ECOLOGICAL PROCESSES IN THE SOUTH ISLAND PASTORAL HIGH COUNTRY

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1. INTRODUCTION

The scope of this review is limited to high country pastoral land (mostly held under pastoral leases) subject to the Crown Pastoral Land Act 1998. High country pastoral land encompasses a considerable diversity of landforms, geology, soils, climate, vegetation, habitats, and ecological processes. Land in pastoral lease tenure occurs from Southland to Marlborough, and also in south Westland. While pastoral lease land originally included substantial areas of beech (*Nothofagus*) forest, many of these forests were subsequently excluded from pastoral lease tenure. The predominant indigenous vegetation remaining on high country pastoral lease land is tussock grassland, although areas of forest and shrubland are also present. Grassland is also the main indigenous vegetation type that is subject to pastoral land use practices such as grazing and burning, but areas of shrubland, and to some extent forest, can also be affected by these land use practices. One consequence of the extensive pastoral use of indigenous grassland is that this vegetation has been the subject of the majority of scientific research undertaken in the pastoral high country. While indigenous forests on western pastoral land have also been the subject of research programmes, woody vegetation in the drier eastern high country has received relatively little.

2. METHODS

This review draws upon published scientific research as well as investigations of high country vegetation and processes by the author[1]. Unless otherwise referenced, the opinions and interpretations expressed in this report are those of the author.

3. KEY ECOLOGICAL INFLUENCES AND PROCESSES

Some of the key drivers of ecological processes in the high country are climate, soil, human history, fire, grazing and browsing, and weed invasion. This review first considers fundamental physical drivers such as soil and climate, before considering the effects of secondary drivers related to human land use. Ecological constraints and opportunities for future use of high country land for pastoralism and conservation are then discussed.

3.1 High country climate

The South Island high country is affected by climatic gradients in temperature and the effects of topography on the predominant west-southwest wind flows. A broad latitudinal (north-south) temperature gradient occurs down the South Island, with southern areas being generally cooler than northern areas. An additional 'continentality' gradient is related to distance from the moderating influence of coastal waters. The result of this is that for a given latitude, inland areas tend to have greater temperature fluctuations (colder winters, hotter summers) than coastal areas. These broad climatic gradients are strongly influenced by topography, particularly the interaction between the predominantly westerly wind flow and the axial South Island

[1] For example Lee *et al.* 2000; Lloyd *et al.* 2002; 2003a; 2003b; Connor & Lloyd 2004; Marx *et al.* 2004

mountains. This generally results in high rainfall zones at and to the west of the axial mountain ranges, and drier 'rain shadows' to the east of these ranges, but also causes pronounced variations in rainfall and temperature at a regional scale[2].

The net effects of these patterns are that western and southern areas of high country land tend to have higher rainfall while eastern areas are drier and warmer, particularly the inland basins of Central Otago which experience a semi-arid climate. Locally, climate is also related to elevation, because in general temperature decreases and precipitation and wind increase as altitude increases.

These climatic effects are of considerable importance to the high country. Temperature and moisture have very strong effects on site productivity, affecting rates of decomposition, mineralization, and plant growth, and rates and types of soil formation (see below). Due to the cooler and wetter climate, soils at higher elevation are generally less productive and have not been developed (e.g. cultivation, fertiliser application, seed sowing) to the same extent as lower elevation land because of insufficient return on development costs. In addition, many weeds of lower elevation land are unable to thrive at high elevation. As a result, higher elevation high country land usually retains an indigenous plant cover (although its composition may have been altered due to the effects of grazing - see below). Temperature and rainfall also influence the flammability of vegetation, which has resulted in greater fire frequency in central and eastern high country areas.

3.2 High country soils

Traditional classification of high country soils has been superseded by the revised New Zealand Soil Classification[3]. Information on the distribution of high country soils is taken from the South Island High Country Review[4]. In the following descriptions, names from the traditional soil classification are given in brackets as these will be more familiar to many readers. The most extensive soil group in the pastoral high country is Brown soils (upland and high country yellow brown earths), which occur in places where summer dryness is uncommon and waterlogging does not occur in winter (upland areas with regular rainfall). Pallic soils (yellow grey earths) are the next most extensive and occur in seasonally dry sites in the low-elevation moderately dry eastern high country and inland basins. Semi-arid soils (brown grey earths) occur where annual precipitation is <500 mm in the inland basins of Otago and southern Canterbury. The remaining areas of high country land are mostly covered by recent soils or areas of rock, scree, or permanent snow and ice.

