The rise to dominance over two decades of *Lupinus polyphyllus* among pasture mixtures in tussock grassland trials

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Abstract
In two trials near Lake Tekapo, one started from sown binary mixtures of 14 different legumes, of which *Lupinus polyphyllus* was one, was cross sown with 16 different grasses, while in the other trial *L. polyphyllus* and *Trifolium hybridum* were over-drilled across established swards of previous 25 different grass and legume species. In both *L. polyphyllus* persisted, increased and spread by seeding in the presence of repeated mob grazing by sheep to become the dominant species over two decades.

Keywords: New Zealand, rangeland pasture development, *Lupinus polyphyllus*, *Bromus inermis*.

Introduction
There is a continuing need to assess species and species mixtures for developing improved pastures for the different type of sites and allowable inputs which make up the South Island high country rangelands. Assessments of methods and species have been given in Floate (1992) and Scott *et al.*(1995).

One of the unexpected results of previous trials has been the success of the horticultural lupin (hybrid of *Lupinus polyphyllus* Lindl. with several other lupin species (Edward 2003)) as a pastoral legume for loose textured, low pH soils of moderate to high rainfall areas at modest superphosphate fertiliser inputs (Woodman *et al*. 1997; Scott 2001). Beside its horticultural use, *Lupinus polyphyllus* has been investigated for its soil conservation use in New Zealand (Nordmeyer *et al.* 1978; Davis 1981; Lambrechtsen 1986).

The species, originally from western America, is now widespread in world temperate regions in horticulture in its coloured variants, and as a forage, or desirable or undesirable adventive species in other areas and environments.

In the New Zealand rangeland context it was its success on the roadsides; wet areas; acidic, low P, high Al soils; eroding subalpine soils; ungrazed areas; but its often general absence from adjacent grazed land (presumably grazed if present) which indicated its possibilities as a controlled sown forage species.

The first larger scale demonstration of the grazing potential of *L. polyphyllus* came from two trials where a common mixture containing 25 contending pasture species, including *L. polyphyllus*, were sown over a large area and then many different fertiliser and sheep grazing management regimes imposed on individual fenced plots.

Those trials were observed over three decades, to date, to see how species grew and persisted in the different contexts and the grazing capacity achieved (Scott 2001, 2008). These were done for both the pragmatic purpose of finding more productive pastures, and an experimental demonstration of the concept of viewing pasture development and species suitability in terms of four environmental gradients of temperature, moisture, soil fertility and animal treading and grazing influence.

The trials described in this paper continue those evaluations by comparing grazed initial binary mixtures of a wide range of legumes and grasses to initially measure the changes in their relative contribution and yields. Also, this was continued over two decades in a common field allowing inter-change of species between plots to determine what may be the longer term sustainable mixtures under the particular inputs and grazing.

Method and materials
The two trials were conducted at the Mt John trial site (43º 59′ S, 170º 27′ E), Lake Tekapo, New Zealand, on an upland yellow-brown Tekapo soil on moraine material and drift material. The site is at 820 m a.s.l. altitude and estimated annual rainfall of 650 mm, in which was adventive hieracium (*Hieracium pilosella*) dominated depleted native short-tussock grassland (*Festuca novae-zelandiae*). A general site soil analysis of undisturbed top soil gave values of pH 5.2, Tamm Al 2.8, Olsen P 40, and sulphate S 5.

Trial A
The main trial was of 1.5 × 50 m strip plots of 14 different legumes cross sown with similar strips plots of 16 different grasses/herbs, each with two superphosphate fertiliser rates (50 or 250 kg ha^{-1} yr^{-1} of 5% P, 50%S) for 11 years and subsequently unfertilised, and four spatial replications of all combinations, thus giving eight subplots of each binary species combination (Table 1). Seed, at conventional seeding rates, was

surface broadcast in September 1991 onto rotary-hoed cultivated ground and raked in. The site had received some previous fertiliser before cultivation and sowing. The trial was given a full year to establish before grazing commenced. Subsequently it was mob-grazed with sheep twice yearly to less than 5 cm residual height as a single block. Pasture composition at the subplot level (each single legume/grass combination) was determined in early summer prior to grazing for 11 years from visual ranking of each species shoot mass contribution and consequent species proportions (Scott 1989) of the 3–5 most abundant species – though for the 5th to the 9th year it was only for the two sown species. For 6 of those years, total relative pasture yield was also simultaneously measured with a capacitance probe (five/subplot). In subsequent years the trial was assessed as a single plot for all species.

