 PASTORAL HISTORY

Land in the reserve lay on the boundary between the original Sawdon and Tekapo Stations, and was probably burnt and grazed from about 1865. Subsequently it provided grazing for an accommodation hotel at Tekapo. The back slope of the moraine was cultivated around the turn of the century, and probably sown with improved grasses to provide hay. Like many areas immediately after the first world war, the reserve was over-run with rabbits, and was probably not, or only very lightly, grazed by stock in the 1920's. When T.D. Burnett acquired the area in 1927, he then leased it to Sawdon Station for grazing. Losses from swamp fever saw the moraines fenced off from the outwash plain. Merino ewes were run on the moraine in autumn and during winter and then on the outwash during summer until sold at the February Tekapo sale (Scott, pers. com.).This pattern of pastoral use continued until 1991, when the Department cancelled stock grazing.

2.2 PHYSICAL ENVIRONMENT

The reserve has a moist-subhumid climate, typical of a large zone in the Mackenzie basin lying between the per-humid to humid mountain ranges and the dry sub-humid centre (O'Connor 1976, Belton & Ledgard 1984). Rainfall averages 606 mm per year at the adjacent meterological station at Lake Tekapo, and is fairly evenly spread throughout the year (Table 1.)

Table 1. Rainfall normal (m m) 1941-1970 (N. Z. Meteorological Service 1983)

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
51	43	48	53	53	48	53	48	56	51	51	51

Wide seasonal and annual climatic variability is characteristic. Mean annual rainfall varies from 859 to 324 mm with monthly variability ranging from minima of 1 or 2 mm in January and July to maxima of 160 and 216 mm respectively. Summer (fan.) air temperature averages 15.3 °C, ranging from 21.3 to 8.3 °C. Winter (July) temperatures average 1.7 °C, with mean daily maxima and minima of 6.0 and -2.8 °C. The extreme summer and winter minima recorded are -3.2 and -13.4 °C. Lake Tekapo enjoys high sunshine hours, 2265 h on average per year, though this, coupled with the prevailing north west winds, results in mean annual soil water deficits of 400- 450 mm (Webb 1992). Frosts can occur at any time of the year.

The reserve is surrounded by mountains composed of indurated sandstones and mudstones of the Torlesse Supergroup (Gair 1967). Geomorphically it has been shaped by a series of Pleistocene glaciations, through a cycle of ice advance, detritus deposition, glacial retreat and subsequent downcutting. The reserve comprises Holocene till, fluvioglacial outwash and alluvium of the Tekapo Formation, deriving from the most recent glaciation ca 12,000 yr. P.B. It falls into two well defined major geomorphic units: the terminal moraine of the Tekapo glacier in the North and the associated floodplain and terraces to the South (Fig. 1). The main fluvioglacial outwash surface has a series of lower, younger terraces, downcut by the Tekapo River. Microtopography is generally smooth on the moraine, due to a thin loess mantle, but undulating (about 1 m) on the main outwash surface, due to dune formation, wind deflation and small scale fluvial channels.

The key characteristics of soils in the reserve are summarised in Table 2. Tekapo and Mary soils, classified as upland yellow-brown earths, have formed on the moraine, with the Mary soils occupying sites exposed to the north and north-west. Deep phases of the Tekapo soil occur on toeslopes with the soil thinning upslope to the crest where shallow soils predominate (Webb 1976). Slightly concave sites contain small inclusions of the imperfectly drained Cox soils. Pukaki soils, upland YBE's formed from loess over alluvium, are found on old terraces associated with the moraine. Fork soils, upland YBE's formed on alluvium, occur on the old outwash surface, encompassing a wide variation in stoniness and depth phases. Stony and bouldery phases occupy the largest area, but in many places grade into a complex pattern of all depth and stoniness phases. Soils in Bendrose-Larbreck association, recent or yellow-brown shallow and stony soils associated with upland yellow-grey earths, are adjacent to the Tekapo River, with distinct terrace scarp separating them from the Fork soils. They are, as their classification suggests, predominantly stony (Webb 1992).

Table 2. Differentiating features of soil series in the reserve (Webb 1992)

Series	Drainage	Horizons	Thickness	Texture of fines
Tekapo	well	A,Bw,C	50 cm	fine sandy loam or loamy fine sand
Mary	excessively	A,Bw,C	<40 cm	sandy loam or loamy sand
Pukaki	well	A,Bw,C	>50 cm	fine sandy loam or loamy fine sand
Fork	excessively	A,Bw,Bh,C	<50 cm	sandy loam or loamy sand
Bendrose	excessively	A,C	<40 cm	sandy loam or loamy sand
Larbreck	excessively	A,Bw,C	<40 cm	sandy loam or loamy sand
Cox	imperfectly	A,Bg,Cg/Cr	>40 cm	silt loam or fine sandy loam

Soil chemical properties of the most extensive soils in the reserve were measured as part of this study and are discussed in section 5.1.

