Merino Sheep Habitat Use in Canterbury High Country Tall Tussock Grasslands

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"*To my mind, the life of a lamb is no less precious than that of a human being.*" Mahatma Gandhi

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Summary

1. The goals of this thesis were to determine whether Merino sheep use habitat at random. Specifically, this research was undertaken to identify areas of intensive use, determine daily activity patterns, explore habitat use between activities, between sheep, define home ranges and to explore the influence of weather on habitat use.
2. Sixteen Merino ewes were monitored using GPS collars recording locations every 15 minutes. A weather station was set up at 1380 m a.s.l. to record weather variables at the study site.
3. Merino ewes do not select and utilise habitat in proportion to its availability. Short tussock grassland was preferentially selected for despite having a low occurrence. Overall, ewes selected habitat that was within 400 metres of a water source, on slopes less than 30° and preferred easterly habitat.
4. Merino ewes utilised different habitat for different activities. The day was divided into grazing, resting and night camping, as determined from hourly movement, backed up by 10 days of visual observations. Grazing occurred mostly on flat to low slopes in short tussock grassland. Resting occurred mostly on the riverbed or on surrounding short tussock grassland. Night camping occurred at higher altitudes (~ 100 m higher) than the resting sites and was on steeper slopes, partly due to the U-shaped nature of the valley. Night camping occurred in tall tussock grassland and native mix habitat. Several night camps were used while a smaller number of grazing sites were used.
5. Sheep differed in their individual habitat use. Two sheep were explorers, one crossing the river to occupy adjacent land, and one sheep moved out of the original study area, passing through a narrow rocky gap. Some sheep stayed close to the main mobs, while others spread out in small groups.
6. Home ranges were affected by the presence of large mobs; those sheep in the main mob had smaller home ranges than those in smaller groups. Home ranges were also smaller in areas of higher quality forage.
7. Weather variables did affect sheep habitat use with rain having the most influence. One cold, wet, windy day resulted in sheep being less active while occupying the middle of the fan, so displayed a preference for grazing and resting at higher altitude than normal. Temperatures and wind had little effect on sheep habitat use.

Glossary

Habitat: habitat is an all-encompassing term that represents where the sheep live; habitat variables include vegetation type, landform, altitude, aspect, slope and distance to water.

Habitat use: how much of each of the habitat's variables are utilised by the animal(s), e.g. measured by the altitude etc. that the GPS locations fall into.

Available habitat: a measurement of what habitat is in the study area.

Design I: measures habitat use by all animals on the same area, e.g. block.

Design II: measures habitat use by individual animals on the same area, e.g. block.

Home range: home range is defined as the area occupied by each sheep, measured by a polygon encompassing 95% of each sheep's locations.

Chapter 1 General Introduction

Statement of research interest

Worldwide, indigenous biodiversity is declining, mainly due to agricultural expansion and intensification. Farming and biodiversity can, however, thrive together, in the form of land sharing or when farming is intensive, where land sparing sets aside land for the conservation of habitats supporting indigenous species (Phalan et al. 2011). Farming in the high country of New Zealand utilises an extensive farming model, which is a form of land sharing. Sustainable farming, therefore, is an ethical choice, that aims to halt the decline in indigenous biodiversity while continuing production.

The high country is effectively land over about 700 m a.s.l. which is often steep, rugged and mountainous. High country farms were established around the middle of the nineteenth century to extend the sheep farming acreage as part of the colonisation of New Zealand.

High country grasslands in New Zealand contain high native plant diversity and are constantly under abiotic stress in the sub-alpine zone, with high winds, frost, snow, heavy rain, high levels of solar radiation and a highly erosive ground surface. Historically, New Zealand has had no indigenous grazing mammals; early grazers were flightless birds such as moa, takahe, weka, kakapo and invertebrates. New Zealand's indigenous grasslands have evolved without mammalian grazers (Antonelli et al. 2011). Therefore, the impact of introduced grazing animals needs to be assessed. Merino sheep (*Ovis aries* L.) on high country farms are raised mainly for fine wool. Merinos are frequently grazed on high altitude tussock grassland blocks (dominated by grasses in the genus *Chionochloa*) during summer (February to April) while lower altitude blocks are spelled, allowing their vegetation to recover. There have been many studies of grazing impacts on lower altitude short tussock grasslands but fewer studies on higher altitude tall tussock grasslands.

Animal habitat use is increasingly being researched worldwide as an important management tool for both wildlife conservationists and domestic production farmers. Several factors can influence habitat use depending on type of animal, breed, age, gender, season and landscape. Major factors that influence habitat use by mammals are vegetation type, water availability, altitude, slope and aspect, and proximity of shade and shelter. Habitat use studies on wild herbivorous animals also show that the presence of escape terrain (from predators) and visibility are important factors.

Grazing, trampling and camping can all affect native plant diversity negatively and contribute to the decline of indigenous biodiversity. Merino sheep are known to have a particular grazing behaviour, foraging in the morning and afternoon, and resting in the heat of the day and camping at night and so may utilise different habitats during the daily cycle. Weather conditions may also affect Merino sheep behaviour as they search for shade in hot weather and shelter in adverse weather. Microclimates provided by vegetation and rocks may attract Merino sheep during certain weather conditions. As the weather and daily rituals affect sheep behaviour, this in turn affects native plant diversity, composition and structure. For example, repeated trampling by several hundred sheep on a favourite patch may damage established plants and restrict seedling establishment while enabling the expansion of the more weedy exotic species, especially those that have evolved alongside mammalian grazers. Comparing vegetation on these frequented patches with other patches on both grazed and ungrazed areas can provide insights into the effects of sheep behaviour on native plant diversity in the high country. This study will also have implications for improved sheep management and plant restoration. It is, however, recognised that sheep are not the only animals present on the blocks: hares, tahr and cattle are also present in low numbers. For the purposes of this study, herbivorous insects are assumed to have little effect on vegetation composition.

Daily and weekly weather patterns can have a strong effect on sheep behaviour (e.g., sheep moving to more sheltered sites during storm events). Within a given grazing block there are a diverse range of microclimates creating a diversity of niches for plants resulting in different plant communities, and shade and shelter for sheep. It is known that sheep camp at night but graze widely in the morning and afternoon. Do these diurnal patterns affect vegetation pattern? Where do sheep go and what are they doing when the weather is fine or adverse (hot, cold, windy, raining)? How do these differences in grazing patterns in response to weather conditions affect native plant diversity? These questions form the focus of the research.

This research project will assess the influence of short-term weather patterns on sheep behaviour in Merino ewe summer grazing blocks in the Canterbury high country in the South Island of New Zealand. Specifically, the research will assess how sheep respond to different weather conditions (e.g. cold and wet versus warm and dry) in terms of their habitat use, and how this movement behaviour interacts with plant diversity.

This thesis will begin with a literature review of current research on animal habitat use and is followed by a summary of the research objectives. Chapter 2 describes the study area on Glenmore Station. Chapter 3 explores vegetation composition, structure and vegetation types within the study area, as these are used as the basis for assessing habitat use. Chapter 4 examines Merino sheep habitat use on Glenmore station in relation to the habitats available. Chapter 5 briefly explores the weather patterns over the summer grazing period and the effects of weather variables on sheep habitat use within the study area. Chapter 6 examines a secondary dataset of sheep habitat use from Otematata in South Canterbury and compares the results with Glenmore. Chapter 7 offers an overview, followed by a discussion of the overall results and suggests implications for management and future research opportunities. Appendix A lists all vascular plant species found at the study site. Appendix B lists animals found at the site. Appendix C contains photos of the different vegetation communities. Appendix D examines the effects of *Hieracium* invasion on the study area. Appendix E provides additional tables and graphs.

Current knowledge

The following is a literature review that looks at current knowledge on sheep habitat use, exploring the factors that influence habitat use, sheep diet, grazing effects on New Zealand grassland plants and animal welfare issues. The literature review focuses in particular on habitat use by sheep.

There are an increasing number of studies worldwide on habitat utilisation and home range of mammals. Habitat utilisation studies have been used to track wild and domestic animals and enhance our understanding, for example, of elk (Hansen & Riggs 2008), wolves (Demma & Mech 2009) and bighorn sheep (Bangs et al. 2005). Research on habitat use by mammals has found that both biotic and abiotic factors affect habitat use. Biotic factors that influence habitat use include availability of forage, water and cover. Abiotic factors influencing habitat use include topography, climate and weather. Temporal and spatial conditions also apply. Daily and seasonal habitat use and movement is shown by many mammals (Arnold 1984; Ager et al. 2003; Gibb 2007; Mysterud et al. 2007). Type of animal, breed, social standing, gregariousness and age also affect habitat use. Habitat is mainly defined by vegetation type and topography.

Factors influencing habitat use

The major factors influencing habitat use at this scale are food and water availability, proximity of human habitation (for wild species), cover, visibility and proximity of escape terrain (for large herbivorous mammals), altitude, slope and sometimes aspect. Habitat use depends quite strongly on season, time of day, species and breed, gender and age, particularly with respect to social grouping. Understanding the use of different habitats for foraging and resting at different times of the day and season supports the management of both wild and domestic species.

First and foremost, habitats have to meet the forage requirements of the particular animal; therefore vegetation type is one of the major factors influencing habitat use during the grazing period, whereas habitats that provide good cover may be most influential for resting periods. For example, the nocturnal possum sleeps in dens during the day among trees and shrubs, but during the night will feed out in open pasture (Glen et al. 2012). Mountain sheep prefer grasslands overall but deer prefer forests during the day and open pasture during the night (Mysterud et al. 1999). The use of different habitats for different daily activities suggests that habitat use needs to be analysed according to time of day or activity period (Arnold 1984; Gibb 2007; Pérez-Barbería et al. 2007). Animals need nutritious food for their health. Crosthwaite and MacLeod (2000) found that sheep health improved when grazing on a diversity of native species, although farmers use simple low diversity ryegrass/clover pastures in most of the New Zealand grazing industry. Distance to water is also an important factor affecting habitat utilisation, especially in arid countries (James et al. 1999; Turner et al. 2004). It is recognised, however, that Merino sheep are low water-users compared to other breeds of sheep (Schlink et al. 2010), so this may be of lesser importance.

Topography is another major factor, particularly altitude, landform, slope, ruggedness, and sometimes aspect (Mysterud et al. 2007; Haddon 2008). Canadian mountain sheep preferred open oak woodland, altitudes of between 1,000 m a.s.l. and 1,600 m a.s.l., and upper slopes and ridge tops (Gionfriddo & Krausman 1986). Habitat use changed seasonally, with sheep moving up the altitudinal gradient as the summer progressed (Mysterud et al. 2007). Good visibility is also important for wild mountain sheep (Risenhoover & Bailey 1985; McKinney et al. 2003; Bangs et al. 2005). Bighorn sheep in the US have real predators such as cougars and mountain lions, so steep rugged terrain is vital for their survival. Ruggedness is a relatively recent addition to habitat use models and was shown to have a significant influence on desert bighorn sheep (Sappington et al. 2007; Shannon et al.). Ruggedness is defined as land that is steep and uneven or broken such as bluffs, rocky outcrops and gullies (Bangs et al. 2005; Sappington et al. 2007). Topographical variables such as altitude, slope and aspect can also be important factors in determining habitat use for mammals (D'Eon & Serrouya 2005; DeCesare & Pletscher 2006). However, aspect per se may be misleading and some scientists prefer to use solar duration as a better predictor (D'Eon & Serrouya 2005).

