Crown Pastoral Land Tenure Review

Lease name : IRISHMAN CREEK

Lease number : PT 014

Ecological Sustainability Advice from SCION

As part of the process of Tenure Review, advice is sought on a case by case basis on how to promote the Management of the reviewable land in a way that is ecologically sustainable. This report is the result of outdoor survey and inspection. It is a key piece of information for the development of a preliminary consultation document

Note: Plans which form part of the Ecological Sustainability advice from SCION are published separately.

These documents are all released under the Official information Act 1982.

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Can trees restore degraded soils and promote ecologically sustainable management in tenure review of dryland Mackenzie Basin properties?

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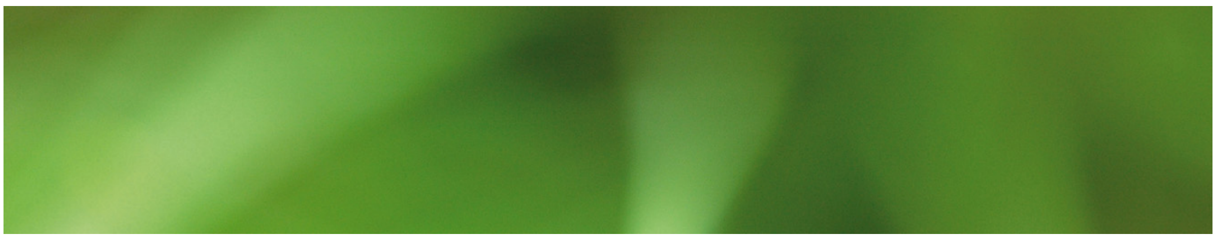

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Commercial in Confidence

Date: June 2009
Client: Darroch Valuations
Contract No:J60953

Can trees restore degraded soils and promote ecologically sustainable management in tenure review of dryland Mackenzie Basin properties?

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Executive Summary

Objective

'To determine the role of trees in restoring degraded soils and promoting ecologically sustainable management in tenure review of dryland Mackenzie Basin properties.'

'Sustainable land use' is considered to mean the same as 'sustainable management', as defined in the Resource Management Act, 1991. This, in turn, equates to a primary tenure review objective of the Crown Lease Pastoral Review Act 1998, which is "to… promote the management of reviewable land in a way that is ecologically sustainable".

Method

Three days (May 12-14) were spent inspecting the dryland 'case study' properties of Maryburn, The Wolds, Irishman Creek and Balmoral stations in the Mackenzie Basin. Simons Pass station was also briefly inspected. Short discussions were held with station owners or managers, and before this report was written, background papers on the stations' conservation resources (prepared by the Department of Conservation) were read.

Main findings

- Soil stability and health are crucial to maintaining the 'life supporting capacity' and sustainability of any site.
- The drier sub-humid parts of the Mackenzie Basin and the case study stations have similar soils, the dominant types being depleted, stony, lightly vegetated and eroding Fork and Mackenzie soils, and the deeper and stable Pukaki and Tekapo soils.
- Fork and Mackenzie soils. On these soils, tree establishment would not only stop soil loss, but would also promote soil accumulation (by intercepting wind blown dust) and increase the availability of key soil nutrients.
- Tekapo and Pukaki soils. On these soils, the establishment of introduced trees would not necessarily enhance 'ecological sustainability' or the preservation of 'life supporting capacity'. The reasoning is that sheep and rabbits have been present on these soils for over 100 years, and with a continuation of sensible domestic and wild animal (plus *Hieracium*) management, it should be possible to sustain the present life supporting capacity, and (arguably) also the present-day ecology, well into the future.
- Introduced trees will grow on these soils, and would out-produce any other plant form in terms of biomass production. There are commercial implications for such growth, in the form of timber, fibre, carbon storage and as a future biofuel resource.

- Introduced trees have a range of impacts (both positive and negative) on the environment in which they grow, and all need consideration in the determination of their role in sustainable land management, and as a land use generally.
- In order to minimise the negative impact of forests on water yield, any tree planting should be kept away from the immediate vicinity of wetlands, streams, springs and seepage areas.
- Forestry is classified as a 'Discretionary' land use in the Mackenzie District Plan, and therefore a resource consent would be required before any planting could be undertaken. The factors most likely to attract attention in the consideration of any consent application would be visual landscape impact and risk of wilding spread.

Conclusions

- These are based on five case study stations in the drier, sub-humid part of the Mackenzie Basin - Balmoral, Irishmans Creek, The Wolds, Maryburn and Simons Pass
- Maryburn and Simons Pass stations have large areas of Fork and Mackenzie soils, while Balmoral and The Wolds have smaller amounts and Irishmans Creek very little.
- These soils have a very light vegetation cover and are still being eroded. ***Therefore, on Fork / Mackenzie soils, tree planting is considered a potentially viable option for assisting the maintenance of 'life supporting capacity' and in the long-term ecological sustainability.***
- Elsewhere on the five stations, on the large areas of Tekapo and Pukaki soils (and better soils), introduced conifers will grow well. ***However, on Tekapo and Pukaki soils, it is not considered that their presence would significantly enhance 'ecological sustainability' or the preservation of 'life supporting capacity'.***

Table of Contents

Information for Scion abstracting:

Contract number	J60953
Client Report No.	
Products investigated	Potential for trees/forestry in dryland high country
Wood species worked on	Radiata, Corsican, ponderosa pine
Other materials used	None
Location	Central Mackenzie Basin, Lakes Tekapo and Pukaki area

1. Introduction

Introduced trees and forests are a potential land use in the drier (or sub-humid) parts of the Mackenzie Basin, and could assist in maintaining the 'ecological sustainability' of the land.