Trial B

The second trial was disc-drilled in 1989 with *L. polyphyllus* and *Trifolium hybridum* across of a previous 1982 sown trial which had had single species in 1.5 m wide strips of 12 different legumes and 13 different grass species under 200 kg ha^{-1} yr^{-1} superphosphate (results un-reported). After allowing a 2-year establishment period for the present trial, four twice-yearly grazing treatments were applied. Three were low sheep number set stocking rates in ratio of nominally 2:3:4 (S2, S3, & S4) and a fourth high mob-stocking to give similar pasture residual to the central set-stocking

Table 1 Trial A: sown species and cultivars, their mean percentage contribution in their subplots (Prop.), annual change (%/yr) and total subplot relative yield (mean=100) for all species for years 2, 4-6 and 8-9. G = Grasslands.

Species & cultivar	Prop. (%)	%/yr	Relative yield
Legumes			
Lupinus polyphyllus - 2 selections	60	-2	119
Trifolium hybridum -‘ Iso4n’, local	23	-10	100
T. pratense	34	-11	100
‘G. Colenso’	50		
‘G. Pawera’	26		
T. repens – ‘G. Huia’, ‘G. Tahora’	41	-10	98
T. ambiguum – ‘Monaro’	6	1	91
Lotus corniculatus – ‘G. Goldie’, ‘Cascade’	11	-4	94
L. uliginosus – ‘G. Maku’	4	-2	98
Medicago sativa – ‘Otaio’	1	0	93
Hedysarum coronarium – ‘G. Aokau’	0	0	96
LSD5%	1.5		3.1
Grasses & herbs			
Dactylis glomerata	60	-2	106
‘Sarborto’	66		
‘G. Kara’	62		
‘G. Wana’	53		
Bromus inermis - ‘G. Tiki’	53	-2	105
B. sitchensis – ‘G. Hakari’	25	-9	94
B. stamineus – ‘G. Gala’	10	-7	101
Schedonorus phoenix – ‘G. Roa’	34	0	104
Agrostis capillaris – ‘G. Muster’	35	-4	98
Festuca rubra – ‘G. Cook’	48	0	105
Lolium perenne – ‘G. Nui’	29	-8	94
Secale montanum – Black mountain rye	15	-6	93
Cichorum intybus – ‘G. Puna’	15	-6	102
Sanguisorba minor	12	-4	100
LSD5%	2.0		3.6

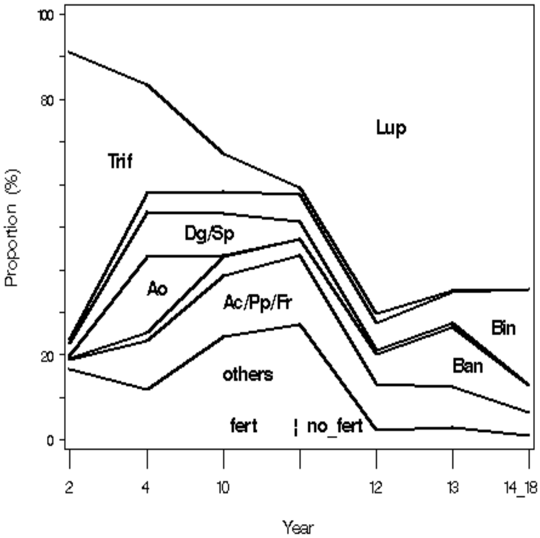

Figure 1 Trial A: changes in overall species proportions over two decades of strips of 14 different legumes cross sown with 16 different grasses/herb strips.
Lup = *Lupinus. polyphyllus*; Trif = *Trifolium hybridum, T. repens, T. medium, T. ambiguum;* Dg = *Dactylis glomerata;* Sp = *Schedonorus phoenix*; Ao = *Anthoxanthum odoratum;* Ac = *Agrostis capillaris*; Pp = *Poa pratensis*: Fr = *Festuca rubra*; Bin = *Bromus inermis*; and Ban = *B. tectorum, B. diandrus, B. mollis.*

rate (M3) without replication. These were applied for nine years. In later years all treatments were mob stocked, but maintaining the differential stocking rates. The plot sizes were 12.5 × 50 m. There was no further fertiliser application after the 10th year. There was annual late-spring visual rank of species composition prior to the first grazing to give species proportions as in the first trial.

Results were analysed by repeat measurement GLM ANOVA.

Results

Trial A

In the ANOVA of the first trial, considering only the sown legumes and grasses within their respective sub-plots, there was a significant difference between the proportional contribution the different species, changed over the years, with some interaction between legumes and grasses, but no significant difference between the two fertiliser treatments.

For the years 2, 4–6 and 8–9 when fertiliser was applied, there were large differences in the proportional contribution of the different legume species with high proportions of *L. polyphyllus,* and three of the *Trifolium* species (Table 1). Most of the legumes, apart from lupin, decreased over the first 9 years after an initial legume dominant stage within sub-plots. However, *T. ambiguum* slowly increased from a low base, and that continued into later years.