Weather conditions can also affect animal’s habitat use through thermoregulation, behaviour and movement. Weather variables affected altitudinal habitat use for sheep in Norway (Mysterud et al. 2007) where they used higher altitudes during warm clear and windy weather and lower altitudes during wet, calm and cool weather. Sheep were less active in cold, foggy or wet weather (Warren & Mysterud 1991). Sheep showed an intensive grazing pattern in the early morning and late afternoon on warm sunny days, but this pattern was less distinct on cool cloudy days (Berggren-Thomas & Hohenboken 1986). Sheep also utilise different habitats according to temperature (Thomas et al. 2008). Shade use by sheep increased in hot weather but was found to be more correlated with high solar radiation rather than air temperature (Sherwin & Johnson 1987). The microclimate of different plant associations can also affect choice of grazing site (Duncan & Gordon 1999).

Temporal and spatial conditions also have a major influence on habitat use. Diurnal and seasonal grazing patterns are well documented (Harris & O'Connor 1980; Arnold 1984; Warren & Mysterud 1991; Champion et al. 1994; Hulbert et al. 1998). Spatially restricted animals will use habitat differently than free-ranging animals that have more choice. Size of groups may also influence habitat use (Squires 1976). Arnold and Maller (1985) found that breed influenced spatial distribution of mobs with Merino spreading out at higher densities but staying close at lower densities, while Corriedales stayed spread out at any density. Merinos rarely form sub-groups i.e. they usually mob together but split when there is a food shortage (Arnold et al. 1981). Single–sex groups behave differently to mixed groups (Michelena et al. 2010). Sheep utilise different habitats depending on social structure of groups (Krausman et al. 1989). Dumont (2007) found that food preferences and social interactions were the main factors that influenced habitat selection. Overall, habitat use is influenced by a complex mixture of interactions between several different factors (Boyd & Svejcar 2009).

In New Zealand, two early studies utilised visual observations of sheep behaviour (Harris & O'Connor 1980; Scott & Sutherland 1981) and one study used GPS to monitor habitat use by Merino sheep (Haddon 2008). Merino sheep preferred broad slopes and ridges, of average steepness, mainly facing east and spent less time in tall tussock grasslands than what was available (Haddon 2008). In Canterbury, halfbred sheep preferred damp sites in summer, where exotic grasses and clovers were abundant (Harris & O'Connor 1980). Also in Canterbury, Merinos preferred slightly higher terraces, grazed into the wind particularly at higher wind speeds, and spent more time resting in hot weather (Scott & Sutherland 1981). The presence of cloud cover also encouraged resting behaviour but rain or snow discouraged resting. Both the above observational studies noted the absence of drinking, suggesting that sheep in New Zealand obtain their water requirements from early morning dew. There are few studies in New Zealand that quantify the influence of weather variables on animal behaviour.

High country sheep diet

Grasslands around the world evolved alongside mammalian grazers and so grassland species have developed mechanisms to cope with or resist mammalian herbivory. In New Zealand, however, the grassland evolutionary story is very different. Due to its isolation from other landmasses for millions of years and recent uplift since the last glaciation, indigenous grasslands have evolved without mammalian herbivores (Antonelli et al. 2011).

Before humans arrived, the native herbivores of indigenous New Zealand grasslands were birds and insects such as moa, takahe, pukeko, kakapo and grasshoppers. However, nowadays, introduced mammalian herbivores provide a substantial role in plant-animal interactions. World-wide, grassland studies find that grazed grasses generally do well, because of their regeneration capabilities. However, New Zealand tussock grassland species are adapted to deal with avian and insect herbivores and have acquired the habit of leaf abscission, which is the shedding of old leaves, leaving the new young palatable leaves vulnerable. Merino sheep (*Ovis aries* L.) originated from Spain and were introduced to New Zealand in the mid-late 1800s. Just how palatable is the sub-alpine native flora to introduced Merino sheep?

In an Italian high altitude study, sheep diet was dominated by grasses, followed by forbs then sedges (La Morgia & Bassano 2009). Seasonal change in habitat use was also evident as diet composition varied along with changes in altitudinal use. Sheep diet was made up of 73% grasses and sedges in the early summer changing to 52% in autumn when the intake of forbs and woody vegetation increased. This study also found a positive selection for forbs and sedges compared to that available (La Morgia & Bassano 2009). In a New Zealand study, sheep ate 76% grasses in December lowering to 47% in March (Harris & O'Connor 1980). Clovers and other herbs made up the remainder of the diet.

As grasses appear to form the main part of the diet, it is interesting to look at the ecology of the predominant grass genera at the study site. There are conflicting opinions as to which species are palatable, which may be related to season. *Festuca novae-zelandiae* is generally unpalatable except for young growth (Cockayne 1920a; Scott & Maunsell 1974). *Poa colensoi* was generally thought to be unpalatable except in spring (Cockayne 1919a, 1920a, b) but was found high on the dietary list by Croker (1958). *Poa cita* was found to be either of low palatability (Cockayne 1919a, 1920a, b; O'Connor et al. 1999) or of moderate palatability (Croker 1958; Lord 1990). *Rytidospema* spp. are also thought to be fairly palatable (Croker 1958). Exotic grasses such as browntop (*Agrostis capillaris*) yorkshire fog (*Holcus lanatus*) and sweet vernal (*Anthoxanthum odoratum*) are preferentially (Scott & Maunsell 1974).

The tall tussocks, *Chionochloa* species, have been well studied in regard to palatability and nutritive value (Connor et al. 1970). In one experiment (MacRae & O'Connor 1970), sheep preferred *C. macra* over *C. rubra* over *C.rigida* over *C. flavescens.* Nevertheless, O'Connor et al (1999) understood that *Chionochloa* species were unpalatable except as seedlings. When tussock grasslands are burnt, the young regrowth is highly palatable, which if immediately grazed, can result in a depleted state. Health-wise *C. rigida* appears to be fairly nutritious, and *C. macra* has high digestibility and energy but is low in protein and minerals, while *C. rubra* is the poorest of the three species (Fenner et al. 1993) and therefore one would expect that it would be eaten the least. Overall, *Chionochloa* species provide poor nutrition compared to introduced pasture grasses (Fenner et al. 1993).

One concern is the continued existence of a healthy population of snow tussocks, where young seedlings are present. Sheep may preferentially eat the young seedlings of any species due to their higher palatability thus resulting in a lack of recruitment. Grazing appeared to inhibit growth of established *C. pallens* to the extent that it could take more than 20 years to fully recover (Lee et al. 2000). Growth inhibition from grazing may also apply to other *Chionochloa* species.

Of the inter-tussock species, *Celmisia* species are most likely to be unpalatable to sheep (Wraight 1964), although Cockayne (1920b) found evidence that *Celmisia spectabilis* had been heavily eaten. *Leucopogon fraseri* and *Discaria toumatou* were found to be unpalatable (Scott & Maunsell 1974). Some well-liked exotic species include *Rumex acetosella, Hypochoeris radicata* and *Crepis capillaris* whereas clovers were not eaten (Cockayne 1920a). Abundance of scabweeds (*Raoulia* spp.), *Leucopogon fraseri, Geranium sessiliflorum* were generally seen as signs of degraded grasslands (Cockayne 1919a) as these are least palatable. Many of the palatable species in the high country, such as *Elymus, Dichelachne, Lachnagrostis* and *Deschampsia* have probably already been lost, after 100+ years of domestic and wild mammalian grazing. Some of the more palatable herbs such as *Anisotome, Ranunculus, Gingidia* have also largely disappeared. Of concern is the rapid spread of the unpalatable *Hieracium pilosella* which is dominating much of the short tussock grassland. This species has a reputation of replacing native species.

Grazing effects on New Zealand grassland plants.

Sheep are confronted with a choice of grazing material both spatially and temporally. Selective foraging affects the grazing area, the plant productivity and nutrient intake for the animal (Soder et al. 2009). Sheep are known to avoid grazing at night, probably due to perceived or actual predation. Diurnal patterns of plant selectivity may exist, preferring different plants in the morning to the afternoon. As sheep are gregarious animals, interactions between sheep differ according to age, gender, social status, nutritional requirements, and predator avoidance behaviour. Plant diversity may be higher in unimproved areas, so sheep may eat a greater variety of foods to increase their nutritional intake (Villalba et al. 2009). However, domestication may have decreased the instinctive ability to select nutrients, a trait that wild herbivores still retain (Villalba & Provenza 2009). The influence of grazing intensity or stocking rate on vegetation change is often underestimated in many studies but surely plays a significant role (Laca 2009).

The major impact on high country vegetation occurred about 700 years ago with Polynesian fires and subsequent rapid deforestation (McWethy et al. 2009; McWethy et al. 2010). Later, when Europeans arrived about 150 years ago, introduced ungulates (domestic and wild) decimated the most sensitive species, so that species composition in the high country was already drastically altered. Indigenous grasslands comprise dominant tussock species, with inter-tussock herbs, shrubs and sub-shrubs. The current low-intensity summer grazing is presumed to have minimum impact on native plant diversity, but impacts may vary depending on habitat patches in the landscape and stocking density. The diurnal pattern of sheep behaviour may also result in varying impacts on habitat patches, e.g. regular night camps may alter nutrient cycling as concentration of urine and faeces build up (O'Connor et al. 1999). Palatable species tend to be grazed out, leaving unpalatable species to dominate. The decline in perennial tussock species may have contributed to an increase in bare ground, which, in turn, favours weed invasion, particularly with *Hieracium* spp. Conservation of biodiversity on agricultural land has not been studied very well suggesting that our knowledge of ecological interactions needs to improve (Dorrough et al. 2004). High intensity grazing has been blamed for the decline in native plant diversity but vegetation clearance, burning, habitat modification and invasion by introduced species also make a significant contribution. Most sheep grazing studies in New Zealand have looked at the effects of sheep versus no sheep but not the effects of different grazing intensities (Norton et al. 2006). In a Scottish study on sheep behavioural impacts on vegetation change, (Oom et al. 2008) impacts varied depending not only on grazing intensity but also on whether the sheep were grazing, trampling or resting.