3. Methods

3.1 VEGETATION ASSESSMENT

To assess the vegetation, the reserve was stratified into six geomorphic/soil strata:

Moraine	Tekapo terminal moraine;	Tekapo & Mary soils,
Moraine Fan	Moraine toeslope/fan;	Tekapo & Pukaki soils,
High Terrace	Main fluvioglacial outwash surface;	Fork soils,
Scarp	Scarp faces between Main & Tekapo Terraces;	Bendrose & Larbreck,
Low Terrace	Terrace adjacent to the Tekapo River;	Bendrose & Larbreck,
Tarn	Kettlehole depressions on, or near, the moraine;	Cox soils.

Two plots were allocated to each strata, excepting the most extensive strata, moraine and High Terrace which were allocated a third plot. Tarns were sub-divided by size into two sub-strata, semipermanent and ephemeral, each allocated two plots, giving a total of 16 plots. Plots were then randomly located within each strata.

For the grassland strata, a standard 20 x 20 m grassland survey plot with 8 random stereo photopoints (Allen *et. al.* 1983), was permanently marked using tanalised posts to mark the plot and aluminium pins to mark the photocenters. A 50 x 50 cm quadrat, subdivided into twenty-five 10 x 10 cm grids, was centred on the photopoint and the ground cover of every plant species, rock, bare soil, litter and dung was assessed by eye (Espie & Meurk 1992) in January 1993 and February 1995. Species occurring in the plot, but not present in the quadrats, were also recorded. In the tarns a line transect was randomly positioned along one of 8 sectors from the centre of the tarn to the grassland margin and eight photopoints randomly located within zonal vegetation strata. Vegetation cover was assessed as previously except a nested 20 x 20 cm quadrat was used to assess cover within the 50 x 50 cm quadrat for fine turf communities. In the 1995 assessment most of the tarn plots were under water, and could not be measured.

Plot were distributed as follows: -

Moraine	plots 10, 11, 12;
Moraine Fan	plots 2, 3;
Outwash Tce	plots 1, 4, 5;
Scarp	plots 6, 7;
Low Terrace	plots 8, 9;
Large Tarn	plots 13, 14;
Small Tarn	plots 15, 16.

Plot locations were recorded by Global Positioning System and are mapped in Figure 1. Further information about plot location and landform is given by Espie (1993) and illustrated by the frontispiece and Plates 1-3.

3.2 DIRECT DRILLING OF NATIVE GRASSES

The experimental design was a 4 site x 6 species x 4 (or 3) fertiliser x 2 depth factorial. Seed from six native grasses, snow tussock, red tussock, blue tussock, silver tussock, blue wheat grass and fescue tussock *(Chionocbloa rigida, Chionochloa rubra, Poa colensoi, Poa cita, Elymus rectisetus, Festuca novae-zelandiae)* was collected in the reserve or, its immediate environs, between February and April 1993, for sowing in the reserve. After storage at room temperature and seed cleaning, 5 or more replicate samples of 20 seeds were germinated on wetted blotting paper in petri dishes from 21 Sept. through to 19th October in an unheated glasshouse to assess viability.

Species were direct drilled in early spring (15-16th September 1993) at four sites in the reserve on contrasting landforms (moraine slope, toe, fan, outwash) (Fig. 1, Plate 2) in 22m x 3m plots using AgResearch's research till seeder drill, which provided precision seed placement, exact sowing rates and removal of resident competition by removing a strip of turf along the drill line. Seed characteristics and sowing rates are shown in Table 3.