3.3 Historical vegetation pattern

Prior to human arrival in New Zealand (*c.*800 years ago), the high country supported a predominantly woody vegetation cover, but there was regional and altitudinal variation in the composition of this vegetation. Closed-canopy beech (*Nothofagus* spp.) forest occurred in relatively wet environments in the western, southern, and Canterbury high country and elsewhere on upper slopes where annual rainfall was

[2] Salinger & Mullan (1999)

[3] Hewitt (1993)

[4] Martin *et al.* (1994)

greater than >700 mm, with open podocarp/broadleaved forest in the drier eastern high country and the inland basins of Marlborough, Canterbury and Otago[5]. Hall's totara (*Podocarpus hallii*), matai (*Prumnopitys taxifolia*), mountain toatoa (*Phyllocladus alpinus*), and bog pine (*Halocarpus bidwillii*) were the typical coniferous components these open forests, together with the broadleaved trees ribbonwood (*Plagianthus regius*), narrow-leaved lacebark (*Hoheria angustifolia*), and in the southern high country, kowhai (*Sophora microphylla*). On semi-arid Otago basin floors, *Olearia* scrub appears to have formed a distinctive vegetation, and fierce lancewood (*Pseudopanax ferox*) has recently been identified as an important species of Central Otago open hillslope forest[6]. Grassland vegetation would have been dominant only in very dry, infertile, or regularly disturbed sites and above the altitudinal limit of forest, but grasses also occurred within open forest and scrub vegetation[7] and on rock outcrops.

3.4 Changes due to human land use

The current state of the high country cannot be understood by considering only current patterns and processes. Historic land uses have generated long term effects and these continue to affect ecological processes.

The major historic change to high country vegetation was the replacement of forest by shrubland and grassland, a process which occurred extensively across the high country. The initial deforestation event was the result of fires lit by Polynesian settlers and is captured by major changes in the fossil pollen record and by an abrupt increase in the frequency of charcoal[8]. These fires virtually eliminated lowland and montane forests in areas receiving less than 1000 mm annual rainfall, while forest loss was partial in the wetter western and southern high country areas. Bracken (*Pteridium esculentum*), grasses, *Aciphylla* spp., and fire-favoured shrubs such as manuka (*Leptospermum scoparium*) and kanuka (*Kunzea ericoides*) were the main beneficiaries of the increase in fire frequency, with bracken becoming abundant on the wetter western mountain flanks, and small grasses, tall tussocks (*Chionochloa* spp.), and manuka and kanuka becoming prominent in central and eastern areas formerly occupied by forest[9]. New Zealand is unusual in having a suite of dry-adapted woody species that are none the less poorly tolerant of fire. At the time of European settlement, much of the eastern high country vegetation below the alpine zone was probably a mosaic of scrub thickets and scrubby grasslands[10], with similar vegetation occupying deforested areas in the wetter west. Fire would have been an important tool at the outset of pastoral occupation, to provide access to new country for stock. More frequent use of fire led to loss of fire-sensitive woody vegetation and an increasing dominance of relatively pure tall tussock grassland[11].

These tall tussock grasslands were quickly changed by more intensive pastoral use (a livestock peak occurred in the early 1870s), which resulted in a decline in grassland

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5 McGlone & Moar (1998); McGlone (2001)
6 Wood (2007)
7 McGlone (2001)
8 McGlone & Basher (1995); McGlone (2001)
9 McGlone (2001); Wood (2007)
10 O'Connor (1982)
11 Connor (1965); O'Connor (1982)

stature, conversion of tall tussock to short tussock grassland, increase in unpalatable and/or fire-tolerant species, and invasion by exotic pasture grasses and weeds[12].

Much of the information on these processes has been gained by inference and from the anecdotal historical observations of early runholders and explorers. Scientific understanding of indigenous vegetation patterns and processes in the high country has been greatly hampered by the lack of representative control sites, i.e. sites that were never burned, grazed, top-dressed, or oversown and which could be used to assess baseline vegetation condition and trends. This deficiency is particularly apparent for montane grasslands. For example Black Rock Scientific Reserve was created in 1971 to preserve 'undisturbed' tussock grassland in eastern Otago, but the site already had a long history of burning and grazing[13], and the reserve was created a full century after the historic peak in livestock stocking rate.

Currently, extensive areas of high country landscape retain practically no indigenous forest, particularly in central Otago and the inland basins of Canterbury. Large areas of indigenous forest remain only on western and southern high country land, with elements of indigenous forest becoming increasingly confined to natural refuges from fire in eastern areas. The extent of tall tussock grassland has also been greatly diminished on high country land, although this process has occurred less intensively on land under pastoral lease tenure relative to land with fewer restrictions on land use activities.

The following sections provide more specific detail on the effects of pastoral use on soil, indigenous vegetation, and species.