Many studies compare grazed plots with ungrazed plots or plots retired from grazing. Exclosure plots are a good way of monitoring the differences between grazed and ungrazed land in the same block. McIntosh and Allen (1997) found that exclosure plots had more biomass than grazed plots, mainly in the root zone but also found that introduced species dominated both. They also found that hawkweed patches were spreading outwards and soils under hawkweed had more calcium and magnesium than non-hawkweed patches. Once grazing is excluded, tussock and shrub species tend to increase in cover and height and herb species decrease (Allen et al. 1995; Rose et al. 1995; Duncan et al. 2001; Mark & Dickinson 2003) but there is an overall decline in species diversity (Mark & Dickinson 2003). Stocking rate also influences vegetation composition. Low stocking rate along with no management inputs may result in higher native diversity but lower native abundance, whereas higher stocking rates with fertiliser inputs can result in lower native species richness but higher native abundance (Norton et al. 2006). Siting of exclosure plots and monitoring plots is therefore, very important.

The native snow tussocks, *Chionochloa* spp. only reproduce by seed which is set during mast years (Rose et al. 1995; Mark & Dickinson 2003). *Chionochloa* plants increase in diameter through vegetative growth, but may only produce one or two tillers per year (Mark 1969). Tussock grasslands retired from sheep grazing for at least 21 years had high proportions of seedlings and juvenile plants, whereas grasslands that were still being grazed comprised mostly senescent tussocks with few seedlings (Rose & Platt 1992). Tussock seedlings survive better with low grazing intensity rather than with moderate or heavy grazing (Lee et al. 1993). Tall tussocks increased after grazing ceased but short tussocks *Poa cita* and *Rytidosperma setifolia* showed no trend while *Festuca novae zelandiae* and *Poa colensoi* decreased (Jensen et al. 1997). Tall herbs in low abundance may be seed limited through sheep eating the large flower heads (Bridle & Kirkpatrick 2001). There is contrasting evidence that inter-tussock species change either way (Grove et al. 2002) but it is important to remember that grassland systems are dynamic. Factors other than grazing come into play, such as competition, facilitation and succession.

Exotic grasses can also increase in ungrazed plots as well as *Hieracium* spp. (Meurk et al. 2002). Silver tussock (*Poa cita*) dominated grasslands generally seemed to decrease after grazing stopped but this may have been due to competition with the large exotic grass, *Dactylus glomerata* (Lord 1990). In Otago, species richness initially declined in tall tussock grasslands retired from grazing (Duncan et al. 2001), but later species richness increased in the second decade (Day & Buckley 2007). Overall, *Hieracium* species richness increased. Significantly declining species tend to be *Festuca novae zelandiae* and *Poa colensoi* and inter-tussock spp. *Anisotome* and *Raoulia*, but these changes are not necessarily only related to grazing regimes. Wraight (1964) found that indicators for declining tall tussock grassland, were decreases in *C. rigida* abundance and increases in the unpalatable *Rytidosperma setifolia.* Although *Poa colensoi* was considered resistant to grazing, Wraight (1964) found increases in *Leucopogon fraseri* and *Rumex acetosella* an indication of grassland depletion.

Research on the influence of feral herbivores is patchy and may depend on population densities. Since commercial hunting of tahr, chamois and deer began, a general increase in the recovery of alpine grasslands has been noted (Rose & Platt 1987; Parkes & Thomas 1999). Goat-free islands showed a remarkable difference to the mainland in the presence and abundance of less palatable species although overall composition was similar (Norton 1995). With any alpine grassland system, there is an ecological time lag effect, which makes it hard to quantify the effects of sheep grazing. Other natural disturbances such as soil erosion, frost heave, length of snow cover, soil structural changes through expansion and contraction when hot and dry, heavy rain as well as the presence of hares make establishing cause and effect difficult. The impacts of feral animals such as deer, tahr, chamois, goats, hares and possums on high country vegetation have been little studied but research on their diet suggests the impacts could be great (Flux 1967; Parkes & Forsyth 2008). A key issue is the difficulty in separating the effects of these animals from those of sheep.

Animal welfare issues – shade and shelter

Consideration for animal welfare is an important part of farming. On a high country farm with only perceived predators, free-ranging sheep have relatively little stress. Situations likely to cause stress, apart from stock management (e.g., mustering), may be weather-related or lack of nutritious food and water. The presence of shade and shelter on the farm may be very important as sheep seek shelter not only from wind, rain, snow and sun (Fisher 2007) but also from predators. Sheep demonstrated physiological stress during hot weather in Israel (Marai et al. 2007) which affected behaviour patterns. Shade seeking behaviour is evident in Australia (Stafford Smith et al. 1985) and has been observed in New Zealand but has yet to be fully quantified here. Heat stress may also be exacerbated by water deprivation or nutritional deficiency (Silanikove 2000). Respiration rates and body temperatures were significantly higher in sheep without access to shade than those with access to shade (Pollard et al. 2004).

Cool weather kept sheep in camps longer reducing their grazing time (Warren & Mysterud 1991). Munro (1962) observed sheep taking shelter from the wind in grassy hollows in Scotland, while precipitation and air temperature bore no effect on sheep behaviour. In Australia, (Taylor et al. 1984) night camps were more upslope and larger in area than day camps and had a much higher concentration of faeces. The use of higher ground for night camping may be a predator avoidance behaviour but also for social interactions. Taylor et al (1984) found that daytime shade camps were situated among the grazing sites at lower altitude. Shelter use by lambing ewes was found to decrease lamb mortality (Pollard 2006). Shelterbelts in the lowlands provide good shade and shelter for sheep (Gregory 1995).

Permission for this research was given by the University of Canterbury Animal Ethics Committee through AEC 2011/02R.

Knowledge gaps

Research on sheep habitat use has been quantified in Australia, Europe and the United States. However, there are few studies on sheep habitat use in New Zealand, particularly in high country tall tussock grasslands. There are millions of Merino sheep in New Zealand. By furthering our understanding of Merino sheep habitat use, the impacts on indigenous plant diversity can be assessed. Knowledge of Merino sheep daily activity periods, vegetation type preferred for grazing, for camping sites, and the use of shade and shelter will enable us to better understand biodiversity impacts as well as to address animal welfare issues.

This research will fill a knowledge gap by quantifying Merino sheep behaviour in high country summer blocks which will add to the current knowledge on lowland blocks. Plant diversity on high altitude (>1000 m.a.s.l.) grazed land has not been well studied, so this research will provide new information. Results may suggest implications for restoration, conservation and farm management. New Zealand has a unique flora, and native plants on a high altitude, dry eastern South Island location need to be studied to improve understanding of interactions between weather, microclimate, sheep and plants in order to arrest the decline in biodiversity.

Research aims and objectives

The aim of this research is to determine the interaction between grazing Merino sheep in high country summer grazing blocks and indigenous plant diversity. If Merino grazing is sustainable, then indigenous plant diversity should continue to thrive without substantial loss, while Merino sheep continue to graze on a healthy diet with access to sufficient shade and shelter. Indigenous plant diversity is defined as diversity in species, composition, structure and function.

The overall objectives of this research are to better understand how Merino sheep utilise sub-alpine grassland habitat from both a vegetation impact and animal welfare perspective. Specifically, this research will address the following questions:

1. Do Merino ewes exhibit daily activity patterns?

2. Do Merinos utilise habitat in proportion to its availability, and does habitat use differ between different activities?

3. Do Merinos alter their behaviour in response to weather conditions?

4. Which habitats are most frequently utilised?

5. What are the daily movements and home ranges of Merino ewes and what is the possible cause for any differences?

6. How do the results of this research on Glenmore Station compare with similar research Merino habitat use in summer grazing blocks on Otematata Station?

7. What are the factors influencing *Hieracium* invasion in summer grazing country on Glenmore Station and how are *Hieracium* spp. influencing habitat quality?

Chapter 2 Glenmore Study Site

Site characteristics

The study area is located in the upper reaches of the Cass River on Glenmore Station, located northwest of Lake Tekapo, in the Godley Ecological District, Canterbury, South Island, New Zealand (43° 40', 170° 22', Figure 1). The study area is accessible in summer from the farmhouse along a graded track along the riverbed, incorporating many river crossings as the Cass River is a braided river. Glenmore Station is an extensive high country station (19,200 hectares) which farms 10,000 Merino sheep, 500 cattle and 600 deer. Fires swept through the region in both Polynesian times and early European times. The land has been farmed for about 140 years. The research study area (1905 ha) is situated within Top Block, Twin Basins Block and Tin Hut Block (Figure 2). These three blocks are part of the summer grazing range of Merino ewes that graze this area from February to April each year while the lower altitude pastures are spelled. Cattle are also grazed here briefly but do not usually venture far above the valley flats. Broadly speaking, this is tall tussock grassland country with some short tussock grassland on the lower slopes. Land to the north, east and west of the study area is Crown Land managed by the Department of Conservation and is part of the Liebig Range/Upper Jollie/Cass Conservation Area.

Landforms

The landscape is mountainous, carved by glaciers in the last glacial period which ended about 14,000 years ago. The Gammack Range lies to the south and west of the study site where steep rocky peaks tower over the U-shaped Cass Valley below. Mt Jukes is the highest peak here at 2526 m a.s.l. To the north of the study site lies another range of peaks known as the Leibig Range where Mt Lucia at 2617 m a.s.l. is the closest of the high peaks. To the east is the lower Hall Range which separates the Cass Valley from the Godley Valley. The headwaters of the Cass River begin in two glaciers, the Faraday Glacier and the Huxley Glacier, both on the slopes of Mt Hutton (2822 m a.s.l.). The mountains have been carved by former glaciers leaving behind cirques, basins, hanging valleys and waterfalls as well as lateral and medial moraines, hummocky moraines, bluffs, fans and alluvial terraces. Scree slopes are common and the area is highly erosive due to steep slopes, high winds and high rainfall. The geology of the site is mainly greywacke of the Torlesse Composite Terrane (Cox & Barrel 2007) incorporating some red chertz and argillite. Grey till from glacial deposits form the moraines and hummocks, while glacio-alluvial deposits form the fans. Soils are predominantly Acid Brown Soils (Hewitt & Whenua 1998) formerly known as high country podsolised yellow-brown earths.

The study area is set within a U-shaped north-south valley, in which lies the braided Cass River. The study area is bordered by Tin Hut to the south, where a fence across the river contains the sheep upstream. To the north the study area is bordered by the left and right forks feeding the Cass River. Just north of Memorial Hut lies a large fan and extensive flats merging with the riverbed. A large south-facing spur lies west of Memorial Hut, with steep sides to the east and west. On the east side, the slopes are deeply cut by side streams leading to the merging of a large fan, which suddenly drops down to the riverbed. At the foot of the southern side slopes is a large flat area leading on to a hummocky moraine behind Memorial Hut. To the southwest of the spur lies a small lateral moraine, which then drops steeply to Ailsa Stream. The Twin Basins Block comprises two basins which feed the two waterfalls plunging into Ailsa Stream. A lateral moraine separates the two basins which runs in a north-easterly direction. Steep slopes lie adjacent to the waterfalls. The land between Tin Hut and Memorial Hut is generally steep, with limited flat land by the riverbed and frequent scree slopes.