Figure One. Location map and experimental sites

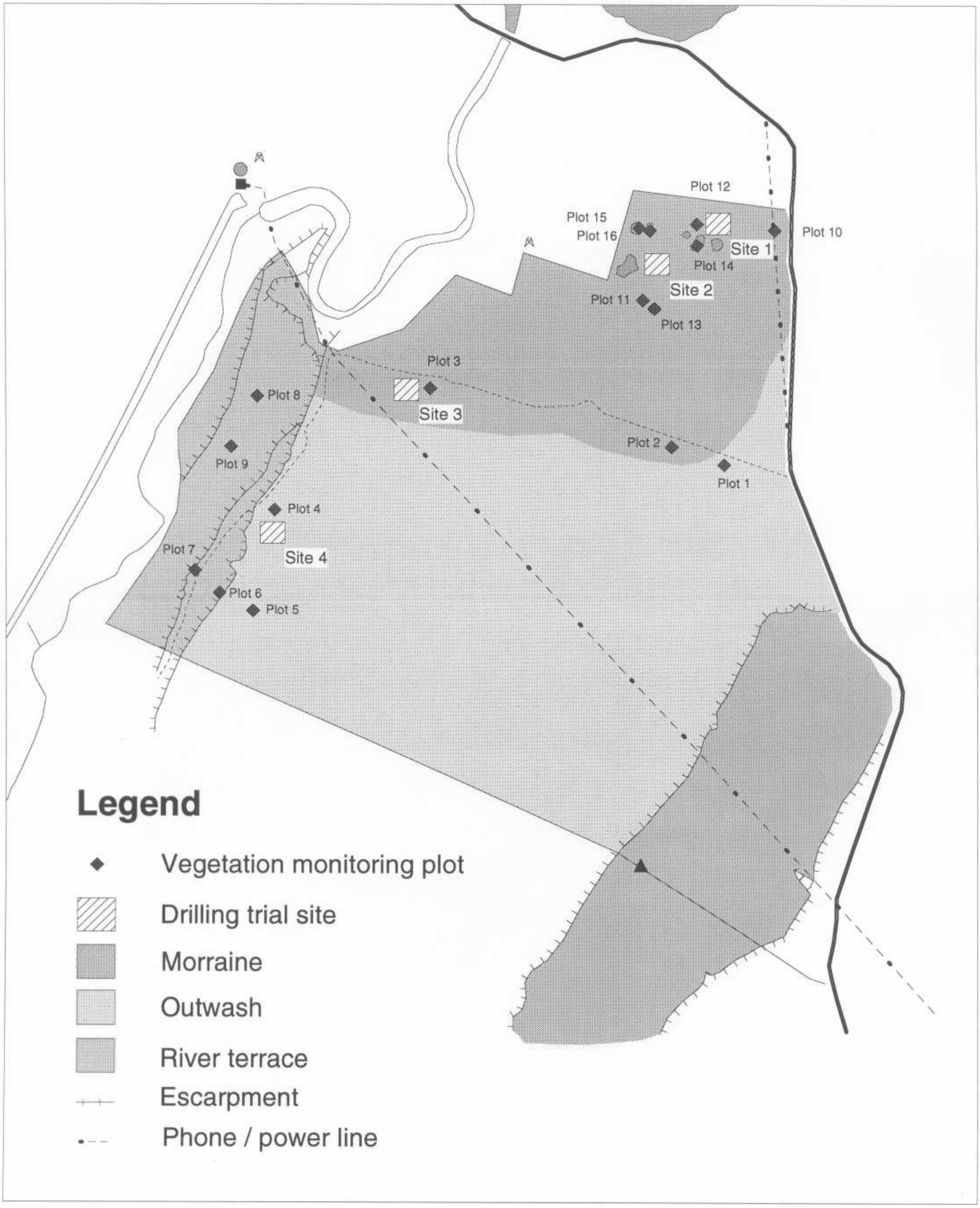


Table 3. Seed characteristics and sowing rate.

Species	Seed No/g	Unit Wt (mg)	Sowing Rate (g)	Total Drilled	Total/m²	Viable /m²
Snow tussock	1144	0.87	3.6	4,117	187	9.4
Red tussock[1]	1844	0.53	5	9,419	428	12.8
Red tussock[2]	1557	0.64	5	7,783	354	10.6
Blue tussock	4301	0.23	2	8,602	391	105.7
Silver tussock	4025	0.25	1.2	4,830	219	30.7
Fescue tussock	2191	0.46	5	10,957	498	159.4
Elymus	217	3.69	5	1,357	62	45.6

[1,2] Two collections of red tussock seed from Balmoral Station were analysed separately, but combined for sowing.

Osmocote Plus fertiliser, in a slow release (over 8-9 months) formulation, providing a complete balanced nutrient supply (16 parts N: 3.5 P: 10 K: 3.6 S: 1.2 Mg: 0.5 iron: 0.06 manganese), was applied at 4 rates (0, 20, 50 and 100 kg / ha). Insufficient seed required the 100 kg /ha treatment to be omitted from the fan and outwash site.There were 4 drill rows per plot with two fertiliser application depths (10 and 20 cm) in paired rows.

Seedling establishment was assessed by counting the number of seedlings (Appendix 1) in two randomly positioned, permanently pinned, lm x 20 cm quadrats in each drill row, giving a total of 8 quadrats per plot. Assessments were made after 10 weeks (23-4 November), 6 months (22 April 1994) and 1 1/2 years (10-12 Feb 1995). After the first assessment, when plants began to produce secondary shoots, it was sometimes impossible to determine whether a group (n > 2) of shoots originated from one individual or from a closely bunched cluster of seedlings. In this case the cluster was recorded as a single group.This will lead to a slight under-estimation of survival in the resulting data.

To determine changes in ground cover along drill rows, the species, or non-vegetative cover, first hitting the tip of the pins were recorded using a 5 pin point analyser (Plate 2). The point analyser was situated directly over the drill line in, and either side of, the seedling count quadrats, giving a total of 15 point cover values per quadrat and 120 per plot. Cover was assessed in April 1994 and February 1995, though funding constraints limited measurement to only two sites in the February assessment.

3.3 TRANSPLANTING NATIVE GRASSES

The experimental design was a factorial randomised block: with 3 species x 2 landforms x 3 (or 2) micro-topography (*Festuca novae-zelandiae, Elymus rectisetus, Dichelachne crinita;* moraine, outwash; crest, mid-, toe-slope, or dune, hollow). Seed was collected from, or immediately adjacent to, the reserve as previously described. Seedlings were propagated in a 1: 1: 1 peat: sand: soil potting mix in 15 x 20cm plastic planting bags in a lowland nursery near Lincoln from May 1993 until February-March 1994 when they were acclimatised at Twizel prior to transplanting in the reserve on the 18-21 April 1994. Pindone poison rabbit baits were scattered around plots at transplanting to discourage rabbits.