3.5 Effects of pastoral land use on soil

Soil condition is a fundamental constraint to both pastoral and conservation outcomes sought from the high country. Soil parameters of importance include topsoil depth, carbon concentration, degree of acidity, and nutrient concentrations. Several aspects of pastoral land use can have direct and indirect effects on soil properties. In the past two decades studies of these issues have become more common, and some are outlined below.

Erosion

Topsoil loss from a sunny upper slope in a semi-arid Central Otago site averaged 3.4 cm over 40 years (an annual loss of 10.2 t/ha), while shady upper slopes and both shady and sunny toe slopes gained 0.3-0.6 cm of top soil (annual gain of 0.5-0.9 t/ha), with erosion and deposition being dominated by northwest winds[14]. In high country environments it can be difficult to measure the relative contribution to soil erosion from natural processes versus pastoral management, but loss of vegetation cover strongly increases wind and sheet erosion[15], and the extensive areas of pastoral land

[12] O'Connor (1982); Treskonova 1991
[13] Bulloch (1973)
[14] Hewitt (1996)
[15] McSaveney & Whitehouse (1989)

that are grazed and burned without fertiliser inputs have greatly increased the extent of bare ground in the high country.

Soil Properties

In short tussock grasslands (without fertiliser inputs) in dry (≤500 mm annual rainfall) basins, grazing alone (with or without burning) has been shown to cause a net annual loss of all the major plant nutrients, while fertilising tussock grassland in a moist (700-1000 mm annual rainfall) zone led to gains of most nutrients on sunny slopes, but a decline of nitrogen on shady slopes, possibly because of nutrient transfer from stock[16]. A carbon turnover model has estimated that degraded semi-arid soils in New Zealand will require 50 years to recover soil carbon to the undegraded state, but this was considered an underestimate[17]. On an Otago upland site (975 m a.s.l.) topsoil carbon and moisture holding capacity were reduced beneath a recently burned narrow-leaved snow tussock (*Chionochloa rigida*) grassland[18]. In seasonally dry Canterbury high country grasslands, excluding stock for 15 years was insufficient to rehabilitate soil nutrient concentrations[19]. In the same study, oversowing and fertilising significantly raised soil nitrogen and carbon levels, but had an acidifying effect on soils. Stopping grazing and oversowing was the only treatment that maintained pH levels; stopping grazing alone did not. Long term grazing of red tussock (*Chionochloa rubra*) grassland in Central Otago uplands is associated with lower soil porosity, greater soil compaction, and reduced biological activity, and soil changes in these grasslands may not yet have reached a steady-state[20], but few differences in soil properties were observable in montane plots near Porters Pass where grazing had been excluded for 45 years[21]. Other studies of the effects of fertilising high country tussock grassland indicate that addition of fertiliser generally raises major soil nutrient and carbon concentrations, increases soil microbial biomass, acidifies the soil, and reduces the cover of bare ground and indigenous plants[22]. Afforestation of tussock grassland with coniferous trees has been shown to increase the availability of some topsoil nutrients to adjacent plants[23]. This could potentially enhance the sustainability of agro-forestry operations, but agroforestry is not compatible with management for conservation.

Research on high country soils has largely been undertaken on the lower to mid-elevation (400-900 m) often seasonally dry and semi-arid sites that have been more intensively used for pastoralism. There appears to be a research gap on the effects of grazing on high elevation soils that experience pastoral use during summer. Studies such as those described above indicate that continued pastoral use of these grasslands (particularly in seasonally dry sites) will not be sustainable without inputs of fertiliser, but fertiliser use reduces the cover and/or diversity of indigenous vegetation, and is associated with increasing soil acidity. These studies also illustrate that soil changes are not easily reversible, may reflect historic processes, and it may take many decades

[16] McIntosh (1997)
[17] Parshotam & Hewitt (1995)
[18] Ross *et al*. (1997)
[19] McIntosh *et al.* (1997)
[20] Gibson *et al.* (2000)
[21] Basher & Lynn (1996)
[22] McIntosh *et al.* (1994; 1999)
[23] Davis and Lang (1991); Davis (1994)

to achieve soil rehabilitation goals through exclusion of grazing animals alone. This is the common strategy for conservation management of formerly grazed pastoral land.

3.6 Effects of fire on high country vegetation

The effects of fire on snow tussock (*Chionochloa* spp.) grassland vegetation have received considerable research with respect to the tussock species (particularly narrow-leaved snow tussock - *C. rigida*), but effects on other components of tussock grassland vegetation and soil, or other kinds of indigenous vegetation, have received relatively less attention, apart from documentation of broad changes in vegetation cover described in Section 3.4.