Altitudes in the study area range from 950 m a.s.l. to over 1600 m a.s.l. where most of the vegetation ceases (Figure 3). Much of the study area is quite steep (>30 degrees; Figure 4). The predominant aspects in the study area are east to northeast (Figure 5). There is little west-facing land here. Water sources in the study area are plentiful, therefore, there is little habitat far from water (Figure 6). Vegetation in the study area consists of tall and short tussock grassland with small patches of shrub land, remnant grey scrub and exotic grass, see next chapter. Scree slopes and rocky bluffs are also common.

Climate

Climate of the study area is typical of the eastern South Island mountains with hot dry summers and cold moist winters with at least 3 months of deep snow above 1000 m a.s.l. Mean annual air temperature at the study site ranges from 10.5 °C on the riverbed to 6.1°C at the higher altitudes (LENZ 2011); annual solar radiation is high at 13.8 MJ m^2 day. The study site has good drainage, is of moderate fertility and has very low annual water deficit (LENZ 2011). When the ewes are grazed on the high country summer blocks, between February and April, the air temperature is variable ranging from -6 to +27 °C. The Southern Alps provide an orographic barrier to the moist westerlies, where high rainfall falls on the western slopes of the Alps and the study site is located just east of the Alps in the rain shadow. Annual rainfall in the region ranges from 600 mm at the homestead to about 6000 mm at the Southern Alps so the study area is estimated to receive about 2000 mm per year (Leathwick et al. 2003). Rainfall between February and April is generally low and while prolonged heavy storms are unlikely, rainfall events can be intense. Mountain winds are notoriously common, sometimes with very cold air from the south but mostly in summer with the hot dry winds of a Norwester. Average wind speeds at this time are about 2 m/s but maximum wind speeds can reach up to 24 m/s. For a detailed description of weather at the study site, see Chapter 4.

Pre-human vegetation

Before sheep farming began, fires swept through the region both in Polynesian times and in early European times and altered the vegetation composition considerably (McGlone 2001; McWethy et al. 2010). Pre-human vegetation in the general area, was probably a mosaic of forest and shrubland including *Podocarpus cunninghamii, Phyllocladus alpinus, Hoheria lyallii, Podocarpus nivalis, Brachyglottis cassinioides, Discaria toumatou, Aristotelia fruticosa, Olearia odorata, Dracophyllum* spp. small-leaved *Coprosma* spp, and *Hebe* spp., with tall tussock grasslands and herbfields above the limit of woody vegetation. Tall tussock grasslands were probably the dominant vegetation within the study area above the tree line at about 1200 m a.s.l. Tall tussock grasslands comprise chiefly *Chionochloa rigida* as well as other tussock species: *C. pallens, C, macra, C. rubra, C. oreophila* and *C. crassiuscula.* Common inter-tussock species include *Celmisia lyalli, C. haastii, C. angustifolia, Poa colensoi, Aciphylla aurea, Dracophyllum* spp., *Leucopogon colensoi* and many small herbs. Tall tussock grasslands in this area occur from about 1000 m a.s.l. to about 1600 m a.s.l. where the grasslands give way to alpine herbfields. Short tussock grasslands, defined by the presence of *Festuca novae-zelandiae*, appear to be replacing the tall tussock grasslands at lower elevations and are now the dominant tussock up to about 1200 m a.s.l. Healthy short tussock grasslands, however, are of limited extent at the study site; degraded short tussock grasslands now cover much of the lower slopes, fans and terraces where the dominant species is the invasive exotic herb, *Hieracium pilosella.* Some open low shrubland occurs on slopes and fans, where *Discaria toumatou, Dracophyllum uniflorum, Ozothamnus leptophylla* and *Brachyglottis cassinioides* are the dominant shrubs. In steep gullies, remnant shrubs and small trees such as *Podocarpus nivalis, Hoheria lyallii* and small-leaved *Coprosma* species occur.

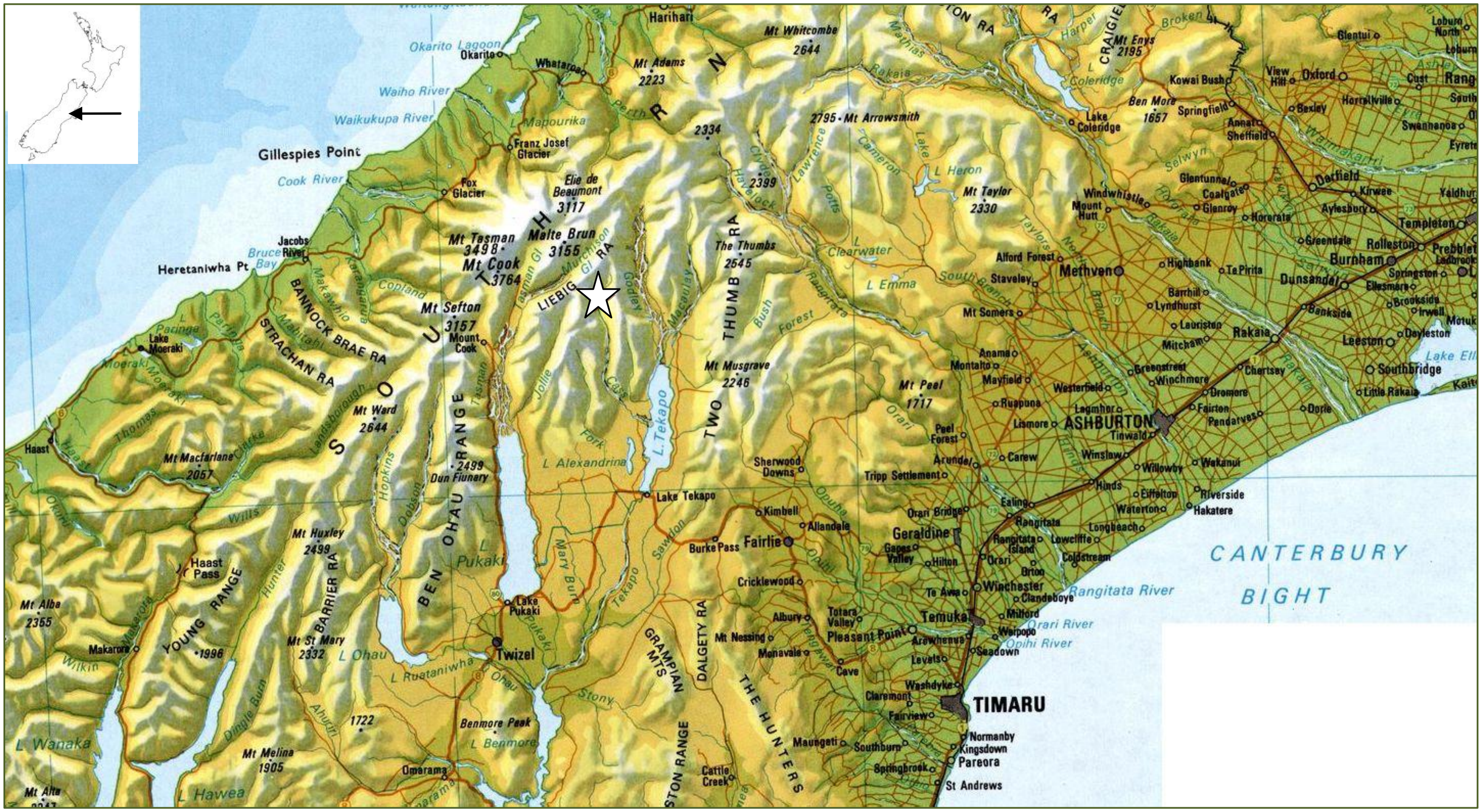


Figure 1. Map of the Canterbury high country, South Island, New Zealand. White star denotes study area, northwest of Lake Tekapo.