For transplanting, 6 plots were positioned at 15 m intervals along a randomly located 100m tape parallel with the contour in three topographic positions on the moraine landform and two on the outwash (Plate 3). This gave a total of 18 plots per moraine site and 12 per outwash site. Plots were hexagonal radial stars to examine the effect of vary planting density (Appendix 2). One plant was located at the centre of the plot with the remainder being located at 15 cm, 30 cm, 60 cm, 120 cm, 240 cm and 480 cm from the centre on six equidistant radial arms, giving a total of 37 plants per plot (Plate 4). One species was planted per plot. Maximum extended live leaf length and basal diameter were measured on transplants along the northernmost radial arm.

Plants were assessed one week after planting for survival and browsing damage (27th April 1994) and after 10 months (8th Feb. 1995). The number of live plants were counted and the basal diameter and the height of the longest extended live leaf were measured for all surviving transplants.

3.4 SOIL CHEMICAL PROPERTIES

At each of the four drilling sites 10 soil cores 2.54 cm in diameter and 7.5 cm deep were taken on the 22 March 1994 at the northern and southern margins of each site and bulked. Soils were air dried at 30°C, sieved through a rotary 2 mm sieve, an analysed for pH, cation exchange capacity (CEC), organic carbon (C), total nitrogen (TN), readily available phosphorus (P) and total phosphorus (TP), readily available sulphur (S), calcium (ca), magnesium (Mg), potassium (K), sodium (Na), exchangeable cations (fCa, fK, fMg, fNa), aluminium (Al), boron (B) and phosphorus retention (PR) using standard AgResearch quick tests and quantitative analyses at Invermay Agricultural Centre, Mosgiel.

3.5 STATISTICAL ANALYSIS

All data was verified after computer entry against the field original data before it was used for statistical analysis.

To test if any differences we found were real, or were simply attributable to chance, we used Analysis of Variance, a statistical technique designed for this purpose. Differences that have a high probability of arising by chance are described in this report as non-significant (symbol ns), those that have a low probability of occurrence by chance, less than one in twenty, are described as significant (symbol *) and those with a very low probability of arising by chance are termed highly significant (symbol ** or *** for less than one in a hundred or one in a thousand respectively). For any mean value, the variation in the range of values that it is calculated from is indicated by the standard deviation statistic. A small standard deviation indicates low variability. This makes it easy to quickly judge how strongly a particular mean differ from other means. Where the means differ by twice the standard deviations, then it is highly likely the means are different.

Multivariate cluster analysis was the procedure used for detecting natural groupings in the vegetation data (Digby and Kempton 1991). Euclidian distance with single linkage in the statistics package SYSTAT (Wilkinson 1992) determined the similarity of plots from cover composition. Analysis of Variance from the general statistics package GENSTAT, compared treatment effects.

5. Results

5.1 SOIL CHEMICAL ANALYSES

Topsoil fertility levels are very much as expected (Table 4). Soils are moderately acidic. Quick test and exchangeable K levels are high, Mg levels medium to low, Ca levels low to medium, and Na levels very low. Cation exchange capacity (CEC), a measure of the soil's ability to hold cations, is uniformly low. Phosphorus levels (P) are medium to high, N levels medium and S levels very low. For plant growth, S levels are highly deficient on all soils. Organic carbon levels are medium and all soils have low levels of phosphorus retention. Exchangeable aluminium levels are high in all soils, so are levels of the trace element boron (B).

The moraine slope was more acid and had higher exchangable Al levels than the other landforms, though the exchangeable Al levels in all the soils are sufficient to cause aluminium toxicity in susceptible plants (Webb 1992). The most consistent differences in soil chemical parameters differentiate the outwash from the other landforms. Organic carbon, N and cations are all lowest on the outwash soils and the base saturation (ratio of Ca, Mg, K and Na to total cations) is very low. These differences are due to limited plant growth and the high degree of leaching, related to the low water holding capacity of these soils.