The highest proportions of sown grasses were for *Dactylis glomerata, Bromus inermis* and *Festuca rubra*, and in the fertiliser period these appeared to be stabilising in proportions.

Over time there was ingress of other species into the subplots – either spread from some of the sown species, or other species previously in or adjacent to the plots. The overall changes in vegetation composition of the trial area are given in Figure 1. The principal change was the spread of *L. polyphyllus* by seeding in the presence of periodic grazing to dominate the pasture, and the decreasing proportions of other species relative to that and the ceasing of fertiliser. There was a large initial clover dominant stage of three *Trifolium* species – mostly *T. hybridum* and *T. repens* (the later predominately from an unanticipated seed bank stimulated by the fertiliser treatments). The adventive *Anthoxanthum odoratum* also had a brief abundance period in the early years. *Dactylis glomerata* spread slightly, reaching a maximum in the intermediate years before declining. *Schedonorus phoenix* was a minor persistent species. The other sown grasses to spread were *Bromus inermis* and *Festuca rubra*. *Poa pratensis* was resident and re-established and increased to become about the third most common grass in the base of the swards. *Agrostis capillaris* increased from resident sources. Annual bromes were also increasing. This was mostly *Bromus tectorum*, appearing first within the *L. polyphyllus* plots in about the fifth year, and later included both *B. diandrus* and *B. mollis.*

There had been some test transplanting of other species into a section of the plot before the present trial. Some from those re-established. Some plants of *T. ambiguum* remained and continued to spread. An occasional plant of the annual *T. balansae* continued to appear. In later years there were two patches of *Agropyron elonagatum* spread from a distant trial. *Secale montanum* was probably under-assessed in the late spring monitoring. Some plants with grain were conspicuous in the autumn throughout the trial period.

The pasture yields prior to first grazing in early summer was low in the establishment years but increased overtime as *L. polyphyllus* spread, with total spring yields prior to first grazing being in the range of 6–7 t DM ha^{-1} yr^{-1} in later years.

Precise yield measurements using a capacitance probe would have required calibration for each species composition and pasture structure – which was untenable. Accordingly the results are only described as being relative and compared to the grand mean for each year.

With sown plus ingress species the differences between relative yields of subplots were small, with a third of mixtures being within 95–105% of the grand mean. The mean relative yield was highest for all mixtures where the sown legume was *L. polyphyllus* and where the sown grass was *D. glomerata* or *B. inermis* (Table 1).

Trial B

In the second trial *L. polyphyllus* and *T. hybridum* were over-drilled across previous strips of different legume and grass strips. The ANOVA of the first two-year establishment phase showed a significant difference in the previous resident *L. polyphyllus* proportions and a significant difference in the subsequently drilled *L. polyphyllus* and *T. hybridum* establishment in the different previous grass and legume strips.

There were differences in the initial establishment phase of *L. polyphyllus* density between the four plots before the differential grazing treatments were applied (Table 2 – S3). That difference did not persist subsequently. There was a significant notable (×12) greater establishment of *L. polyphyllus* plants in the previous grass strip sub-plots compared to the legume strip sub-plots. The exception was the low establishment in the dense sward of the *F. rubra* sub-plots. The difference may have related to a carry-over effect of nitrogen fertiliser as well as super-phosphate on the previous grass sub-plots.

The initial establishment of *T. hybridum* was about double that of *L. polyphyllus* but did not show the same difference between previous grass and legume sub-plots, though establishment was low in the dense swards of *F. rubra, T. ambiguim, T. medium* and the taller swards of previous *L. polyphyllus* sub-plots.

Subsequently the differential grazing treatments were applied. The average grazing intensity over the trial period was 1560 sheep-grazing-days ha^{-1} yr^{-1} with the differential between the grazing treatments shown (Table 2). There was large variation in the mean grazing between years related to some uncontrollable outside management constrains and the pasture variation between years. There was no grazing during the first two establishment years, heavy grazing during the 7th and 8th year and lax grazing in the 12th year (Figure 2 – where the relative grazing intensity referred to the year prior to the vegetation measurement).

The ANOVA showed that there was a significant difference between the resulting spring pre-grazing vegetations in the subsequent four contrasting grazing treatments.

The significant difference between the spring pre-grazing vegetations in the four contrasting grazing treatments was not large. The combined mean composition over time showed swards were generally

Table 2 Trial B: *Lupinus polyphyllus* proportions (%) when over-drilled into previous established strips of other species under different grazing treatments (mob stocking M3 and 3 levels of set stocking – S2, S3, S4). Mean for years 4, 6, 7 and 9-14.