Snow Tussock Responses

Spring burning of narrow-leaved snow tussock initially stimulates leaf growth and tiller production in the subsequent 2-3 years, but this is at the expense of rapid internal reallocation of nutrients from roots to shoots, and subsequent leaf growth rates are depressed for at least 14 years[24]. The same study showed that leaf nutrient concentrations decline in subsequent years but increase to reach equivalence with unburnt tussocks after eight years. Nutrient concentrations in tussock stems and roots remained significantly depressed for the 14-year duration of the study. Spring burning also stimulates flowering in narrow-leaved snow tussock the year after the fire, which appears to be a response to greater warmth experienced by stem apices due to the fire-blackened tussock bases[25], but subsequent flowering is depressed for at least 14 years[26]. Species of *Chionochloa* are renowned for irregular 'mast' flowering which is initiated by particularly warm temperatures in the preceding summer[27].

Tussock Grassland Responses

When tussock grassland is burned, the tussock canopy is removed and inter-tussock vegetation and leaf litter are depleted. This facilitates invasion of exotic pasture grasses, which are heavily targeted by stock along with regrowing tussock foliage[28]. Removal of nutrients in this young tussock foliage by stock browse has an effect that is additional to the effects of fire, and prolongs the period required for tussock recovery even further. If burning and/or grazing is repeated before the completion of tussock recovery, effects on tussock vigour are exacerbated and an ongoing decline in tussock grassland condition results, with a decrease in tussock stature and in the montane zone, replacement of indigenous intertussock vegetation by exotic species. This process appears to be operating extensively in montane high country tussock grasslands subject to pastoral use.

[24] Payton *et al.* (1986)
[25] Rowley (1970)
[26] Payton & Mark (1979)
[27] Connor (1966)
[28] Yeates & Lee (1997)

Fauna

In the Otago high country, local dispersal of nationally threatened grand skinks (*Oligosoma grande*) is reduced where tall tussock grassland is converted to pasture, and this has effects on the genetic structure and survival of grand skink populations[29]. Spring burning of montane tussock grassland in Otago has been shown to significantly reduce the local population density of skinks (*Leiolopisma nigriplantare maccanni*), but some skinks are able to survive fire, presumably by seeking shelter in soil crevices or tussock bases[30]. Also in Otago, microinvertebrates have been shown to recover rapidly after burning of tall tussock vegetation[31], but few studies have assessed the effects of pastoral management on invertebrates.

3.7 Effects of grazing on high country vegetation and habitats

Tall Tussock Grassland

On low elevation high country land, intensive grazing pressure alone can convert indigenous tall tussock and short tussock grassland to exotic grassland[32]. Surveys of montane to alpine tall tussock grasslands at sites in Canterbury, Otago, and Southland have shown that exclusion of stock generally promotes tall tussock recovery[33]. At high alpine sites, there is usually a reduced response to exclusion of stock. In the central Canterbury high country, 80 years of grazing resulted in almost complete loss of slim snow tussock and *Chionochloa flavescens* subsp. *brevis*, with exclusion of grazing resulting in strong recovery of slim snow tussock but slower recovery of *C. flavescens*. Another Canterbury high country study showed stronger indigenous vegetation recovery in ungrazed plots near stands of indigenous vegetation than in plots more distant from indigenous seed sources[34].

Sheep in high country grasslands also cause local but intense fertility shifts by repeatedly congregating in favoured 'stock camps', for example beside shady rock outcrops or on hilltops. Increased exotic grass growth in these habitats is often limited to a closely-cropped turf maintained by intense grazing pressure, and indigenous herbs of turf habitats are able to exploit these habitats. Removal of grazing pressure generally releases the exotic grasses, allowing a taller sward that excludes indigenous turf species.

These studies indicate that indigenous dominance in tall tussock grasslands is generally promoted by exclusion of grazing animals, but that the diversity and abundance of inter-tussock species is usually reduced. In heavily depleted grasslands, indigenous recovery can be limited by availability of seed sources.

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[29] Berry *et al.* (2005)
[30] Patterson (1984)
[31] Barratt *et al.* (2006)
[32] Walker *et al.* (2002)
[33] Duncan *et al.* (2001); Grove *et al.* (2002); Meurk *et al.* (2002)
[34] Basher & Lynn (1996)

Snow Tussock Regeneration

Regeneration of snow tussock can occur in tussock grasslands in the absence of fire and at low grazing intensities, but recruitment occurs mostly within 2 m of the parent plant. Only low levels of regeneration occur uphill and upwind of mature tussocks or under high grazing intensities by either sheep or European hares (*Lepus europaeus*)[35]. Snow tussocks tend not to regenerate on bare ground, probably because of frost heave of bare soil in winter. The patchy nature of snow tussock regeneration indicates that retention of sparsely distributed snow tussocks in depleted tussock grasslands will be important to speed the recovery of such grasslands under conservation management. Freedom from fire should promote accumulation of tussock litter and growth of inter-tussock vegetation over bare ground, which may also enhance snow tussock regeneration.