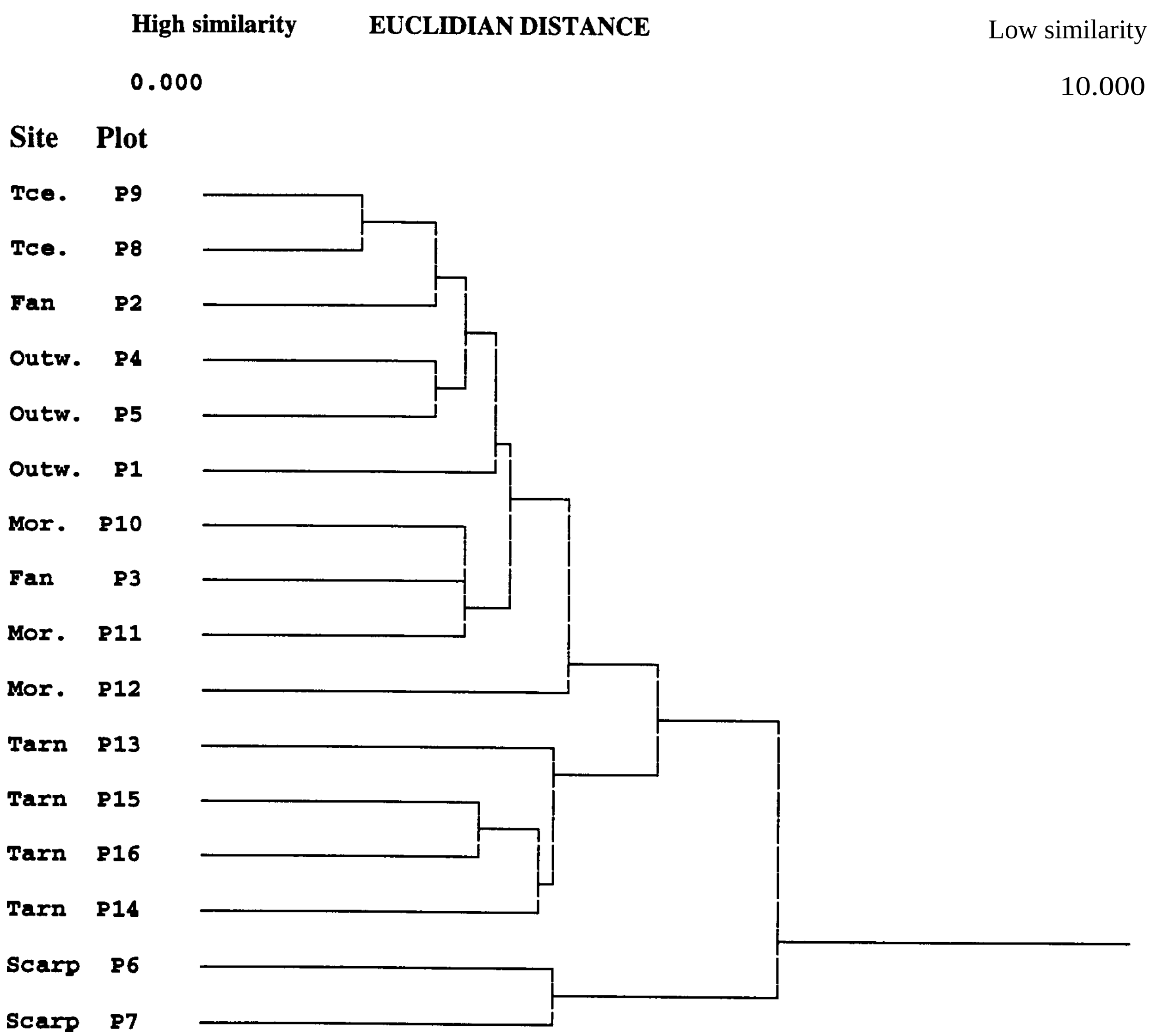
Table 4. Chemical analysis of topsoil nutrient levels.

Site	Rep.	pII	P	S	Ca	K	Mg	Na	PR
Quick Tests									
Moraine toe	1s	5.5	17	3	8	8	33	2	29
	1n	5.5	16	2	8	10	35	2	28
Moraine slope	2s	5.0	21	2	6	10	31	2	21
	2n	5.0	28	2	7	11	34	2	21
Moraine Fan	3s	5.6	17	5	9	12	33	2	18
	3n	5.4	29	2	8	9	30	2	22
Outwash	4s	5.4	28	3	6	8	25	2	11
	4n	5.3	29	4	6	7	24	2	

Site	Rep.	Al	B	fCa	fK	Mg	fNa	CEC	OC	TP	TN
Analytical Determinations											
Moraine toe	1s	5.5	1.77	10.1	0.90	1.88	0.10	13.1	9.1	145	0.54
	1n	6.1	1.09	8.0	0.79	1.56	0.05	9.9	8.6	142	0.50
Moraine slope	2s	9.2	1.68	6.9	0.74	1.68	0.08	10.0	8.7	145	0.50
	2n	6.3	1.82	7.9	0.96	1.81	0.06	10.0	8.1	146	0.45
Moraine Fan	3s	4.8	1.21	8.5	0.76	1.47	0.06	9.4	8.1	118	0.41
	3n	4.1	1.35	7.0	0.83	1.40	0.04	8.1	6.8	120	0.35
Outwash	4s	5.7	1.60	4.3	0.43	0.95	0.03	4.8	4.7	124	0.30
	4n	5.5	0.73	5.1	0.54	1.02	0.03	6.6	6.0	116	0.28

Analytical Units: Al, B (ppm); fCa, fK, Mg, fNa, CEC (me%); PR, OC, TP (ppm), TN (%).

Figure Two. Plot similarity grouped by ground cover



5.2 VEGETATION COVER AND CHANGE

One hundred and thirty nine vascular species, thirty eight of which were adventive, were recorded in the reserve (Espie 1993). The mean ground cover values greater than half a percent at the first assessment are given for each grassland plot in Table 5. The similarity between plots is shown by cluster analysis dendogram (Fig. 2).