This report is being undertaken as part of the Tenure Review process, as required in the Crown Lease Pastoral Act 1998 (CPLA). Within this Act, a primary tenure review object is *"to … promote the management of reviewable land in a way that is ecologically sustainable".* 'Ecologically sustainable' is not defined in the CPLA, but there is general agreement that 'sustainable management' in relation to land resources means sustaining the life supporting capacity and productivity of the land on an ongoing basis. 'Sustainable management' as defined in the Resource Management Act 1991 is:

"Managing the use development and protection of natural and physical resources in a way, or at a rate, which enables people and communities to provide for their social, economic and cultural wellbeing and for their health and safety while -

- sustaining the potential of natural and physical resources to meet the reasonably foreseeable needs of future generations;
- safeguarding the life supporting capacity of air, soil and ecosystems;
- avoiding, remedying, or mitigating any adverse effects of activities on the environment."

"Management … in a way that is ecologically sustainable" has a similar meaning, but gives priority to sustaining the life supporting capacity of the ecosystems and the ecological processes of the land being reviewed.

On any land where soil loss is occurring, trees and forests can be particularly important in terms of retaining the life supporting capacity of the land. This is the case in parts of the study area.

2. Objective

'To determine the role of trees in restoring degraded soils and promoting ecologically sustainable management in tenure review of dryland Mackenzie Basin properties.'

In this report, the term 'sustainable land use' has been interpreted as described above for 'sustainable management'.

The focus of the report is five 'case study stations - Balmoral, Irishmans Creek, The Wolds, Maryburn and Simons Pass.

3. Methods

In the company of Pat Curry (employed by QV Valuations), 3 days (May 12-14) were spent inspecting Maryburn, The Wolds, Irishman Creek, Balmoral and Simons Pass stations in the Mackenzie Basin. Brief discussions were held with station owners or managers (except for Simons Pass), and before this report was written, background papers on the stations' conservation resources (prepared by the Department of Conservation) were read.

Figure 1: Typical shallow and stony Mackenzie soils in the eastern parts of Maryburn and The Wolds stations, alongside the Tekapo river. In this depleted state, pastoral productivity is very low, rabbits are abundant, and soil loss continues. Introduced trees can be grown here, and would assist in maintaining 'life supporting capacity', by promoting soil retention and improvement. However, early survival would be variable and growth slow.

Figure 2: 'Typical' Tekapo and Pukaki soil areas on Irishmans Creek station. On these deeper soils, vegetation cover is complete and sites are capable of development for improved pastoral production. The potential for introduced trees is good, but their presence is not considered necessary to maintain 'life supporting capacity' (cf., Mackenzie / Fork soils).

4. Main Findings

This section is divided into two parts:

i) A summary description of the most important background environmental factors which influence land use decision-making relative to the role of trees in the drier, sub-humid parts of the Mackenzie Basin

ii) Factual information about introduced trees in the drier, sub-humid Mackenzie Basin environment, which relate to the conclusions reached. Most of this stems from the results of research undertaken by Scion /NZ Forest Research Institute in the high country, especially in their dry-land trial area on Balmoral station.

(i) Summary of the major background environmental factors influencing land use decisions

a) ***Climate:*** The major climatic factors affecting plant growth in the study area are extremes of moisture, temperature and exposure (especially to wind). Hence, the high country dry-land environment can be difficult for plant growth. In the study area, mean annual rainfall ranges from 450mm in the east and south to 700mm in the north and west, with moisture stress exacerbated in the summer by frequent strong drying winds. Winters are cold, with temperatures down to as low as -19^{0}C (July, 1995). New Zealand's 'island' climate means that frosts can occur in any month of the year, and these can be very damaging to introduced tree growth – particularly for those originating from continental climates (Ledgard and Baker, 1988).

b) ***Soils:*** The major soils in the study area are upland and high country yellow-brown earths (DSIR, 1968) or Brown Soils in the more recent classification of Hewitt (1992). Tekapo and Pukaki soils (plus their close associates) dominate the rolling hills and moraines of the middle and northern parts of the study site, while the shallower and more stony Fork and Mackenzie soils feature along the drier eastern and southern margins (Webb, 1992). Relative to 'life supporting capacity', soil retention is most threatened on these shallower soils, where vegetation is lightest, bare ground most frequent, and soil loss remains most active (Webb, 1992; McGowan et al, 1996; McGowan and Ledgard, 2004).

c) ***Flora:*** The vegetation is well described in the DOC Conservation Resource reports written for all five properties as part of the tenure review process. The vegetation ranges from tall tussock grasslands and shrublands, mainly in the moister northern and middle parts, through over-sown and top-dressed adventive grasslands, to short tussock / mouse-ear hawkweed grasslands in the drier eastern areas. All these vegetation types are slower growing and of shorter stature than introduced conifers, which can therefore suppress them over time.

d) ***Fauna:*** Rabbits, sheep, cattle and deer are the main introduced animals, all of which are vegetation browsers. The major native fauna are birds, reptiles and insects. These are well described in the DOC Conservation Resource reports written for all five properties as part of the tenure review process. By and large, the remnant native fauna reside in open areas where the vegetation is of low stature - and therefore fast-growing, erect, introduced conifers will have a significant impact on their future existence.

e) ***Rabbits:*** Numbers have been low since the arrival of rabbit hemorrhagic disease (RHD) in 1997, but are now on the increase, and even though numbers will fluctuate, they will forever be a major influence on plant survival and early growth – and hence the life supporting capacity and ecological sustainability of the land.

f) ***Impact of browsing animals*****:** Sheep and rabbits have been present in the Basin for over 100 years, so the vegetation that remains has to have some tolerance of their presence (Espie, 2001; Muerk et al., 2002). Hence, it could be insinuated that the present ecology can be largely sustained, as long as there is a continuation of sensible domestic and wild animal management. The exception would be the depleted and most rabbit-infested, Fork and Mackenzie soils, where vegetation cover is lightest, severe wind deflation occurs and erosion still continues (Webb, 1992; McGowan et al, 1996). Rabbit numbers will fluctuate relative to the status of RHD and the frequency of control operations. The incentive for effective control is not high, due to the low productivity potential of the worst affected land.