Short Tussock Grassland

Displacement of indigenous plants by exotic grass swards in montane short tussock grassland in Canterbury has been implicated in a drastic reduction in the abundance of common indigenous moth species that depend on a wide range of host plants[36]. Strategic use of grazing was suggested as a management tool to limit the exotic grass sward and thus favour indigenous diversity. Exclusion of grazing animals from montane short tussock grassland often results in an increase in the abundance of exotic plant species (especially tall grasses), and a decrease in the abundance and diversity of indigenous plants[37], but on seasonally dry terraces in Central Otago, grazing had more adverse effects on indigenous tussocks and shrubs than did competition with exotic species[38], and in a range of montane Canterbury high country sites, indigenous woody species increased following exclusion of stock and rabbits (*Oryctolagus cuniculus*)[39].

Semi-Arid Grassland

In a highly depleted semi-arid grassland in Central Otago, vegetation change over six years was mostly related to rabbit and sheep grazing pressure, but on very harsh sites differences in grazing pressure had little effect on vegetation, probably because the depleted soil is unable to support rapid vegetation change[40]. At a nearby semi-arid site, exotic species richness and abundance increased across many groups five years after exclusion of grazing animals, but tall indigenous grasses also became more frequent[41]. Exotic shrubs and sward-forming exotic grasses were identified as threats to recovery of the indigenous vegetation.

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35 Rose & Platt (1992); Lee *et al.* (1993)
36 White (1991)
37 Lord (1990); Grove *et al.* (2002)
38 Walker *et al.* (2003)
39 Meurk *et al.* (2002)
40 Allen *et al.* (1995)
41 Walker (2000)

Shrubland

Shrublands often persist on high country land and are often accessible to farm stock. These shrublands are composed of species that are relatively unpalatable to stock, for example matagouri (*Discaria toumatou*), mingimingi (*Coprosma propinqua*), inaka (*Dracophyllum uniflorum*), and *Olearia bullata*. Sheep tend to use such shrubland stands for shade and shelter and also browse the ground layer vegetation. This use generally results in depletion or loss of the indigenous ground layer vegetation, with weedy exotic herbs and grasses becoming dominant. Palatable shrub species (for example the indigenous coral broom (*Carmichaelia crassicaule*) and *C. petriei*) also occur on high country pastoral land, but tend to be restricted to sites that have a low intensity of grazing, or are components of declining populations with poor long-term prospects for persistence under current grazing regimes[42].

Forest

Effects of stock on areas of forest that remain on high country pastoral land depend on the difficulty of stock access and the type of stock grazed. Both sheep and cattle affect forest regeneration by preferentially browsing on the seedlings and saplings of palatable trees, but the effects of sheep are generally limited to forest margins, while cattle penetrate more deeply into forest interiors. Palatable ground cover plants are also grazed by stock, and this, coupled with the depletion of understorey vegetation, physical disturbance, and nutrient inputs promotes expansion into forest understoreys of exotic herbs and grasses. Montane forests generally respond positively to the exclusion of stock, which results in indigenous understorey and ground cover species becoming more dominant and diverse.

Feral Browsing Animals

Himalayan thar (*Hemitragus jemlahicus*), chamois (*Rupicapra rupicapra*), red deer (*Cervus elaphus*), goats (*Capra hircus*), pigs (*Sus scrofa*), hares, Bennett's wallaby (*Macropus rufogriseus*), and rabbits are all present on high country land and can have significant browsing effects on both pastoral and/or conservation values. Himalayan thar and chamois are present in the higher, western areas of high country and range into high alpine areas where they can affect indigenous grassland and herbfield vegetation, but also browse in forests and other areas at lower elevation. Red deer occur widely in the high country and have similar effects to cattle on indigenous forest vegetation. Goats are chiefly found in drier montane high country areas, particularly where there is abundant shelter in the form of rock outcrops. Goats are heavy browsers of woody plants from a wide range of species, and their agility enables them to obtain access to steep sites that cattle and sheep cannot reach. Pigs occur widely, and can deplete populations of palatable species (e.g. some *Aciphylla* and large *Celmisia* spp.) by selectively targeting and uprooting individual plants. Hares are widespread in the montane high country and range into alpine areas where rabbits are less common. They browse a wide range of indigenous and exotic species, including mouse-ear hawkweed (*Hieracium pilosella*), and can have substantial effects on vegetation in some cases but only minor effects in others[43]. Rabbits are widespread

[42] Walker *et al.* (2003)
[43] Rose & Platt (1992); Wong & Hickling (1999)

but attain greatest abundance in the drier parts of the high country. At high densities, rabbits can compete strongly for pasture with farm stock, and have been subject to numerous control programmes. Their numbers were reduced following the introduction of rabbit calicivirus in 1997, but rabbits still require ongoing control in many areas.