The great influence of geomorphology is strikingly shown in the vegetation groups. The two scarp plots (P6, P7) with high percentages of exposed boulders and shrub species form a group distinct from all other plots. The four tarn plots, P13-P16, not surprisingly, then form the next group, with the ephemeral tarns subsequently differentiating from the larger, semi-permanent tarns. The three moraine plots, P10-P12 plus an associated fan plot, P3, separate into a distinct group from the remaining group, plots that all occur on shallow, stony soils with low water holding capacity. Two clear sub-groups can be seen in this group, the high terrace outwash plots P1, P4, P5 and the low terrace plots P8, P9. Plot P2, occurring at the border of the moraine fan and the outwash, is somewhat intermediate.

	Plot											
Cover	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Rabbit	2.7	0.8	0.8	0.7	2.9	0.5				1.4	1.3	1.2
Litter	4.9	2.3	2.3	1.6	4.4	3.9	2	1.8	1.3	7.3	1.1	3.3
Bare	43	73	43	56	55	42	21	79	89	43	49	38
Rock	3.3	2.2		3.1	3.5	41	45	6.8	4.6			
Algae												
Agrostis capillaris	1.6	3.5	1.1	2.8	2.6					7.2	2.1	8.7
Agrostis muscosa									0.5			
Anthosanthum odoratum				0.6		1.6						8.5
Coprosma petrei	7.6		3.2	1.6								
Epilobium hectorii						0.7						
Festuca novae-zelandiae				0.9		1.4						
Hieracium caespitosum	0.6											
Hieracium pilosella	23	14	43	8.9	17	0.8	3.4			37	41	47
Hieracium praealtum							2.0			0.5	2.1	
Leucopogon fraserii	5.5	1.7		1.9	0.5							
Melicitus alpinus						12						
Poa colensoi			0.6									
Poa lindsayi							0.8					

	Plot											
Cover	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Poa maniototo				1.1	1.6	0.9		1.1	1.0			
Polytrichum juniperinum	0/5							0.5				
Pyrranthera exigua			1.6									
Racomitrium crispulum							1.9	0.6				
Raoulia australis					2.5		0.8					
Raoulia parkii				2.0		3.3						
Rytidosperma pumila						3.8						
Rumex acetosella	0.9			2.8	3.4	1.4			2.9			
Stellaria gracilenta							0.7					
Wahlenbergia albomarginata										0.8		

By 1995 there was a significant decrease in bare ground with a corresponding increase in *Hieracium* and introduced grass cover (Table 6). Native grasses and tussocks also increased. This is directly attributable to the reduction in herbivory and two favourable growing seasons. The restriction of the tussock and native herbs increase to the scarp site, almost certainly reflects previous vegetation patterns, presumably resulting from historically lower grazing pressure on these sites. If they had also been present on other sites in similar quantities, then similar increase would be expected. With stock and rabbit removal, as expected, litter and dung decreased.

It is notable the greatest changes in vegetation occurred on the moraine, followed by the fan and outwash, which is probably directly related to the relative soil moisture holding capacity of these sites. Of the individual species, three adventives *Hieracium pilosella, Agrostis capillaris* and *Anthoxanthum odoratum* showed the greatest change (Table 7). Native species also increased their cover, but at a slower rate.This reflects the difference in primary ecological strategies that underlies their ability to respond: the adventives being CSR strategists (i.e., balanced between Competitor, Stress-tolerator and Ruderal strategies) whereas the natives are more strongly orientated towards Stress toleration strategies (Grime *et al.* 1988).

Table 6. Percentage change in ground cover 1993-1995

Group Cover	Fan	Moraine	Outwash	Scarp	Terrace	Mean
Bare Soil/Rock	-8.4	-12.0	-4.1	-5.8	0.2	-6.0
Litter	-1.6	-2.7	-2.6	-0.9	0.7	-1.6
Dung	-0.6	-1.1	-1.6	-0.4	-0.1	-0.9
Native Grass	1.3	0.1	-0.0	-0.3	0.3	0.2
Native Herb	-0.1	-0.2	0.0	0.9	-0.4	0.1
Native Tussock	-	-	0.4	1.2	-	0.7
Shrub	-0.0	-0.0	0.3	-0.1	0.0	0.1
Introduced Grass	2.5	4.3	1.4	1.7	-	2.5
Introduced Herb		0.1	-0.3	-0.1	-0.5	-0.2
Hieracium	4.7	7.6	5.5	2.1	-	5.5
Lichen	0.0	-0.1	0.0	-0.0	-0.1	-0.0
Moss	-0.0	0.0	-0.1	0.1	-0.1	-0.1

5.3 SEED GERMINATION

After field collection, storage at room temperature and seed cleaning, 5 or more replicate samples of 20 seeds were germinated on blotting paper in petri dishes from 21 Sept through to 19th October in an unheated glasshouse. The final germinations, summed over one month, differed considerably (Table 8).