g) ***Hawkweeds (Hieracium species):*** Hawkweed dominance is more recent than that of rabbits, and its impact in high country dryland areas is more complex. Strategic grazing and pastoral development can reduce or eliminate the problem (Espie, 2001). The main species of concern in the dryland parts of the Basin is *Hieracium pilosella*. Even though the percentage cover of *Hieracium* will vary both during and within seasons (Peter Espie, pers comm), its overall presence is increasing over most of the drier, sub-humid parts of the Mackenzie Basin, with a consequent suppression of other vegetation, particularly native (Espie, 2001). The dominance of *Hieracium* is greatest in the drier zones, whilst in the more moisture-retentive soils and in the higher rainfall zones, the competition with, and suppression of, other vegetation is less.

h) ***Relative impact of rabbits, sheep and hawkweeds:*** Eight sheep and rabbit exclosure trials were established in the Basin in 1983 (Muerk et al., 2002). In the trial on a Mackenzie soil at Simon's Pass station, *Hieracium* cover increased many fold between 1990 to 2000, at the expense of native species, especially fescue tussock (*Festuca novae zelandiae*). This transition was independent of grazing treatment (Muerk et al., 2002). At the time of the author's visit, 26 years after the trial was established, there was no visible difference in vegetation cover between the control (access for both sheep and rabbits) and the sheep-only exclusion block. However, there was a noticeable difference between that and where both sheep and rabbits have been excluded. Here, there was a more obvious vegetation cover, particularly of *Hieracium,* plus a few remnant fescue tussocks. The reason for this reduction of native species is competition for moisture and nutrients by *Hieracium,* which will out-compete the former vegetation (Espie, 2001). The only places where fescue tussock remains on these dry, depleted Mackenzie soils is on patches of deeper fines, where there is better moisture retention. Elsewhere on these soils, the range and frequency of the other smaller natives is also diminishing, while the *Hieracium* cover continues to increase (Espie, 2001). Therefore, it appears that any removal of sheep alone will do little to correct the vegetation decline – unless it is also accompanied by rabbit exclusion. Even then, and despite short-term declines in *Hieracium* cover on some sites in some seasons (Peter Espie, pers comm), the dominance of *Hieracium* continues to reduce the number and frequency of native species.

i) ***Wilding conifer establishment:*** Wilding conifers have difficulty establishing on Fork/Mackenzie soils, especially where sheep and rabbits are present. There was good evidence for this in the exclosure on a Mackenzie soil at Simons Pass, were there were eleven contorta pine wildings (6-8 years old) in the sheep and rabbit exclosure plot, but none elsewhere. Although the pine seed rain would have been the same onto all treatments, wildings only established on these droughty soils in the absence of both sheep and rabbits. Wildings can establish more readily on the deeper Tekapo/Pukaki soils, as long as the grazing/browsing pressure is not excessive. Hence, if a conifer seed source is present upwind, a likely outcome of any land use which excludes rabbits, is an increase in wilding invasion.

ii) Factual information about introduced trees in the dry-land Mackenzie Basin environment

Most of this information stems from results of research undertaken by Scion /NZ Forest Research Institute in the high country, especially on Balmoral station.

a) ***Tree potential:*** The South Island high country is a natural environment for woody species (O'Connor, 1981), and vegetation is constantly trying to move in that direction. Some species of introduced trees (especially the conifers) can establish well (see 4ii(b) below), but it is much more difficult to establish native species, especially on exposed, drought-prone Fork/Mackenzie soils. Table 1 shows survival of six locally sourced indigenous woody species 10 years after planting on a Fork soil terrace and a more sheltered scarp slope alongside.

Table 1: Survival of native species10 years after planting on a flat Fork soil terrace and an adjacent scarp slope on Balmoral station (adapted from Forest Research, 2004a)

Species	Common name	Number plants surviving (number planted)	
		Terrace Fork soil	Scarp slope
Podocarpus hallii	Halls totara	0 (26)	21 (80)
Carmichaelia australis	NZ broom	2 (20)	7 (29)
C. crassicaulis	Coral broom	0 (8)	2 (9)
Ozothamnus leptophyllus	Tauhinu	0 (30)	none planted
Coprosma propinqua	Mingi mingi	2 (29)	none planted
Melicytus alpinus	Porcupine shrub	3 (20)	none planted

b) ***Tree establishment:*** This is most cost-effectively carried out when using a planting machine and mass-produced bare-rooted stock (Ledgard and Davis, 1994). However, planting machines are only suitable for uniform sites (which can be quite stony) with a relatively light vegetation cover. Elsewhere, traditional hand planting will give more reliable results, but will be more expensive. Practical basic advice on tree establishment is given in the Forestry Fact Pack (1994). The high country environment can vary dramatically from year to year, so that survival rates will vary. In trial plantings over 3 years (1992-1994) at Balmoral station (Ledgard, 1999), the survival of pine species planted on a Pukaki soil averaged over 90% for all years. On the more droughty Fork soil, survival from the 1992 and 1993 plantings was also over 90%, but after a very dry 1994/95 summer period, survival of the 1994 plantings dropped to 40%. Davis et al. (2001a) found that additional fertilizer at planting did not assist growth – although there were indications of boron deficiency, which could be corrected by a light application of Ulexite 2-3 years after establishment.

Direct seeding has been successfully tried on Pukaki soils, but has not succeeded on the more stony and drought-prone Fork soils (Davis, 1989; Davis et al., 1996). Large areas of the better soils could be sown with conifer seed relatively cheaply, but establishment is much more variable than for planting, and success will vary according to seasonal climatic differences – most notably relative to moisture availability.

c) ***Tree growth:*** Trees are the most rapidly growing vegetation form in the Basin. Unfortunately, native woody species are much harder to establish than introduced species (Ledgard and Miller, 1980; Ledgard and Baker, 1988; Forest Research, 2004). Introduced conifers have the most biomass-producing potential, and growth rates compare very favourably with growth rates within the species' natural home ranges (Ledgard and Belton, 1985), (Table 2). The most suitable forest species and regimes for the high country is addressed by Ledgard (1994), with more detailed advice given in the Forestry Fact Pack (1994) sent to every high country farmer as part of the Rabbit and Land Management programme in the early 1990s. Further discussion on the species most suited for the study area is in 5(i) and 5(ii) below.