3.8 Weeds

Woody Weeds

A wide range of woody weeds is present in the high country, with wilding conifers causing the greatest concern, with 40,000-50,000 ha of high country land affected[44]. The most important of these are several species of pine (*Pinus* spp.), Douglas fir (*Pseudotsuga menziesii*), and larch (*Larix decidua*). These species have seeds dispersed by wind, allowing long-distance spread in favourable circumstances, but they are also associated with dense fringe spread close to the parent plant. They are hardy species of continental origin and, if left uncontrolled, have the potential to form dense stands over most of the extensively-grazed high country, including alpine areas above the altitudinal limit of indigenous tree species.

Broadleaved tree species are less of a problem in the high country, but hawthorn (*Crataegus monogyna*) is present in some parts of the montane zone. It has thorns that deter grazing animals, and fleshy fruits that are dispersed by birds. Hawthorn can form dense stands if left uncontrolled, and is capable of resprouting from cut stumps.

Exotic shrub weeds in the high country include sweet brier (*Rosa rubiginosa*), Scotch broom (*Cytisus scoparius*), gorse (*Ulex europaeus*), thyme (*Thymus vulgaris*). Thyme and sweet brier are most abundant in montane areas of the semi-arid and seasonally dry high country, whereas gorse and Scotch broom have wider ecological tolerance. Scotch broom in particular is locally abundant in some areas of high country and is capable of more rapid invasion than gorse. If uncontrolled both Scotch broom and gorse have the potential to become much more extensive in the high country.

Grazing by stock (and rabbits) can reduce recruitment of palatable woody weeds, including the wilding conifers described above. Scotch broom and to some extent gorse are also palatable to stock, but sweet brier and thyme are not. Effective control only occurs in circumstances where grazing is intensive, repeated at sufficient intervals, and where the woody weeds are not already at high density. Intensive grazing is generally incompatible with conservation management, but can be used as a buffer strategy on the margins of plantations to limit fringe spread. Once a woody weed individual has exceeded the browse height of stock, there is no further limitation by stock browse. Exclusion of grazing results in rapid release of suppressed woody weeds.

As much of the high country has environmental conditions that would naturally support woody vegetation, non-woody vegetation is unstable, and there is a powerful ecological tendency for the return of woody vegetation, whether composed of indigenous or exotic species.

[44] Ledgard (2001)

Hieracium

Species of *Hieracium* (hawkweeds) have attracted widespread concern in the high country over the past two decades and a considerable body of research is available on the ecology and distribution of the three most common species, mouse-ear hawkweed, tussock hawkweed (*H. lepidulum*), and king devil hawkweed (*H. praealtum*). Mouse-ear hawkweed occurs throughout the eastern high country of the South Island, and is a major and extensive component of depleted tall and short tussock grassland vegetation. Mouse-ear hawkweed has a rosette habit and is not tolerant of heavy shading or intense competition for light. Tussock hawkweed is chiefly found in Otago but also occurs in North Canterbury. It has an erect habit and occurs in disturbed habitats close to the main divide but is also present in seasonally dry and semi-arid areas, where it is more abundant on shaded slopes and at higher elevation. Tussock hawkweed also occurs on rock outcrops and in forest where ground cover vegetation is not too dense. King devil hawkweed is most common in Canterbury, particularly on disturbed sites in western areas close to the Main Divide where rainfall is higher. It is a rosette species but holds its leaves more erectly than mouse-ear hawkweed.

A feature of *Hieracium* invasion is consistent differences between the extent of invasion in Canterbury and Otago, with lower overall hawkweed abundance in Otago. This could be due to *Hieracium* invasion being less complete in Otago, or factors related to the difference in climate and soil parent materials between the two regions.

Invasion of extensively grazed indigenous grasslands by hawkweeds is related to pastoral management[45] and appears to be at least partly due to a vegetation and soil degradation process that began when the first settlers began burning and grazing New Zealand's high country vegetation. This process is typically defined as a movement from forest to scrub to tall tussock to short tussock to vegetation dominated by rosettes or flat-weeds.[46] In east Otago tussock grasslands, mouse-ear hawkweed invasion was related to degraded sites which had a greater percentage of bare ground, reduced tussock cover, and reduced pasture development, while in Central Otago red tussock grassland, hawkweed invasion was associated with sites that have had the greatest intensities of long term grazing[47]. This suggests that that current invasion patterns may be more related to past practices than to current management. For example, *Hieracium* may continue to increase in abundance despite recent exclusion of grazing, if the site was predisposed to *Hieracium* invasion by past management. Species of *Hieracium* are more abundant at intermediate elevation in semi-arid areas where their lower limit appears to be related to a requirement for adequate soil moisture, but the explanation for their reduced abundance at higher elevations (>1,000 m) has not been determined[48]. Mouse-ear hawkweed is adversely affected by pastoral development, does not thrive in areas where more productive pastures are present, and can be almost eliminated in less productive sites where grazers are