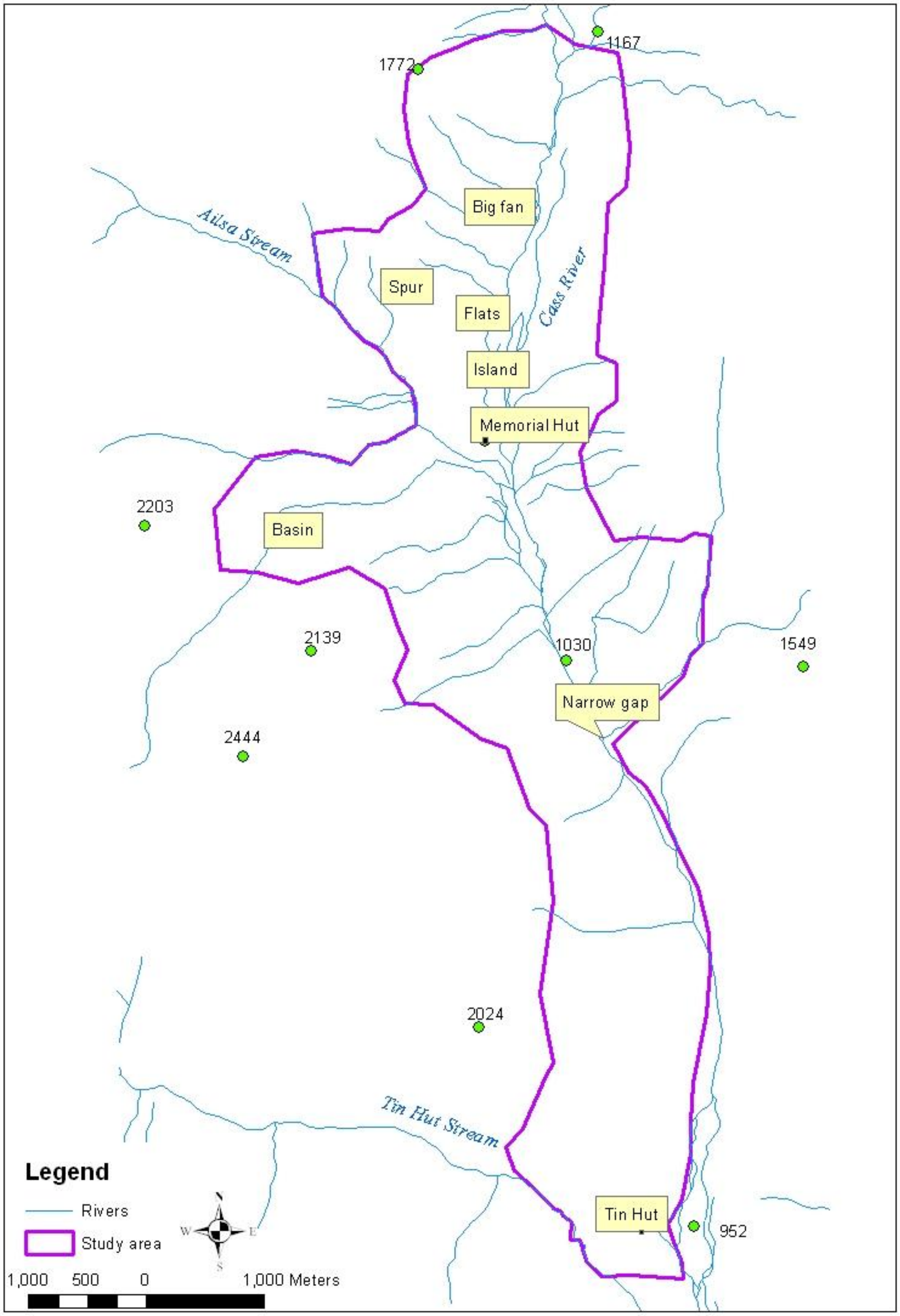


Figure 2. Outline map of study area and main features

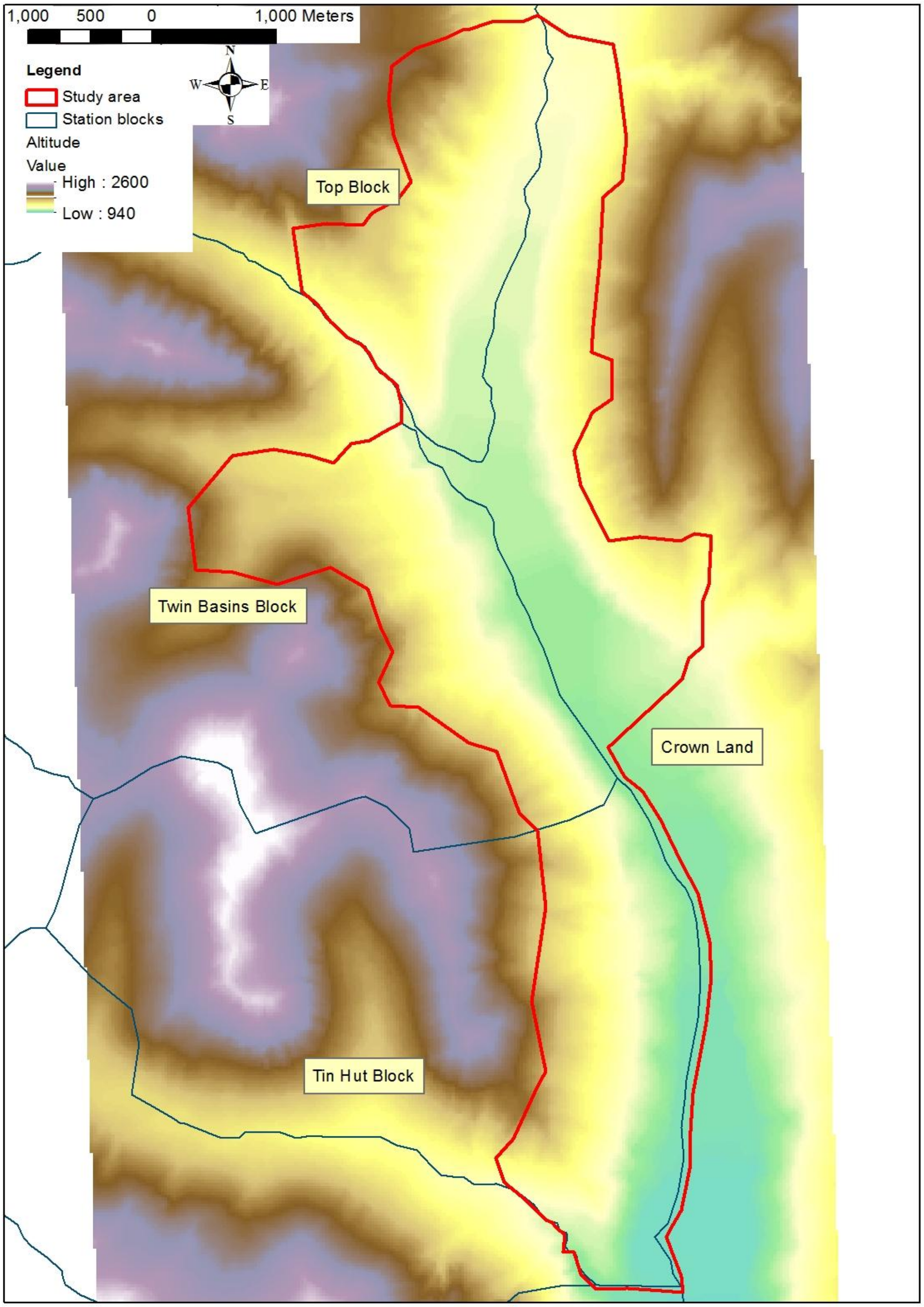


Figure 3. Altitude map of Glenmore study area

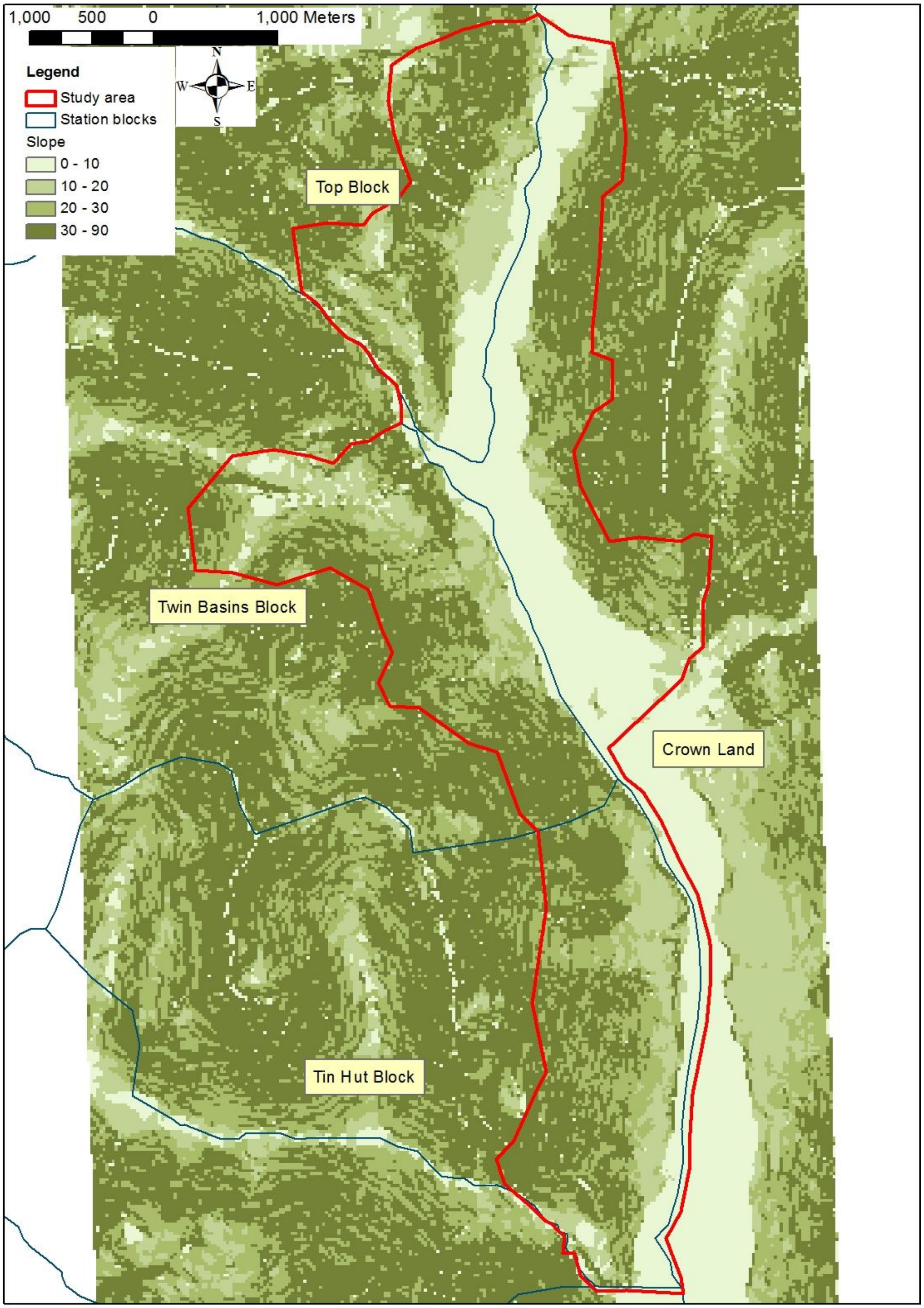


Figure 4. Slope map of Glenmore study area

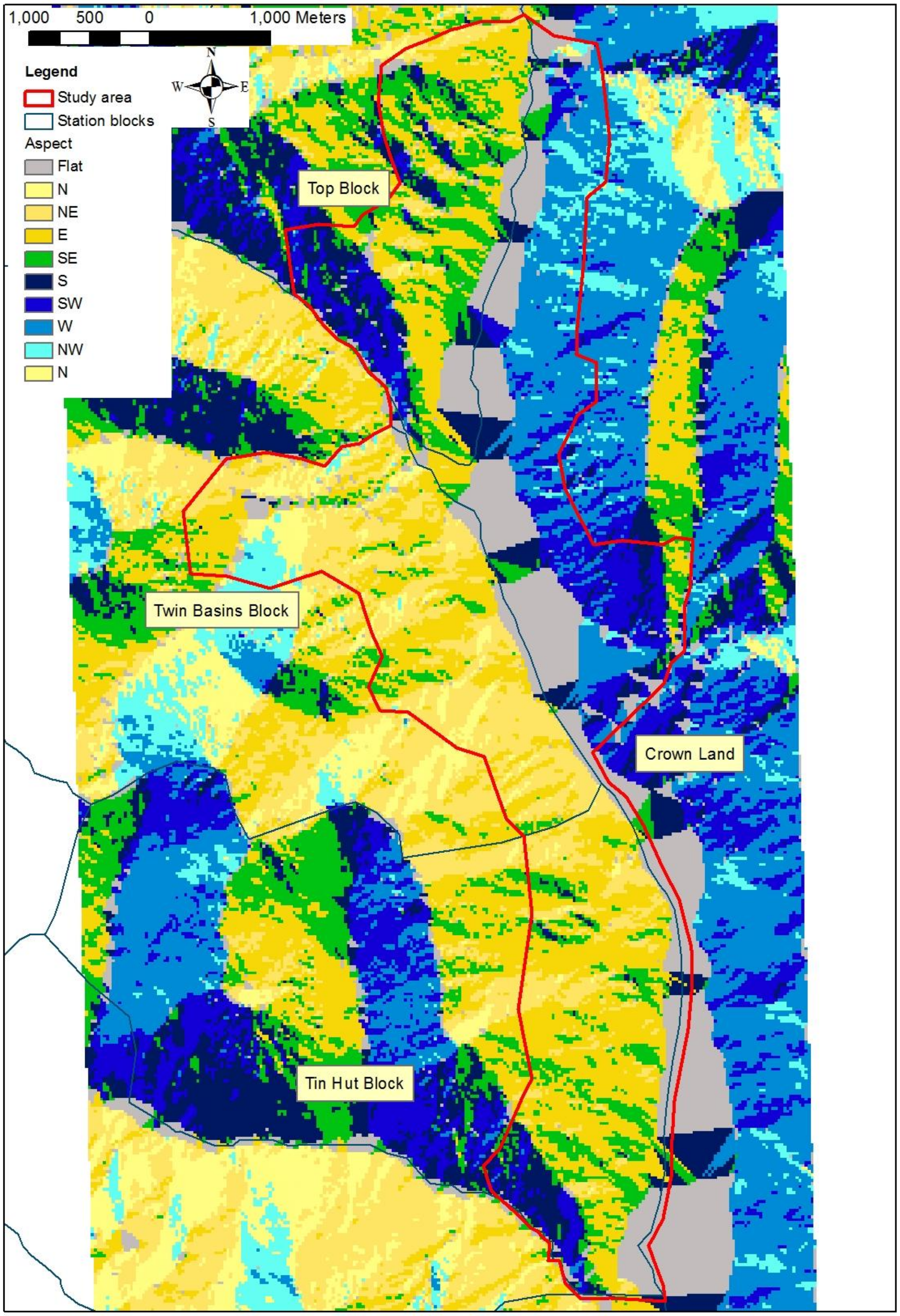


Figure 5. Aspect map of Glenmore study area

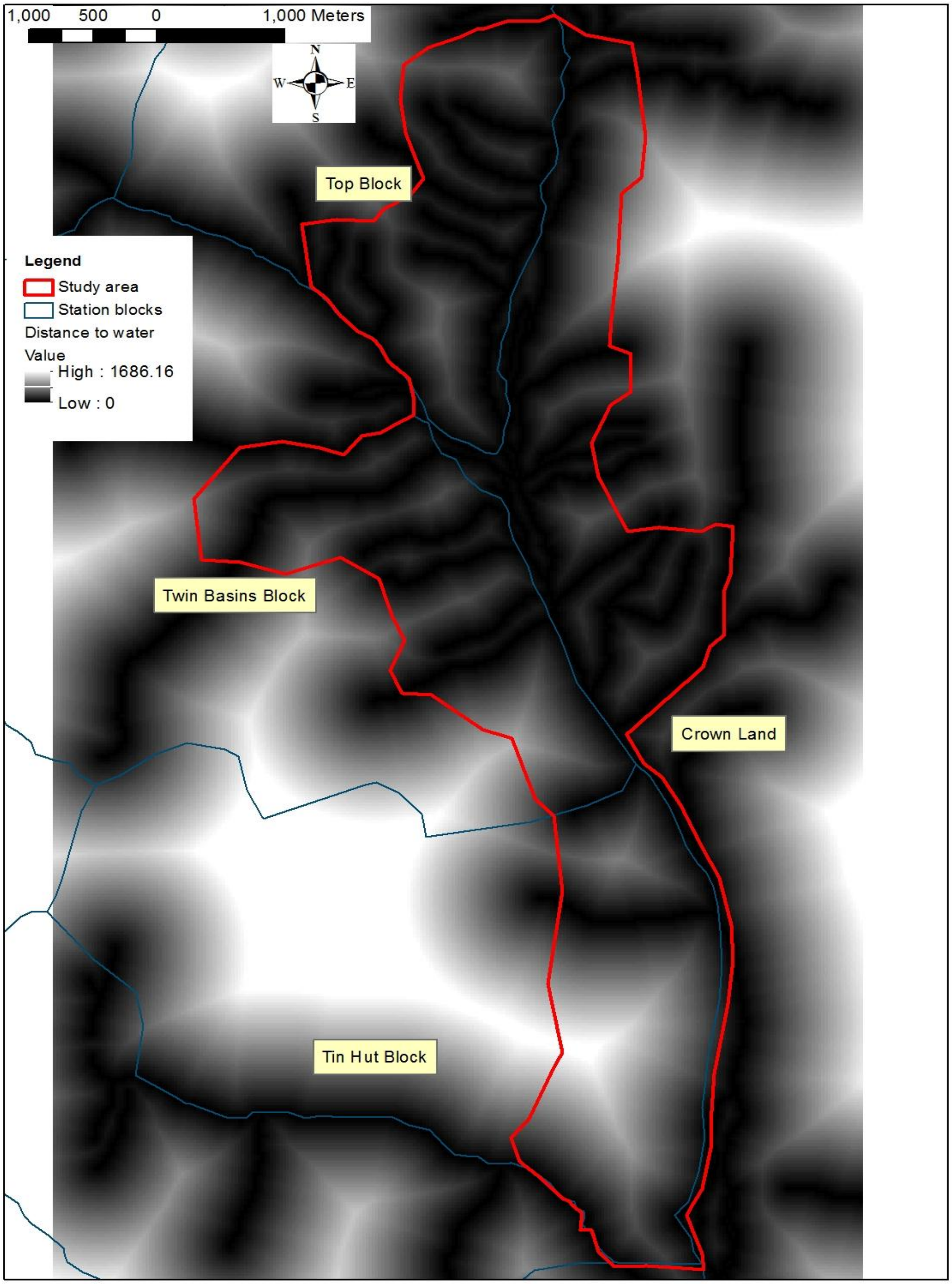


Figure 6. Distance to water sources map of Glenmore study area

Chapter 3 Vegetation composition, structure and type

Introduction

Tussock grasslands have been grazed by domestic sheep for c. 150 years. On a high country sheep station, large areas of high altitude rugged land is grazed over the summer months while the lowland pastures are spelled. These high altitude blocks are generally above the winter snow-line and present a variety of landforms and vegetation types for the sheep to explore. Free-ranging sheep within these blocks have access to the full altitudinal range of vegetated surfaces, on a variety of slopes but are somewhat restricted in choice of aspect, as there is little north-west and south-facing land available. Landforms here are also much more varied compared to where they spend the rest of the year on the flatter lowlands (c. 700 m a.s.l.). These high altitude blocks offer a larger range of indigenous plant species that vary in their palatability and nutrient and energy content. Even though the sheep are on these blocks for about 2 months, seasonal changes in plant phenology are relevant and some species may be more palatable early on, some later.

Vegetation composition and structure of a tussock grassland community varies according to biotic and abiotic factors. Species presence and abundance is initially dependent on seed source availability, successful pollination and dispersal. Grassland communities comprise vascular plants, bryophytes, fungi, worms and insects, birds and mammals. At a broad scale, tussock grasslands can be divided into short and tall tussock grasslands, but at a finer scale, these grasslands form a mosaic of different vegetation types. Alpine and sub-alpine vegetation patterns form a mosaic of habitat types that reflect a compositional variety of dominant species alongside minor species. Vegetation composition in the Canterbury high country tussock grasslands varies considerably from patch to patch (Dickinson & Norton 2011). Species richness, composition and abundance are rarely the same at any scale. Habitats vary according to topography and geomorphology, moisture, nutrients, competition, facilitation and herbivory. In this post-glacial environment, at a landscape scale, different habitats appear on ridges, south-facing slopes, lateral moraines, fans and alluvial terraces. At a smaller scale of metres, habitats also vary with micro topography, such as in mounds and hollows and where the slopes are concave, convex or straight.