Table 7. Mean change in species ground cover 1993/1995 (%)

Species Cover	Fan	Moraine	Outwash	Scarp	Terrace	Mean
Increased						
Hieracium pilosella	7.1	15.2	9.2	3.1		9.3
Agrostis capillaris	4.1	7.0	2.2			4.5
Anthosanthum odoratum	1.8	2.3	1.4	3.3		2.3
Raoulia australis				1.3		1.3
Festuca novae-zelandiae			0.5	2.4		1.20
Leucopogon fraserii			1.0			1.0
Pyrranthera exigua	2.7	0.1	0.1			1.0
Raoulia parkii			-0.2	2.7		0.6
Coprosma petrei	0.0	-0.0	0.8			0.3
Poa lindsayi					0.2	0.2
Poa colensoi			0.31	-0.1		0.2
Verbascum thapsus				0.2		0.2
Rosa rubiginosa				0.1		0.1
Decreased						
Bare ground	-12.4	-20.0	-8.1	-6.9	-0.3	-10.3
Litter/Dead	-1.5	-2.7	-2.6	-0.9	0.7	-1.6
Rabbit dung	-0.6	-1.1	-1.6	-0.4	-0.1	-0.9
Rock	-0.4	-0.1	-0.0	-4.6	0.7	-0.8
Rumex acetosella	0.0	0.1	-0.8	-0.3	-0.9	-0.4
Stellaria gracilenta			-0.1	-0.1	-0.7	-0.2
Epilobium hectorii					-0.2	-0.2
Polytrichum juniperinum	-0.04	-0.2	-0.1		-0.4	-0.2
Wahlenbergia albomarginata	-0.1	-0.3	-0.1		-0.1	
Melicitus alpinus				-0.1		-0.1
Geranium sessiliflorum			-0.1			-0.1

Table 8. Seed germination (%).

Species	Sample size	Average	Std. Deviation
Elymus rectisetus	100	7.40	8.8
Fescue tussock	200	32.0	5.1
Blue tussock	200	27.0	5.1
Silver tussock	100	14.0	7.2
Snow tussock	200	0.5	4.6
Red tussock	300	0.3	3.8

5.4 DRILLING ESTABLISHMENT OF NATIVE GRASSES

Initial field establishment was excellent for *Elymus,* silver, blue and fescue tussock, ranging from 13 plants/ m to 6 plants/ m, but was very poor for snow and red tussock (< 0.1 plants/ m; Fig. 3a). *Elymus* had an establishment rate of 14.6% viable seed sown, followed by both blue and silver tussock at 2.7%, fescue tussock at 1.3% and finally snow and red tussock under 0.1%. Except for the change in order between fescue tussock and silver tussock, this closely follows that of seed germination.

Seedling survival of all species decreased with time, with *Elymus* having the lowest mortality (Fig. 3a), but it is not possible to differentiate between the effects of rabbit browsing, plant competition or climatic stress in reducing seedling numbers. Note that the final assessment slightly underestimates the true survival rate due to the counting protocol we used. Sites strongly affected seedling survival after 1 1/2 years (Fig. 3b) with *Elymus* and *Poa colensoi* differing in response. *Elymus* survival increased as sites became progressively drier (moraine toe < moraine slope < fan c outwash) whereas the reverse held for *Poa colensoi.* Alternatively, this may be confounded by the intensity of rabbit browsing, as pellet densities were highest on the moraine toe (see Table 9). The two species also differed in response to fertility (Fig. 3c), *Elymus* having superior performance at lower levels in contrast to *Poa's* relatively constant rate of increase with increasing fertility. Fescue tussock responded similarly to *Poa colensoi* while *Poa cita's* initial response levelled off.