[45] Treskonova (1991); Duncan *et al.* (1997); Johnstone *et al.* (1999); Walker *et al.* (2003)
[46] Connor (1965); Treskonova (1991)
[47] Johnstone *et al.* (1999); Gibson *et al.* (2000)
[48] Duncan *et al.* (1997)

excluded and fertiliser is added[49]. The propagule pressure (seed output) of existing mouse-ear hawkweed populations must be immense, and facilitates its invasion of eastern suburban lawns to remote mountain areas in the western national parks[50].

In heavily depleted vegetation, mouse-ear hawkweed may help to recover degraded soils by enhancing organic matter and soil structure and reducing the potential for soil erosion. In a seasonally dry Canterbury high country site, soils beneath mouse-ear hawkweed had higher organic carbon and soil nutrient concentrations, but lower pH, than surrounding vegetation[51].

Tussock hawkweed has invaded Mount Aspiring National Park from high country land in the West Matukituki Valley, where its invasion has been facilitated by natural disturbance.

Pasture Grasses

While not weeds in a pastoral sense, increases in the extent of low fertility grasses, particularly browntop (*Agrostis capillaris*) and sweet vernal (*Anthoxanthum odoratum*) have been documented in the high country[52], and have been implicated in declines of indigenous plant and invertebrates.

3.9 Woody successions

As described above, high country pastoral management requires the ongoing operation of fire, grazing and other practices to sustain grassland and suppress woody regeneration over extensive low to mid-elevation areas. On the other hand, regeneration of indigenous woody vegetation is generally consistent with conservation objectives, and should be encouraged on protected land. While indigenous shrubs are present in most high country landscapes, indigenous trees are often lacking, resulting in a deficiency of seed sources that would allow natural regeneration of indigenous forest. Even where indigenous beech forest is present, expansion of beech forest fragments usually occurs very slowly by successive phases of fringe spread. In contrast, many of the weedy exotic trees in the high country are adapted for longer distance dispersal and have fewer establishment constraints. These factors indicate that active intervention will be required to restore indigenous forest vegetation to formerly-forested areas of the high country. While initial management requirements may be higher, indigenous forest is generally self-sustaining after canopy closure, provided that browsing animals do not prevent recruitment.

[49] Johnstone *et al.* (1999); Walker *et al.* (2003); Norton *et al.* (2006)
[50] Lloyd *et al.* (2006)
[51] McIntosh *et al.* (1995)
[52] Treskonova (1991); White (1991); Johnstone *et al* (1993); Walker *et al.* (2003)

4. OTHER CONSIDERATIONS

4.1 Water conservation

Snow tussock grassland in the Otago high country is known to have exceptional value for water conservation, although the causes of this are still being debated[53].

Agricultural conversion of south-eastern Otago high country tussock grassland to exotic pasture vegetation has been shown to alter streamside vegetation, and increase stream bank erosion and supply of nutrients and fine sediment to streams, but can enhance aquatic invertebrate biodiversity and tussock litter decomposition[54].

4.2 Pastoralism and biodiversity

Pastoral intensification has been implicated as a major cause of indigenous plant biodiversity loss in high country indigenous grasslands[55]. A widespread reduction in indigenous plant diversity in snow tussock and red tussock grasslands in the Mackenzie country occurred between 1964 and 1989[56]. Continual grazing was related to a decline in indigenous plant species richness and cover on seasonally dry terraces in Central Otago[57]. The relative abundance of many species, both indigenous and exotic, is declining in the tussock grasslands of Otago and Canterbury, and the decline is greatest at lower elevation, on pallic and semi-arid soils, and on schist bedrock[58]. As described in Section 3.7 above, exclusion of grazing stock from tussock grasslands can also cause declines in the plant diversity, usually due to loss of small inter-tussock plants, both indigenous and exotic, but the potentially dominant indigenous plants (large tussocks and shrubs) usually increase[59].

4.3 Threatened species

Vascular Plants

The high country provides habitats for a wide range of nationally threatened and uncommon plant and animal species. Threatened plants are found predominantly in the montane zone, generally in refuges from grazing and intense competition with exotic species. Some threatened plants are also found in induced turfs such as stock camps and turf in the centre of farm tracks. The effects of pastoralism are generally related to the habitats of these species. Those that are browsed are more likely to recover when grazing is removed, but may experience regeneration failure due to competition between grass swards and seedlings. Species that depend upon short turf habitat may have less habitat when grazers (including rabbits) are removed, because exotic grasses freed from grazing pressure can convert turf habitats to taller grassland[60].