Landforms in this environment were shaped by glacial processes about 14,000 years ago and further shaped by recent and current alluvial processes. Recent disturbances that dramatically altered vegetation composition were fires at the time of Polynesian settlement (<850 ybp) and later introduced herbivores following European settlement (about 150 ybp). Uplift and erosion are regular ongoing processes in the Southern Alps, and rock falls, slips and debris avalanches are evident at the study site. At a smaller scale, frost heave, snowfall, freeze-thaw, drought, heavy rain and wind provide a considerable amount of disturbance. Herbivory and disturbance through trampling and fertilising from a variety of animals provide a secondary impact on the environment. Animals present include not only domestic sheep, but also hares, tahr, cattle, birds, reptiles and invertebrates.

Prior to human arrival in the area, the sub-alpine landscape may have been an open podocarp/broadleaved forest, probably with *Podocarpus cunninghamii, Aristotelia fruticosa* and *Hoheria lyallii* as the main species up to the tree line, about 1200 m.a.s.l. The alpine region would have been clothed in tussocks, herbs, shrubs and cushion plants. Following the Polynesian fires and forest clearance by the newly arrived Europeans, tussock grassland spread down-slope and shrubland would have begun to develop (McGlone 2001; McWethy et al. 2010). After pastoral settlement in the 1850s, grazing pressure from introduced herbivores would have restricted shrub establishment and tussocks and inter-tussock plants prevailed. Pasture improvement with introduced species lower down the valley would have also enabled the spread of exotic species up valley into the study site (Römermann et al. 2005).

Vegetation on the high country summer blocks is dominated by native tussocks, sub-alpine herbs, shrubs, sub-shrubs and introduced grasses. Vegetation composition varies in a complex mosaic of patches, both small and large. On a large scale, nearly half the vegetated area is dominated by the tall (snow) tussock, *Chionochloa* spp.; most of the other vegetated area is dominated by the short tussock, *Festuca novae-zelandiae*, with herbfields and shrubland making up the remainder. These blocks have been previously surveyed for the Crown Pastoral Land Tenure Review by the Department of Conservation (DOC 2006) which also recognises a state of high native biodiversity.

Chionochloa are tall tussock species that survive the extreme temperature range experienced at high altitude. *Chionochloa* only reproduce by seed during mast seeding years (Connor 1966). They have to be highly competitive in order to survive the high winds, heavy rainfall events, deep snow, high solar radiation and highly erosive ground (Lloyd et al. 2002). Although disturbance is a natural event, some disturbances are so severe that some species cannot recover and composition is drastically altered (Hobbs & Huenneke 1992). *Chionochloa* has been well studied (Mark & Dickinson 2003), unlike many of the inter-tussock species, so we know a lot about its biology. Different grazing management systems can affect species composition (Harris & O'Connor 1980; Van Vuren & Coblentz 1987), biomass and canopy height (Holland et al. 2008). Grazing also impacts on nutrient cycling (O’Connor et al. 1999). Long term monitoring is better for revealing grazing impacts on species composition (Gibson & Bosch 1996; Meurk et al. 2002; Norton et al. 2006) but short-term effects can be monitored by sampling vegetation for evidence of defoliation and faecal sampling.