Species	Prior	*L. polyphyllus* (%)				B. tec
		M3	S2	S3	S4	(%)
Plants m^{-2}		0.66	0.56	0.18	0.57	
Relative grazing		1.11	0.65	0.98	1.27	
Legumes						
Lupinus polyphyllus	na	46	39	57	60	29
Trifolium hybridum	na	42	51	60	57	18
T. ambiguum	3.9	5	10	17	24	16
T. medium	1.0	34	39	47	55	31
T. repens	0.1	35	46	46	54	16
Others		34	46	48	55	22
Grasses						
Agrostis capillaris	4.7	26	41	41	40	17
Schedonorus phoenix	3.6	13	32	31	34	22
Festuca rubra	1.9	14	29	45	24	3
Bromus inermis	1.2	18	31	46	26	1
Phleum pratense	0.9	38	39	51	45	20
Others		29	41	49	45	27
LSD5%			12.6			5.9

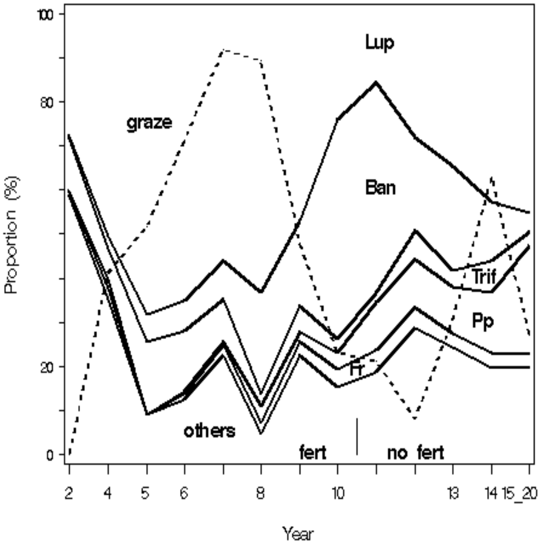

Figure 2 Trial B: Changes in overall species proportions and relative grazing in previous year (dotted) over two decades of *L. polyphyllus* and *T. hybridum* over-drilled across previous strips of different legume and grass strips. Coding as for Figure 1.

dominated by *L. polyphyllus* (Figure 2). The annual *B. tectorum* had high abundance during an intermediate period. The other legumes were only a small component. There was a slow increase in the unsown *Poa pratensis* and in the sown *F. rubra*.

The effect of the four grazing treatments on the proportional contribution of *L. polyphyllus* is given in Table 2. Only a few of the prior sown species had sufficient abundance to consider interaction effects with the re-seeding and spread of *L. polyphyllus*. Its proportion was greatest in the previous legume sub-plots which had received a high-rate and set-stocking in the initial years (S4). There was no such trend within the sub-plots previously sown to grass.

L. polyphyllus proportions were lowest in the treatment which had been moderate-density mob-stocked (M3) in the early years. Lupin is only moderately stock-acceptable and the effect may relate to partial selection possible in the set stocking treatments compared and the lesser selection possible with mob-stocking. Lupin proportions were lower in the tighter swards of *T. ambiguum, F. rubra, Agrostis capillaris, Bromus inermis* and *Schedonorus phoenix*.

The high abundance of *B. tectorum* appears related to a lag effect of the heavier relative grazing about 3 years earlier opening up the sward and allowing the annual brome to enter. Its abundance was highest in the previous *L. polyphyllus* sub-plots, as it was in the Trial A. It was high in the *T. medium* sub-plot and lower in the denser swards.

Discussion

The trials give continuing evidence for the potential role of *L. polyphyllus* for grazed moderate-fertiliser input, rangeland sheep pastures, though it is conceded that they are from the same site as several of the previous investigations. Of the two trials, one started from *L. polyphyllus* over-drilled into different swards of previous species, the other starting from sown binary mixtures. In both *L. polyphyllus* persisted, increased and spread by seeding in the presence of repeated close grazing over two decades. Both trials remained legume dominant.

The species has only moderate sheep acceptability, due to its alkaloid content (c. 3%; Gibbs 1988), but sheep show adaption to it. That contrasts with its high growth rate, long term persistence and the type of sites and inputs it is suited to. The next stage should be the selection for low alkaloid forms of the local material as has been done for some annual lupin species and for *L. polyphyllus* in Eastern Europe (Kurlovich *et al.* 2008). The use of its high summer bulk and hollow stem for hay or silage should be investigated.

None of the short-term or medium term "high-fertility" grasses featured. The "moderate-fertility" grasses *F. rubra, D. glomerata* and *B. inermis* made modest contributions as secondary species.

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