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53 Mark & Rowley (1976); Pearce *et al.* (1984); Campbell & Murray (1990)
54 Niyogi *et al.* (2003); Riley *et al.* (2003)
55 Johnstone *et al.* (1993); Norton *et al.* (2006)
56 Treskonova (1991)
57 Walker *et al.* (2003)
58 Duncan *et al.* (2001)
59 Duncan *et al.* (2001); Meurk *et al.* (2002); Mark & Dickinson (2003); Walker *et al.* (2003)
60 Rogers *et al.* (2007)

Fauna

Montane tussock grassland and rock outcrop habitats in the south-eastern high country support a lizard fauna that is relatively diverse for a mainland site, but some of these fauna have also been adversely affected by factors related to pastoral intensification[61].

The high country supports a wide range of indigenous and introduced birds, including significant permanent populations of nationally threatened falcon (*Falco novaeseelandiae*), New Zealand South Island rifleman (*Acanthissita chloris chloris*), black-billed gull (*Larus bulleri*), and black stilt (*Himantopus novaezelandiae*), and important riverbed habitats which South Island pied oystercatcher (*Haematopus ostralegus*), black-fronted tern (*Sterna albostriata*), pied stilt (*Himantopus himantopus*), banded dotterel (*Charadrius bicinctus*), and wrybill (*Anarhynchus frontalis*) use for breeding in spring and summer.

The high country also supports significant populations of introduced birds, including some (e.g. Canada goose (*Branta canadensis*) and chukor (*Alectoris chukor*)) whose primary habitat is in the high country

4.4 Research

This is not a comprehensive review of ecological and pastoral management processes in the high country. Nevertheless, it is evident that research effort has not been evenly-spread across altitude and climatic gradients, soils, or vegetation types. This probably reflects a range of factors, such as political pressure to deal with specific issues such as hawkweeds and rabbits. More recent changes in legislation and policy have also played their part, with the Resource Management Act 1991 and Crown Pastoral Land Act 1998 promoting sustainable land use, and the New Zealand Biodiversity Strategy introducing biodiversity goals. The development of a national system and classification for all threatened and uncommon flora and fauna was only recently achieved[62], and new tools such as Land Environments of New Zealand (LENZ) and the Threatened Environment Classification[63] have placed the high country in a new context.

5. CONCLUSIONS

There is no doubt that pastoral management has been responsible for substantial and ongoing detrimental changes to the vegetation and soils of high country land, and that the sustainability of current pastoral use is in doubt over much of the 'unimproved' high country land, particularly in seasonally dry and semi-arid areas. High elevation land generally has a more intact indigenous vegetation cover and can be relatively easily managed for conservation by retirement from grazing. Low and middle elevation land that is sufficiently moist (either from precipitation or irrigation) is more easily developed into productive exotic pasture with intensive grazing regimes that

[61] Towns & Dougherty (1994); Berry *et al.* (2005)
[62] Molloy *et al.* (2002)
[63] Walker *et al.* (2007)

prevent weed invasion, but this development is inimical to indigenous biodiversity. In between these land systems are large areas of high country land that provide extensive grazing for stock, have a mixed cover of indigenous and exotic plants, provide habitat for a wide range of nationally threatened species, but also support a wide range of problematic weeds. Ecological issues and processes are more complex in these areas due to the interwoven and inseparable matrix of natural, pastoral, and cultural values. These values often conflict, resulting in a need for more complex solutions, which will often require active intervention, ongoing monitoring, and integrated management. Key biodiversity objectives are to increase the amount of indigenous woody vegetation in these landscapes while retaining and enhancing populations of threatened species. Pastoral management must be focussed on practices that do not result in further declines in soil condition.

Most scientific studies of 'unimproved' low and middle elevation high country vegetation are limited to short time scales and have results that are affected by local context (e.g. climate, soil, landform, proximity of indigenous seed sources). Management requirements for indigenous restoration in short tussock grasslands may vary according to site and goals should be carefully considered when there is a change from pastoral to conservation management. Studies of the effects of irrigation and/or fertiliser inputs in the absence of grazing are rare. More of this kind of research, which does not confound inputs and grazing, would assist post-pastoral conservation management of lower elevation high country. Recent studies of this nature have identified a range of tools that can be used to rehabilitate indigenous elements in these low elevation grasslands. The challenge is to develop a strategic framework in which these tools can be used, and ensure that sufficient resources are available for their use.

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