Table 2: Growth rates of five coniferous species in the Canterbury high country, elsewhere in New Zealand, and overseas (adapted from Ledgard and Belton, 1985).

Species	**Location**	**Age (yr)**	**Mean annual volume increment (m^3/ha/yr)**
Radiata pine (*Pinus radiata*)	Canterbury high country (dry <800mm r'fall) Canterbury high country (wet >800mm r'fall) Kaingaroa, North Island Chile (average)	c. 45 c. 45 40 27	18.7 28.6 28.0 24.0
Corsican pine (*Pinus nigra*)	Canterbury high country (dry <800mm r'fall) Canterbury high country (wet >800mm r'fall) NZ Site Quality 1 United Kingdom (best)	c. 45 c. 45 50 50	13.1 22.9 17.3 20.0
Ponderosa pine (*Pinus ponderosa*)	Canterbury high country (dry <800mm r'fall) Canterbury high country (wet >800mm r'fall) NZ Site Quality 1 USA (N. California)	c. 45 c. 45 50 50	14.5 24.8 19.1 15.0
Douglas fir (*Pseudotsuga menziesii)*)	Canterbury high country (dry <800mm r'fall) Canterbury high country (wet >800mm r'fall) NZ Site Quality 1 United Kingdom (best) Canada (best)	c. 45 c. 45 50 50 70	14.4 28.6 23.1 24.0 18.5

European Larch	Canterbury high country (dry <800mm r'fall)	c. 45	11.9
	Canterbury high country (wet >800mm r'fall)	c. 45	18.9
(*Larix decidua*)	North Island pumice land	65	9.8
	United kingdom (best)	50	12.0

d) ***Growth rates:*** Results from growth plots and research trials allow fairly accurate estimates of production to be made (Ledgard and Belton 1985; Te Morenga et al., 2000). Rainfall is the major determinant of growth rate (Table 3).

Table 3: Mean annual stand volume increment (m^3/ha/yr) of fully stocked mature stands in four rainfall zones in the Canterbury high country (adapted from Ledgard and Belton, 1985).

	Mean annual volume increment (m^3/ha/yr)			
	600-800 mm annual rainfall *	800-1000 mm annual rainfall	1000-1200 mm annual rainfall	1200-1500 mm annual rainfall
Radiata pine	18.7	24.0	27.7	29.6
Corsican pine	13.1	17.6	21.3	24.0
Ponderosa pine	14.5	19.6	23.5	26.2
Douglas-fir	14.4	20.5	26.1	31.2
European larch	11.9	14.6	17.4	20.4

* Most data collected from plots on Tekapo and Pukaki soils, not Fork and Mackenzie soils

As part of a study of land use change involving forestry in the high country (Hock et al., 2001), detailed forest yield tables were produced for Corsican and ponderosa pine and Douglas-fir (Lawrence, Forest Research Institute, unpublished report). In the early 1990s, Belton (1991a/b) and O'Connor (1994) proposed forestry as a potentially economically viable and ecologically sustainable land use for degraded high country areas.

e) ***Carbon sequestration:*** There is increasing interest in growing forest for carbon storage and claiming carbon credits as part of the Emission Trading Scheme. Forest growth rates and carbon storage potential in the study area can be determined from actual on-site plots, or estimated from the likes of Table 3, but in the absence of any proven measurements they can be obtained from look-up tables on the MAF website (www.maf.govt.nz/sustainable-forestry/ets/guide/lookup-table-guide.pdf).

f) ***Environmental impacts – on site:*** From an ecological point of view, the establishment of a stand of introduced trees in the dryland areas of the Mackenzie Basin will have the following impacts:

- *Biomass:* Above-ground biomass will be increased significantly (Ledgard and Belton, 1985; Davis et al., 2007). Ten years after planting Corsican pine at 750 stems/ha on a Pukaki soils site at Balmoral station, above ground pine biomass was 15.2 tonnes/ha (Davis et al., 2007), compared a mean of 3.2 tonnes/ha for the unplanted grassland (Nordmeyer, Forest Research Institute, unpublished data). At age 10, the below-ground biomass (roots) of the pines was only around 50-60% that of the resident grassland roots, but pine root biomass will eventually exceed the root mass of the grasslands (Nordmeyer, unpublished data).

- *Soil nutrients:* Key soil nutrients will be made more available for plant growth, especially P and N and S (Davis and Lang, 1991; Davis, 1995 and 2001b). This nutrient increase under conifer plantations is mainly from mineralization of large organic matter pools existing in grasslands (Condron et al., 1996). O'Connor and Nordmeyer (1996) stated that "These findings and the evidence that they apply throughout the montane zone of the North Otago-Canterbury high country (Belton et al., 1995), have enormous implications for the activation of nutrient cycling in future land use systems and for the efficiency of pastorally invested nutrients".

- *Soil loss/accumulation:* Trees protect soils from erosion (O'Loughlin, 2005) and promote the capture of wind blown soils and hence soil accumulation (McGowan and Ledgard, 2005). Results after 2 years of trapping dust in the open and in amongst trees (stand density 1150 trees/ha, mean height 2.3m) on Balmoral station showed dust deposition in the trees to total the equivalent of 199 kg/ha compared to 110 kg/ha in the open (Fig. 3).