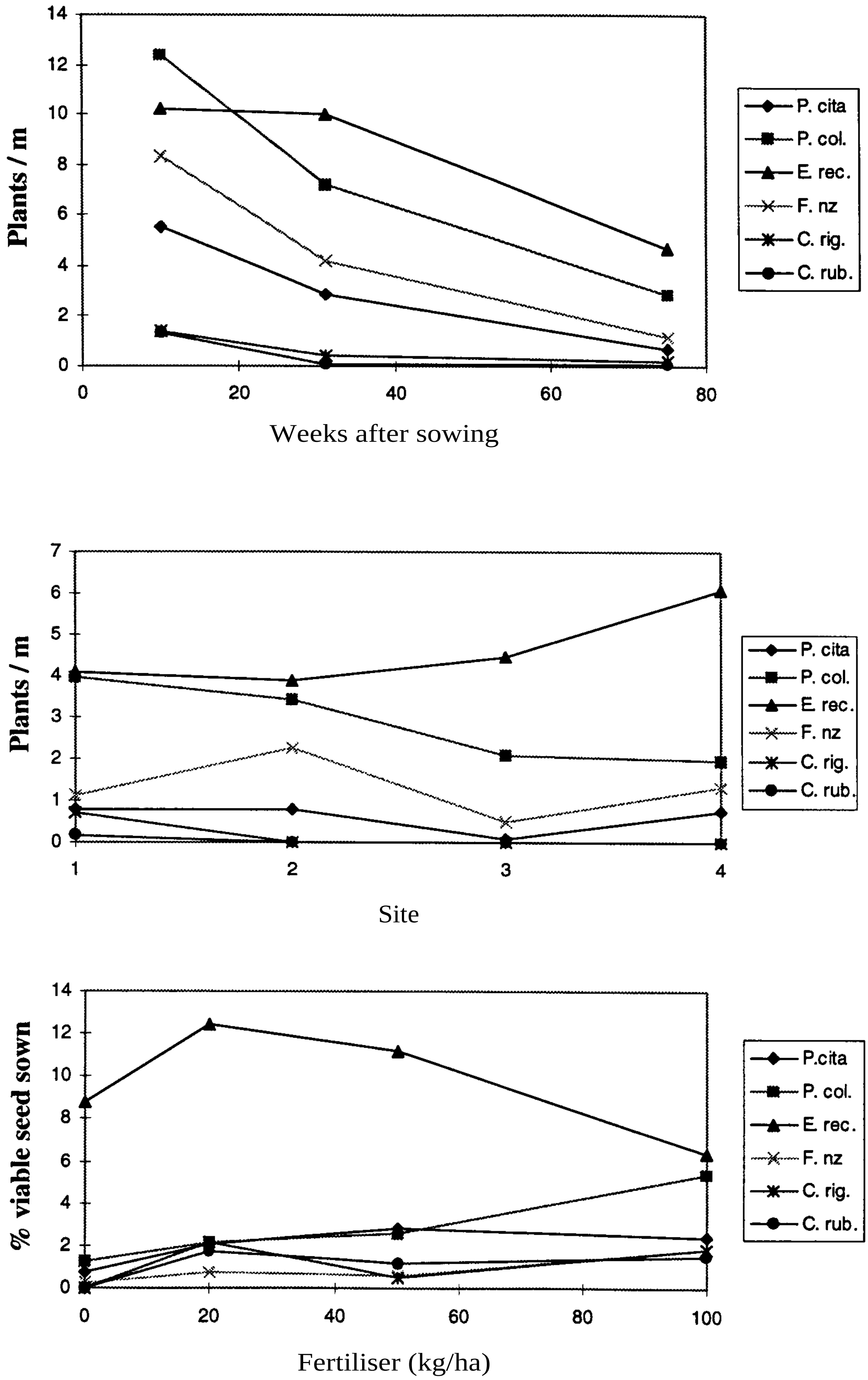


Figure 3. (a) Establishment and survival, (b) topography and (c) fertiliser effect on direct drilled native grasses.

Point analysis cover measurements showed real differences between sites (Table 9). Bare ground comprised nearly 100% cover immediately following drilling, but after one and a half years the moraine toe site had less bare ground remaining exposed and less litter than the drier outwash site. Rabbits' pellets, *Hieracium pilosella* and *Coprosma petrei* cover were also significantly higher on the moraine site. Conversely *Hieracium praealtum* cover was greater on the outwash, though this may simply reflect the low frequency and local occurrence of this plant (Table 5). Site differences had no effect on *Rumex* regrowth. Re-colonisation by adventive grasses was greatest on the moraine site (Table 10).

Table 9. Site effect on general, herb and sub-shrub cover (mean % cover, Std. Dev.)

Site	Bare	Litter	Rabbit	*H. pilosella*	*H. praealt.*	*L. fraserii*	*R. acetosella*	*C. petrei*
Toe	30.6 13.5	3.9 4.8	3.3 4.4	39.6 14.3	0.5 1.6	0.0 0.0	5.1 9.4	0.4 1.7
Out.	45.1 14.4	12.2 8.3	1.6 2.8	24.5 15.1	2.3 4.9	4.0 6.5	5.9 5.9	0.01 0.6
Sig.	***	***	***	***	***	***	ns	***

Table 10. Site effect on grass cover (mean % cover, Std. Dev.)

Site	*A. odoratum*	*A. capillaris*	Shown native spp.
Moraine toe	5.0 6.3	5.0 6.1	2.0 5.5
Outwash	0.5 1.6	1.4 2.9	2.7 7.6
Sig.	***	***	ns

Higher rates of fertiliser decreased litter cover, probably via more vigorous plant growth, but had no effect on rabbit or cover of native herbs (Table 11). This lack of response contrasts with that of the adventive herbs, where both *Hieracium* species and *Rumex* significantly increased regrowth at higher fertiliser rates.

Table 11. Fertiliser effect on general, herb and sub-shrub cover (mean % cover, Std. Dev.)

Fert	Litter	Rabbit	*H. pilosella*	*H. praealtum*	*R. acetosella*	*L. fraserii*	*C. petrei*
0	10.0 9.5	2.5 3.4	32.4 15.8	1.1 3.3	5.2 7.6	1.4 3.3	0.4 1.6
20	8.2 7.9	2.5 3.9	30.8 15.7	0.9 2.3	6.0 6.3	3.6 7.2	0.4 1.8
50	6.4 6.3	2.2 2.8	31.2 17.3	2.0 5.1	10.3 9.7	1.2 3.3	0.1 0.5
100	3.4 4.4	3.4 4.7	42.0 14.5	0.5 1.5	8.9 8.4	-	0.2 1.0
Sig.	***	ns	***	*	***	ns	ns

In contrast to the herbs, both native and adventive grasses significantly responded to higher fertiliser rates (Table 12).

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