Methods and Materials

Sampling for vegetation type

Vegetation data was recorded in 5m x 5m quadrats randomly stratified to be representative of the area according to changes in vegetation composition, landform and elevation. Where possible, several plots were established for replication where the topography was similar. Sampling methods were based on the National Vegetation Survey Manual (Hurst & Allen 2007), where species and their abundance, as percentage cover, were recorded. All vascular plant species were identified and given a percentage cover value. As many species were tall and overlapped other species, the total vegetation cover was frequently well over 100%. Average vegetation height was estimated for each plot. Tall tussocks (*Chionochloa*) were also delineated as small (few tillers up to 5cm basal diameter), medium (basal diameter of 5 to 20 cm) and large (basal diameter of > 20cm) to denote approximate age (Mark 1969). For each plot, topography (altitude, slope, aspect) and geomorphology (ridge, spur, gully, moraine, hummock, topslope, midslope, toeslope, side-slope, rocky bluffs, screes, terrace and fan) were recorded. For each of the 130 plots, GPS co-ordinates were also recorded.

Sampling for evidence of defoliation and faecal signs of camping

Fifty metre transect lines were randomly sampled (separate from the plots) within each vegetation type and quadrats of size 0.5m x 0.5m were measured every 5 metres along each transect. Transects were sampled in the first and last weeks of sheep grazing. Major species within the plots were subjectively allocated to a defoliation class to account for grazing effect: 0 – no evidence of grazing, 1 – a little chewed, 2 - moderately chewed, 3 – heavily chewed (Hercus 1963). Where sheep were observed grazing the previous season, two transects were measured. For signs of day and night camping, the same 0.5m x 0.5m quadrats were examined for presence/absence of sheep faeces on both occasions. When walking to and from the plots, any signs of camping i.e. high faecal counts were noted and GPS marked. Defoliation signs were also examined inside three exclosure plots; half of each plot had hare-proof netting.

Data Analysis

Vegetation data were analysed using several techniques to determine vegetation types. Ordination and classification were chosen for their relevance to ecological data and are widely used by the ecological community. Classification groups sites based on the relationships between them. Classification is a form of cluster analysis utilising either a divisive or agglomerative technique. TWINSPAN was chosen as a polythetic divisive system, which relates species with sites (Hill & Šmilauer 2005). It utilises a divisive system whereby the plot and species data are split together, often several times, to obtain groups of similar compositions. Ordination is a technique that groups sites spatially in multidimensional ordination space relating species and sites with environmental data (Lepš & Šmilauer 2003). CANOCO was chosen for the ordination (Ter Braak & Smilauer 2002). Similar sites lie close together in ordination space, dissimilar sites are further apart. Similarly species that are correlated together also lie close to each other.

Vegetation data comprising of species and their percentage cover from the 5m x 5m plots were first analysed using TWINSPAN (two way indicator species analysis) to determine groups of vegetation types. The cut levels used in this analysis were 0, 2, 5, 10, 20 and percentage cover was square root transformed. Individual species were used as indicators in the resulting dendrogram. Indicator species are the species most likely to represent one side of the division in the dendrogram. *Hieracium pilosella* was not used as an indicator species as it was dominant in most plots anyway and was not the main focus for determining vegetation types. The main tussocks, *Chionochloa rigida* and *Festuca novae-zelandiae* were given equal weighting in the analysis. The resulting dendrogram was used to aid determination of vegetation types (Figure 7; Celhaa – *Celmisia haastii,* Agrcap – *Agrostis capillaris,* Pimore – *Pimelia oreophila,* Raosub – *Raoulia subsericea,* Blepen – *Blechnum penna-marina,* Keldie – *Kelleria dieffenbachii,* Leucol – *Leucopogon colensoi,* Antodo – *Anthoxanthum odoratum,* Fesnov – *Festuca novae-zelandiae,* Chirig – *Chionochloa rigida,* Cellya – *Celmisia lyalli,* Celang – *C. angustifolia*).

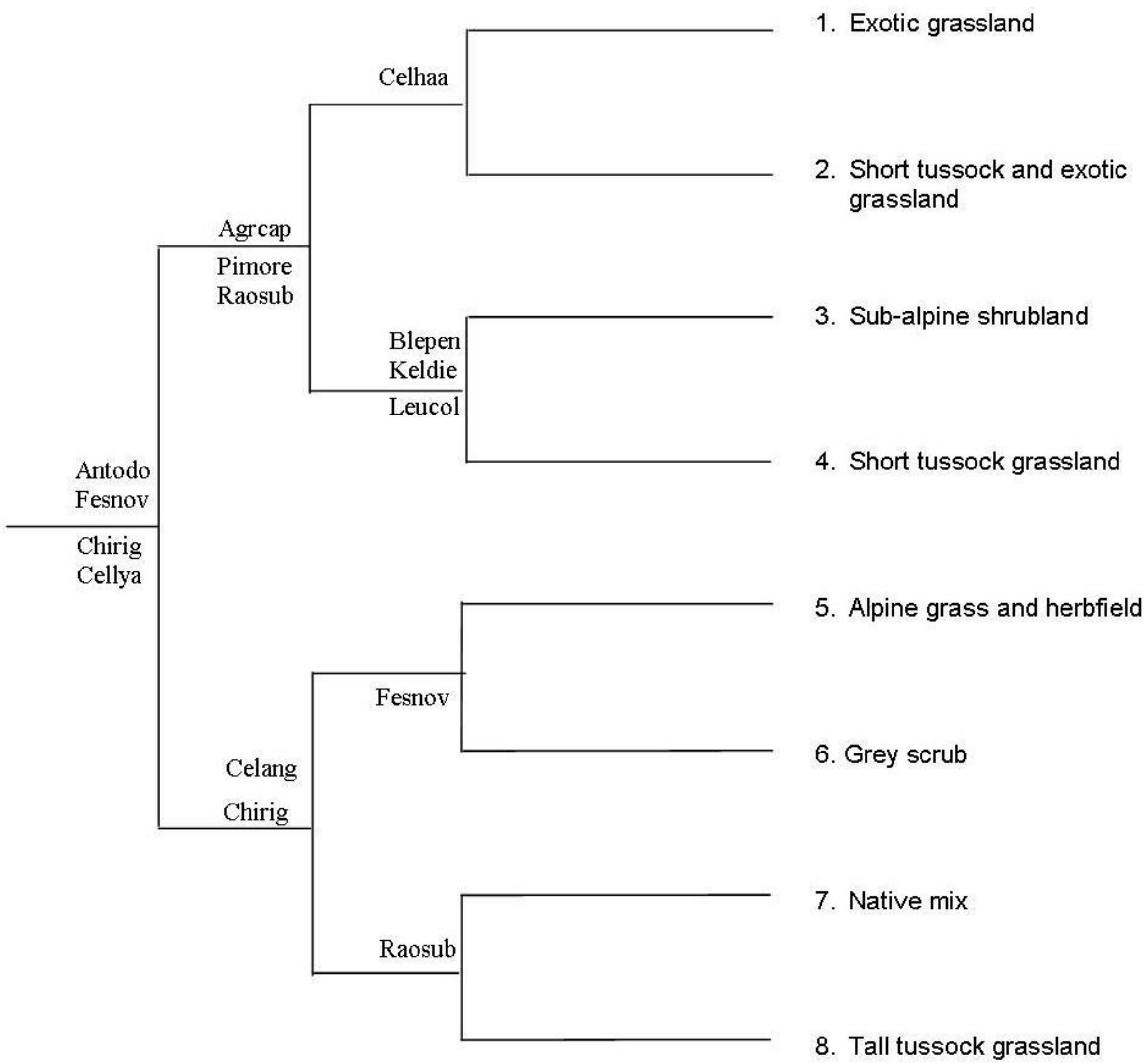


Figure 7. Dendogram representing the groups of vegetation types, how they are split and their indicator species. For species, check Appendix A.

Ordination was used to relate species and sites with environmental data using CANOCO. A total of 133 plots and percentage cover of 100 species were entered into the programme as species data. Environmental data included in the analysis were altitude, slope, north-south aspect, moisture index (Duncan et al. 1997), species richness, and total vegetation cover. Vegetation data were first explored with an indirect gradient analysis using the detrended correspondence analysis (DCA, Figure 8). It can clearly be seen that altitude is the main driver of vegetation composition.

This was followed by a direct gradient analysis (Figure 9) using a detrended canonical correspondence analysis (DCCA), identifying which environmental variables had the most influence on vegetation composition (Lepš & Šmilauer 2003). As can be seen in Figure 9, altitude had the most influence on species composition and vegetation type. Slope and aspect had a moderate influence on vegetation composition. The eigenvalues for axes 1and 2 were 0.171 and 0.076 respectively, together explaining 83.6% of the variation in community composition.

For the purpose of this habitat utilisation research, it is necessary to organise the full range of available habitats into different vegetation types. With the help of TWINSPAN and CANOCO, 10 habitat types were derived for the summer grazing land available to Merino ewes on the Glenmore study area. All ten vegetation types are summarised in Table 1, but are described in more detail as follows: (altitude, slope and species richness are given as mean ± standard deviation).

It was notable that although there were no threatened species in the study area, some species were locally uncommon.