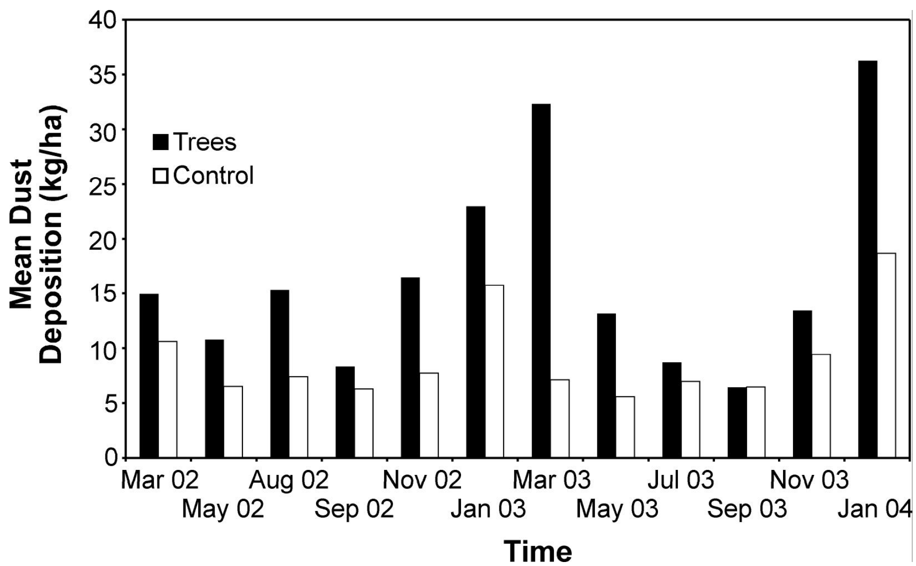


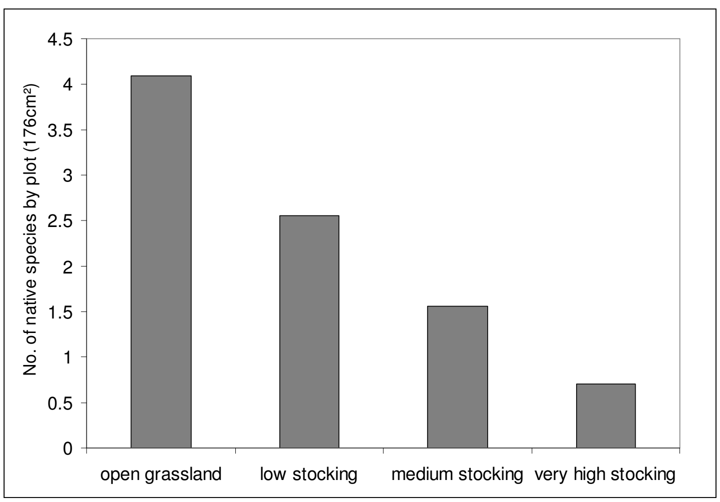
Figure 3: Dust deposition rates measured over 2 years in and alongside a 7-year-old conifer stand at Balmoral station (from McGowan and Ledgard, 2005)

- *Biodiversity:* Introduced trees will induce changes in existing bird and invertebrate populations. During a survey of high country trees in the early 1980s (Ledgard and Belton, 1985), native birds were recorded at 10% of the 243 introduced tree sites visited (Ledgard, 1995). The grey warbler was seen most often, accounting for 46% of all recordings. Other native birds seen, in decreasing order of frequency were fantails, South Island pied tit, bellbird and New Zealand falcon. Since 1994, bird counts have been undertaken in spring and autumn at Scion's Balmoral research site. The most frequently seen bird has been the skylark, followed by introduced passerines (mainly finches). Results to date with native species echo the 1980s survey findings (Ledgard, unpublished data). Grey warblers were the first to appear, in 1999 when the trees were 6 years old; since then pied tits and fantails have been seen, as has the falcon. The falcon was no doubt attracted by the high numbers of small birds (mostly passerines) now frequenting the area. Beetle populations in the grasslands and within a range of conifer stands have been studied on, and adjacent to, Balmoral station over a 2-year period. Interim results (S. Pawson, Scion, unpublished data) indicate that the highest numbers of native beetles are in the oldest conifer stands (aged 80), followed by the grassland sites and then by the stands of younger trees (aged 15).

- *Rabbits and trees:* Run-holders were asked about their impression of how a tree presence affected rabbit numbers. In general, it was agreed that rabbits are attracted by the extra cover and shelter afforded by trees, and for that reason numbers are likely to be higher close to trees than if no trees were present. Rabbits are most likely to take advantage of a tree presence when there is also a good food source adjacent (such as improved pasture or crops). In this case, where trees are an added attraction for rabbits, it should also be easier to determine where to focus control efforts

- *Suppression of existing vegetation:* Trees will reduce the numbers of existing plant species and their frequency (Paul and Ledgard, 2008). Figure 4 shows the decline in native plant species 12 years after planting Corsican pine at three densities in Scion's research area on a Pukaki soil at Balmoral station. Dense trees will also suppress *Hieracium* species, although these are the last plants to disappear.

Figure 4: Numbers of native plant species 12 years after planting Corsican pine at three densities on a Pukaki soil at Balmoral station (adapted from Paul and Ledgard, 2008)



g) ***Environmental impacts – off-site:*** From an off-site point of view, introduced trees will have the following impacts:

- *Water quality:* This will be improved (Quinn and Stroud, 2002; Hamilton, 2005). Forests reduce sediment erosion, via which phosphate can be lost into waterways. They also leach a fraction of the nitrate of most pastoral lands (except for a short period just after forest harvest), particularly when compared to modern pastoral regimes, where labile nitrogenous fertilizers are added to increase pasture growth and support higher stock numbers (Hamilton, 2005).

- *Water quantity:* Water quantity/yield can be significantly reduced by forest establishment (Pearce and Rowe, 1979). In experimental studies around New Zealand, reductions in annual water yield of between 30-80% have been measured following afforestation of pasture (Davie and Fahey, 2005). However, a reduction in yield is difficult to detect if the tree cover is less than 20% of a catchment. In some catchments, significant quantities of water are derived from relatively small high rainfall areas, seepages and deep groundwater sources; the yield from which may not be greatly affected by tree planting elsewhere in the catchment. This is probably the case in the study area, relative to total water flows into the Tekapo and Pukaki rivers – as most water originates in the high rainfall Southern Alps to the west of the Basin.

- *Wilding spread:* Natural regeneration, in the form of wilding trees, can spread onto adjacent land, especially if it is lightly vegetated and/or lightly grazed/browsed (Hunter and Douglas, 1984; Ledgard, 2004). However, some species are much less prone to spread than others. In addition, wildings have difficulty establishing on dryland Fork and Mackenzie soils, especially in the presence of sheep and rabbits (Espie, Ledgard, pers. comm., Davis et al 1996).

h) ***Commercial production:*** The capacity of introduced trees to quickly produce biomass provides commercial opportunities for traditional timber, roundwood (posts and poles) and fibre sales; carbon storage and biofuel production (Belton, 1991a, 1993; Hock et al., 2001; Forest Research, 2004b). The current markets for timber and fibre are poor, for roundwood reasonable, while those for carbon and biofuels have yet to be fully explored. These markets will undoubtedly change in the future, and with the rising interest in climate change and alternative energy sources, those for carbon storage and biofuels should become more attractive. On the negative side, introduced trees can also impact on future land use options, by creating a physical presence which can increase the cost of conversion to the likes of pasture or another tree crop (Ledgard, pers comm).

i) ***Economic and social impacts:*** In the early 1990s, a multi-disciplinary study was undertaken of the economic and social impacts of potential land-use change in the unimproved pastoral lands of the high country (Evison and Swaffield, 1994; Hock et al., 2001). The focal area of study was the Mackenzie Basin. Excluded from consideration was land above 1100m, of greater than 35^0 slope, public conservation land or areas of natural significance, and of prime agricultural use. Land use options included retirement from grazing, pastoral agriculture and plantation forestry. A survey of representative high country stakeholders found that a scenario involving 15% introduced trees (with wilding control) received more indications of acceptability than the other four scenarios (one of which was complete land retirement with no tree establishment). The potential social impacts of the 15% tree land use option in the Mackenzie Basin was addressed by Butcher (1997), who calculated significant increases in both income and employment. In addition, this option was explored more intensively on an individual property basis, using Balmoral station as a case study (McElwee et al., 1995). Under the most practical scenario, the farm surplus would drop initially by a maximum of 59% (during the main tree establishment phase) and would not return to normal for 20 years. When harvesting began after 40 years, the farm surplus would increase dramatically, with the minimum annual surplus being over five times greater than normal.

j) ***Trees and sustainability:*** The ability of introduced trees to halt erosion, capture wind-blown soils and increase soil nutrient availability (see 4iif above), and hence have a role in land-use sustainability, has attracted attention in the recent past. In 1990/91, two reports questioned the sustainability of dry tussock grasslands under the present management regimes, and both mentioned forestry as a potentially more sustainable land use. The Mountain Lands Committee at Lincoln University in their report on the degradation resulting from hawkweed invasion (Mountain Lands Committee, 1990), proposed that 'agroforestry or large-scale forestry as a sustainable land use must be considered'. In 1991, Helen Hughes, the Parliamentary Commissioner for the Environment, released a major report titled 'Sustainable land use for dry tussock grasslands in the South Island' (Hughes, 1991), in which she was more specific about a role for trees. She wrote "A future scenario for the Mackenzie Basin, for example, might see an aesthetic blend of reshaped and more financially robust properties grazing cattle, sheep, goats, deer as appropriate to land type and management need; having areas in agroforestry with larger blocks of production forestry either as wide shelterbelts or stands on severely degraded land or land with aluminium toxicity …. Elsewhere, larger blocks of privately managed plantation forests across formerly desertified lands could blend in with managed conservation areas and rural townships designed to service and process products from or for the land." Belton (1991) and O'Connor (1994) also promoted forestry as a major component for future high country sustainable land use.

k) ***Visual landscape:*** Introduced trees quickly become obvious and can both disrupt and enhance existing landscapes (Ashdown and Lucas, 1987; Boffa Miskell 1992; Thompson and Weston 1994). This aspect of introduced tree presence is particularly relevant in the dryland parts of the high country, which are largely treeless.

l) ***Resource consents:*** Under the current Mackenzie District plan, all tree planting in the Mackenzie Basin is a discretionary or non-complying activity, which means that a resource consent for forest establishment would be needed. The process for obtaining such consent is likely to be expensive and time consuming (Ledgard, 1997; Ledgard et al., 1997). The factors most likely to attract attention in the consideration of any consent application would be visual landscape impact and risk of wilding spread. In addition to environmental considerations, local councils require plans for intended roading/tracking and fire mitigation/control.

5. Conclusions

As indicated above (Table 1), native trees are much more difficult to establish (and slower growing) in the high country than introduced trees, particularly in low rainfall areas. Hence, they were not considered as an initial woody cover in the drier, sub-humid regions of the Mackenzie Basin. However, native tree establishment may be easier in the more favourable micro-climates which the more hardy introduced trees can create (Paul and Ledgard, 2008).

The following conclusions involving introduced trees and forests relate to the future 'sustainable management' (see Introduction for definition) of the drier sub-humid parts of the Mackenzie Basin, with specific focus on Maryburn, The Wolds, Irishmans Creek, Balmoral and Simons Pass stations. In order to comprehend them, the points made in 4i) and 4ii) above must be understood. As all the stations have similar soil types, and soil stability and health are crucial to maintaining 'life supporting capacity', conclusions are addressed primarily by soil type.

i) Fork/Mackenzie soils

On the Fork and Mackenzie soils, tree planting is considered a potentially viable option for assisting the maintenance of 'life supporting capacity' and in the long-term ecological sustainability. The soils are located along the drier eastern and southern margins of the stations. Soil erosion continues due to the shallow and stony nature of the soils, on top of which is a depleted and light vegetation cover with frequent patches of bare ground. In addition, *Hieracium* and rabbit populations can be high – contributing significantly to on-going land degradation.

A cover of introduced trees would not only stop soil loss but also promote soil accumulation (by intercepting wind blown dust) and increase the availability of key soil nutrients. Tree establishment is certainly possible, but may well be difficult on the most stony areas, due to the mix of harsh climate and variable seasons, which leads to survival rates that will vary from year to year. During three consecutive years of planting on a Fork soil at Balmoral station, survival was over 90% for two years, but dropped to 40% in the third year, after a very dry summer period. Mackenzie soils are drier than Fork soils, which could mean a greater frequency of such poorer establishment

Operationally, much of the land involved lends itself to the use of tree planting machines, which reduces costs considerably, although establishment may not be possible on the most compacted stony sites, due simply to the physical difficulty of planting trees into such ground. However, interspersed with these sites are large, less stony areas, where machine planting would be possible. Establishment costs using this method of planting (seedling price omitted) could be as low as 0.20c/tree.

The intention should not be to blanket plant, but to get sufficient cover to bring about a decline in wind speed and exposure – a significant wind reduction will occur for about 10 times the height of any barrier created (Horvath et al., 1997). Tree establishment would have to be carried out immediately after a primary rabbit poison, so that the seedlings attain a 'rabbit-proof' height (0.5-1m) before the rabbit population recovered.

Relative to the choice of tree species for these harsh sites, the two most important criteria would be hardiness (particularly tolerance of drought) and a low likelihood to spread wildings. In this regard, the best species would be radiata pine (*Pinus radiata*), in particular the cross with its inland hardier 'cousin' knobcone pine (*P. attenuata*) - to produce the hybrid *P. radiata x attenuata.* Radiata pine is susceptible to snow damage, and can be damaged by extreme early frosts; hence the hardier hybrid appears more suitable. When compared to other likely candidates such as ponderosa and Corsican pine, its greater drought tolerance, lower spread risk and faster growth makes it more attractive.

Table 3 above indicates the productive capability of a fully-stocked conifer forest established in the 600-800mm rainfall zone., If the production was for carbon sequestration, the C storage achieved can be determined from plots, by extrapolations from Table 2, or 'by default' from look-up tables on the MAF website (www.maf.govt.nz/sustainable-forestry/ets/guide/lookup-table-guide.pdf). Any figures resulting from extrapolation of Table 3 need to be treated with caution, and will probably over-estimate sequestration rates, as the majority of the data for the 600-800mm zone in Table 3 was collected from stands growing on Tekapo and Pukaki soils.

Harvesting trees on these flat, well-drained terraces would be easy at any time of the year.

The CO_2 sequestered by a tree cover on the Fork/Mackenzie soils would help offset the increase in green-house gas emissions resulting from any conversion to irrigated pasture and intensive animal grazing - which might occur on other parts of these soils. They could also provide shelter for the animal stock grazing the improved pasture. *In the long term, the ability of the trees to improve the availability of key soil nutrients could lead to a self-sustaining land use succession, involving a tree crop followed by pasture (and grazing) to make use of the improved nutrients, before returning to forests*.

The areas of Fork/Mackenzie soils are large, particularly on Maryburn, Balmoral and Simons Pass stations (where each has >1000ha), so it is unlikely that there would be 'blanket' conversion to tree or improved pasture crops. In the intervening areas, the existing native dry-land vegetation could be maintained, with the better financial returns resulting from the trees and any improved/irrigated pasture, allowing extra investment into the likes of weed and pest (particularly rabbit) control. The effect of the tree shelter on existing native fauna and flora in the unplanted and unimproved pasture areas is unknown.

In order to minimise the impact of tree establishment on water yield, no trees should be planted in the immediate vicinity of high water yielding areas, such as streams, wetlands, springs or seepages.

Irrespective of the long-term 'sustainability' and 'life supporting capacity' benefits of trees in the Basin, such a land use is classified as 'discretionary' or 'non-complying' in the Mackenzie District Plan, and therefore a resource consent would be required before any planting could be undertaken. The factors most likely to attract attention in the consideration of any consent application would be visual landscape impact and risk of wilding spread.

If trees were considered an appropriate sustainable land use for the Fork/Mackenzie soils, it is unlikely that the present owners would want to pay for their establishment – the assurance of a positive economic return being currently too uncertain. It is also unlikely that DOC would be interested in forest establishment with exotic species. Therefore, the need for some form of state investment is most likely, and could come in the form of the Ministry of Agriculture and Forestry's Afforestation Grant Scheme (see MAF website - www.maf.govt.nz/climatechange/forestry/initiatives/ags). However, this is a contestable fund, and applications from dry-land areas with comparatively poor growth rates, may not compete well.

ii) Tekapo and Pukaki soils

In the long term, it is not considered that the establishment of introduced trees would significantly enhance 'ecological sustainability' or the preservation of 'life supporting capacity' on the large areas of Tekapo and Pukaki soils (and better soils) in the study area. The reason for this is that sheep and rabbits have been present on these soils for over 100 years, and with a continuation of sensible domestic stock and wild animal management (together with that of *Hieracium* - Espie, 2001), it should be possible to sustain the present life supporting capacity, and (arguably) also the present-day ecology, well into the future.

Although a tree cover is not considered necessary in order to 'sustainably manage' these soils, introduced trees could be readily established and would grow well. This forest option may be attractive for commercial reasons (timber, C storage or as a biofuel source) on the areas of land which have low pastoral and/or conservation and visual landscape values. The Pukaki and Mt John moraines, located between the Mary Range and Lake Pukaki on Maryburn and The Wolds station are one such area. Grazing values are considered low, and wilding trees are more common than in any other part of the study area. From a visual landscape point of view, the DOC Conservation Resources report for Maryburn includes conflicting statements about the value of these moraines. On P 4 it is stated that 'the moraines between the Mary Range and Lake Pukaki are likely to have a limited role in the public perception of the Basin's landscape', whereas on P7 it is stated that 'the Pukaki moraine areas are of high significant inherent visual value'.

Compared to the Fork/Mackenzie soils, there is a wider range of forest species which could be established on the Tekapo and Pukaki soils. The major forestry candidates are listed in Table 3, and addressed in more detail in the Forestry Fact Pack (1994), produced as part of the Rabbit and Land Management Programme, and delivered to all farmer participants. Growth rates would also be significantly better than on the Fork and Mackenzie soils, with the best sites equating more to the 800-1000mm annual rainfall levels given in Table 3. The risk of wilding spread would probably rule out the best commercial timber performer, Douglas-fir, as well as Corsican pine and European larch. Ponderosa pine is less prone to wilding spread, but the least wilding risk and the fastest growth rates would be from radiata pine and its hybrids with Knobcone pine. This species and the hybrids would be the best performer for biomass and C storage, where a susceptibility to stem damage from high winds and particularly snow, should not significantly affect returns. The most uniform parts of the Tekapo/Pukaki soil area would suit machine planting, which would make the establishment of bulk-produced bare-root stock very cost effective. The relatively easy terrain would also present few problems for harvesting, although this would be more expensive than on the flat, well drained and more compacted Mackenzie and Fork soils.

Factors associated with the funding of forest establishment on the Pukaki and Tekapo soils, their use for carbon storage and the need for a resource consent from the local council, would be the same as stated for the Fork/Mackenzie soils.

Afforestation location summary

Below is a summary of the author's perception of the need for forests in the drier, sub-humid parts of the Mackenzie Basin, using the five stations as case studies:

- **Maryburn Station**
  A tree cover would maintain 'life supporting capacity' on the Mackenzie soils (and adjacent areas) east of Irishman's Creek (outwash and river terrace areas covering almost 4000 ha), which have a very light vegetation cover and are still being actively eroded (Map 1a). Elsewhere on the station, on the large areas of Tekapo and Pukaki soils (and better soils), it is not considered that the establishment of introduced trees would significantly enhance 'ecological sustainability' or the preservation of 'life supporting capacity'. However, introduced trees would grow well on these soils, and would out-produce any other plant form in terms of biomass production. When considering alternative land use options on these soils, the site where trees would be best suited (and where pastoral improvement options are least attractive) is an area of almost 1000 ha on the Pukaki moraine surfaces west of the Mary Range (refer 5ii above, plus Map 1b).
  Before any forest planting could take place on Maryburn station, approval would be needed from the Mackenzie District Council. The factors most likely to attract attention would be visual landscape impact and risk of wilding spread. In order to minimise the negative impact of forests on water yield, any tree planting should be kept away from the immediate vicinity of wetlands, streams, springs and seepage areas.

- **The Wolds Station**
  A tree cover would maintain 'life supporting capacity' on the Fork soil (approximately 700ha) along the eastern margin of the property alongside the Tekapo River (Map 2). This area has a very light vegetation cover and is still being actively eroded. Elsewhere on the station, on the large areas of Tekapo and Pukaki soils (and better soils), it is not considered that the establishment of introduced trees would significantly enhance 'ecological sustainability' or the preservation of 'life supporting capacity'. However, introduced trees would grow well on

these soils, and would out-produce any other plant in terms of biomass production. When considering alternative land use options on these soils, the site where trees would be best suited (and pastoral improvement options are least attractive) is an area of about 700 ha on the Mt John moraine surface west of the Mary Range (refer 5ii above, plus Map 2).

Before any forest planting could take place on The Wolds station, approval would be needed from the Mackenzie District Council. The factors most likely to attract attention would be visual landscape impact and risk of wilding spread. In order to minimise the negative impact of forests on water yield, any tree planting should be kept away from the immediate vicinity of wetlands, streams, springs and seepage areas.

- **Irishmans Creek station**

  This station has only a very small area of Fork soils (approximately 200 ha), where tree planting could assist in the maintenance of 'life supporting capacity' (Map 3). Elsewhere on the station, on the large areas of Tekapo and Pukaki soils (and better soils), it is not considered that the establishment of introduced trees would significantly enhance 'ecological sustainability' or the preservation of 'life supporting capacity'. However, introduced trees would grow well on these soils, and would out-produce any other plant form in terms of biomass production. When considering alternative land use options on these soils, the site where trees would be best suited (and pastoral improvement options are least attractive) is on an area of approximately 900ha of Mt John moraine surface to the west of the Mary Range (refer 5ii above, plus Map 3).

  Before any forest planting could take place on Irishmans Creek station, approval would be needed from the Mackenzie District Council. The factors most likely to attract attention would be visual landscape impact and risk of wilding spread. In order to minimise the negative impact of forests on water yield, any tree planting should be kept away from the immediate vicinity of wetlands, streams, springs and seepage areas.

- **Balmoral station**

  This station has 200 ha of Fork soils along the southern bank of the Fork Stream, where it meets the Tekapo river, plus another approximately 1,000 ha of recently acquired land bounded by the Fork Stream, SH 8 and the Godley Peaks road on its western, southern and eastern boundaries respectively (Map 4). These soils have a very light vegetation cover and are still being eroded – hence tree planting could assist in the maintenance of 'life supporting capacity'. Elsewhere on the station, on the large areas of Tekapo and Pukaki soils (and better soils), it is not considered that the establishment of introduced trees would significantly enhance 'ecological sustainability' or the preservation of 'life supporting capacity'. However, introduced trees would grow well on these soils, and would out-produce any other plant form in terms of biomass production.

  Before any forest planting could take place on Balmoral station, approval would be needed from the Mackenzie District Council. The factors most likely to attract attention would be visual landscape impact and risk of wilding spread. In order to minimise the negative impact of forests on water yield, any tree planting should be kept away from the immediate vicinity of wetlands, streams, springs and seepage areas.

- **Simons Pass station**

  This station is similar to Maryburn and The Wolds, in that it has a significant percentage of its area (more than 50% or approximately 2200ha) in Mackenzie soils (Map 5), which have a very light vegetation cover and are still being eroded – hence tree planting could assist in the maintenance of 'life supporting capacity'. Elsewhere on the station, on the large areas of Tekapo and Pukaki soils (and better), it is not considered that the establishment of introduced trees would significantly enhance 'ecological sustainability' or the preservation of 'life supporting capacity'. However, introduced trees would grow well on these soils, and would out-produce any other plant form in terms of biomass production.

  Before any forest planting could take place on Simons Pass station, approval would be needed from the Mackenzie District Council. The factors most likely to attract attention would be visual landscape impact and risk of wilding spread. In order to minimise the negative impact of forests on water yield, any tree planting should be kept away from the immediate vicinity of wetlands, streams, springs and seepage areas.

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