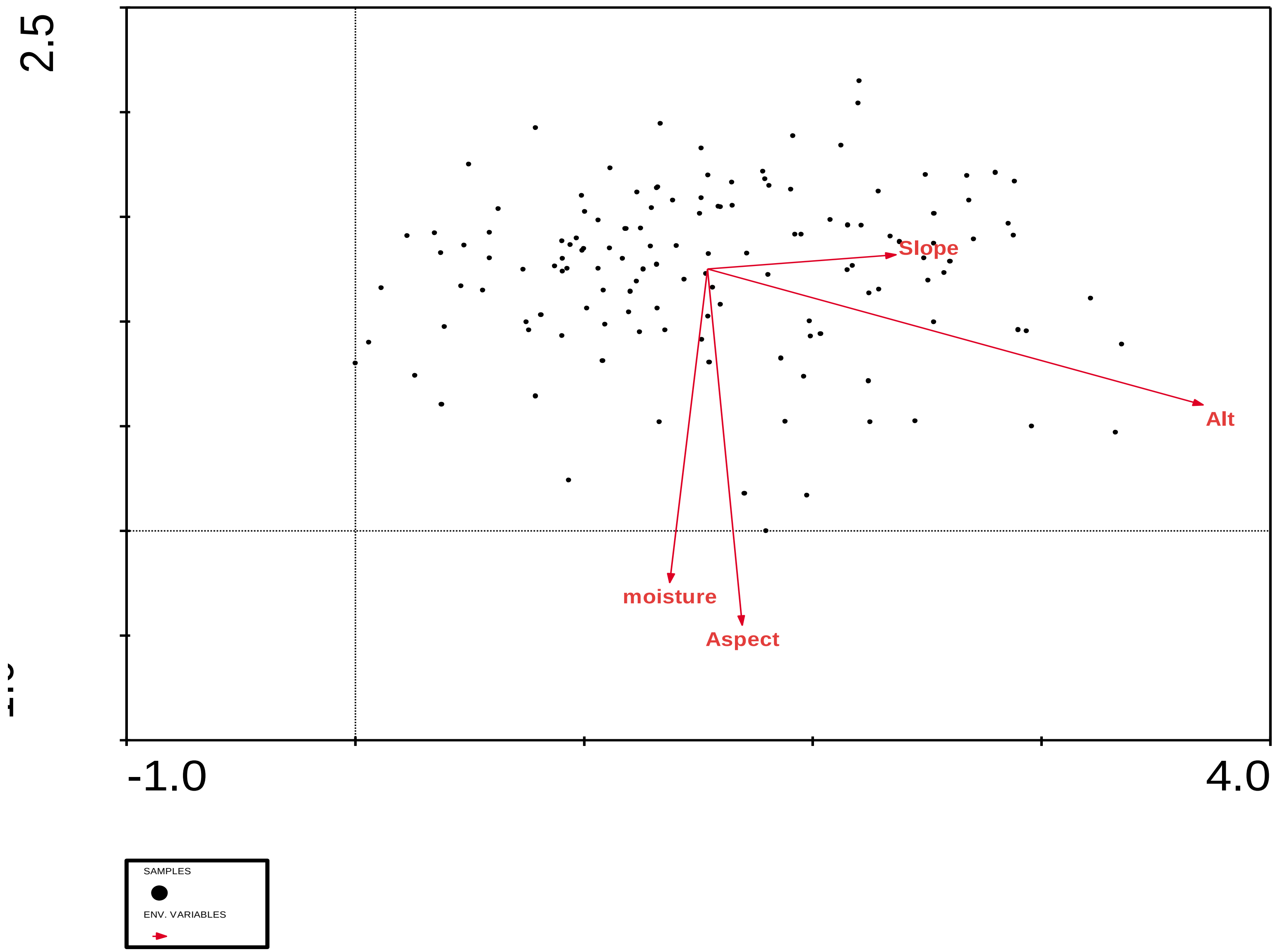


Figure 8. DCA showing the distribution of the vegetation plots, with the environmental variables overlaid on the diagram

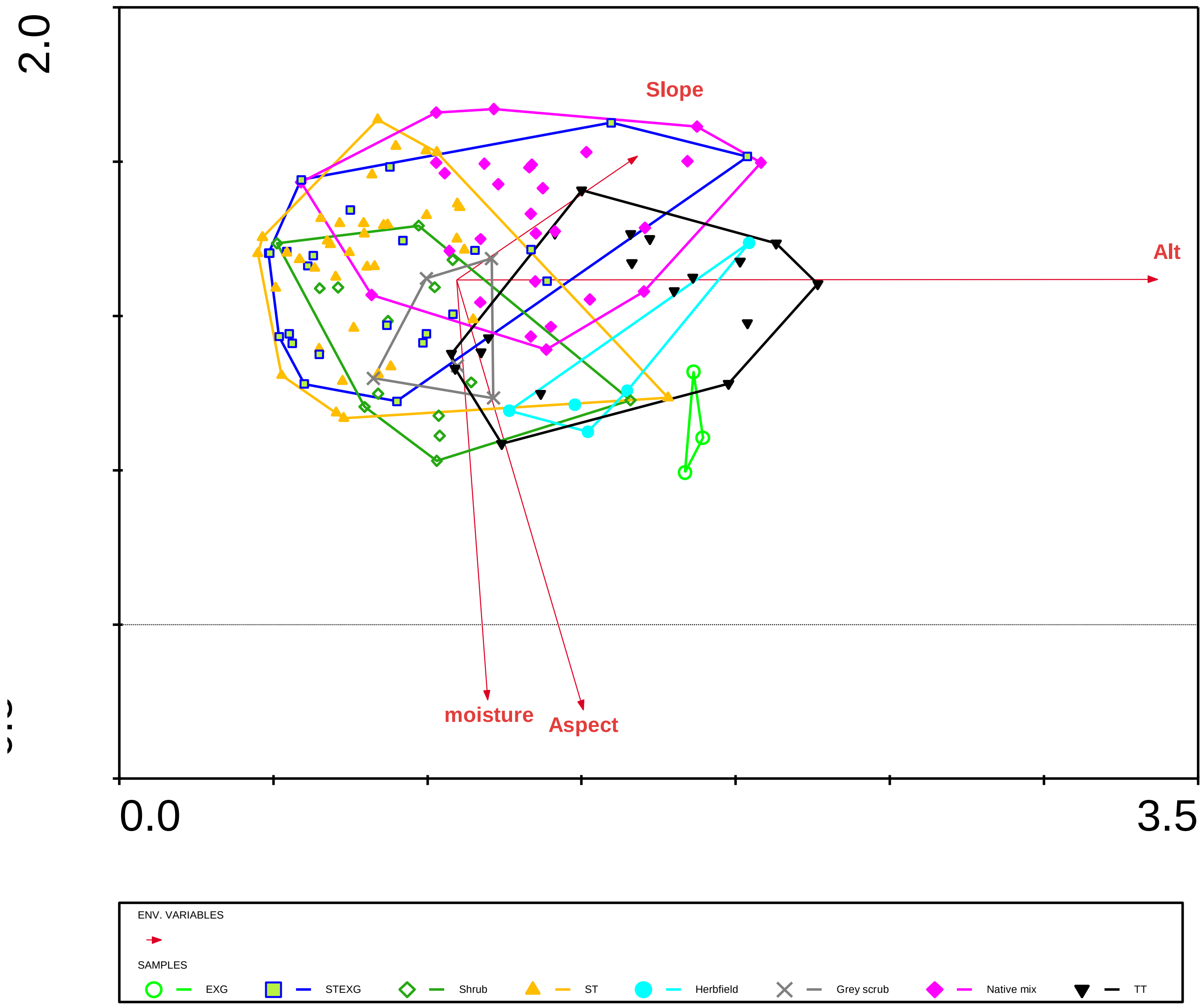


Figure 9. DCCA depicting the groups of vegetation plots and the relationship with environmental variables

Results – vegetation types

Group 1 Exotic grasses (3 plots, 2 ha, 0.1% of study area)

This habitat type is usually dominated by *Hieracium pilosella* with a fair cover (>30%) of exotic grasses, *Anthoxanthum odoratum* and *Agrostis capillaris* alongside the native grasses *Festuca novae-zelandiae* and *Poa colensoi*. *Trifolium repens* is also present. This vegetation type occurred at high altitude (mean altitude 1512 m ± 14), on gentle slopes (mean 14°) along the lateral moraine above Ailsa Stream and on top of the main spur on Top Block. Exotic grass habitat also occurred all over the study area in small patches, often occurring at lower altitude, on moist flat river terraces and toeslopes; well-trodden sheep tracks exhibit this vegetation type throughout the study area, forming exotic corridors through other indigenous habitats. For the purposes of this research, only one patch was large enough to be identified from GPS locations (>1ha). Average species richness was moderate at 23 ± 8. Native species consisted of 30 out of 36 species in total. See Appendix C for photos of vegetation types.

Group 2 Short tussock grassland and exotic grassland (24 plots, later incorporated into group 4)

This vegetation type was also dominated by *Hieracium pilosella* but had a high exotic grass cover (>20%) and slightly lower indigenous grass cover (<20%). This vegetation type was found at the lower altitudes (mean 1197 m ± 128, range 1100 – 1570 m, on a range of aspects on moderate slopes (15° ± 13). *Poa cita* and *Muehlenbeckia axillaris* were present in this vegetation type. Average species richness was 19 ± 6. Native species consisted of 42 out of 65 species in total. This vegetation type was found in small patches amongst short tussock grassland so was incorporated for mapping purposes.

Group 3 Sub-alpine Shrubland (14 plots, 50 ha, 2.6% of study area)

Open shrubland was dominated by *Hieracium pilosella*, with sub-dominant grasses, mostly *F. novae-zelandiae* interspersed with shrubs such as *Ozothamnus leptophylla*, *Dracophyllum uniflorum* or *Brachyglottis cassinioides*. Open shrubland frequently occurs on mid-slopes, in gullies and at the bottom of fans. Mean altitude here is 1204 m ± 83, range 1090 – 1430 m, mean slope is 19° ± 10, range 0 - 35°. Species richness was high (mean 27 ± 4 species per plot), while native species consisted of 53 out of 64 species in total.

Group 4 Short tussock grassland (38 plots, 369 ha, 19.3% of study area)

Short tussock grassland is actually dominated by the exotic mouse-ear hawkweed, *Hieracium pilosella*, but the main grass is *Festuca novae-zelandiae*, usually accompanied by *Poa colensoi* and occasionally the silver tussock, *Poa cita*, appears. This vegetation type was chiefly along the sides of the riverbed at low altitude, (mean altitude 1166 m ± 78, range 1070 – 1500 m), on moderately low slopes (mean slope 20° ± 13, range 0 - 38°). This type was found on any aspect. Inter-tussock herb species are frequently *Wahlenbergia albomarginata*, *Brachyscome longiscapa*, *Raoulia subsericea*, *Luzula rufa*, *Acaena* spp., *Carex breviculmis*, *Helichrysum filicaule*, *Viola cunninghamii*, *Geranium sessiliflorum*, *Hydrocotyle novae-zelandiae* and *Celmisia gracilenta.* Common sub-shrubs present are *Leucopogon colensoi*, *L. fraseri*, *Muehlenbeckia axillaris* and *Pimelia oreophila.* Exotic herb species that frequently occur but are in low abundance are *Rumex acetosella*, *Hypochoeris radicata* and *Hieracium praealtum.* Average species richness here is moderate at 25 ± 5 species per plot. Native species consisted of 60 out of 74 species in total.

Group 5 Alpine Grassland and Herbfield (5 plots, 35 ha, 1.8% of the study area)

The herbfield in the study area was dominated by *Celmisia* spp. commonly *Celmisia lyallii*, *C. angustifolia* and *C. haastii*, along with the co-dominant grass *Poa colensoi.* Sub-dominant herbs are *Anisotome* spp. *Kelleria dieffenbachii* and *Lycopodium fastigiatum. Dracophyllum pronum* and *Gaultheria* spp. are also common here. This vegetation type occurs mainly on southerly steepish slopes (mean slope 27° ± 6) at high altitude (mean altitude 1408 m ± 98, range 1300 – 1600 m). Average species richness here is moderate at 24 ± 7 species per plot. Native species consisted of 38 out of 44 species in total.

Group 6 Grey scrub (5 plots, 25 ha, 1.3% of the study area)

Grey scrub occurred mainly on the steep south-west facing slope along Ailsa Stream on Top Block, but also occurred in patches in steep gullies (mean altitude 1238 m ± 56, range 1160 – 1300 m, mean slope 25° ± 7, range 20 - 37°). Grey scrub consists of shrubs about one metre tall, typically *Ozothamnus leptophylla*, *Dracophyllum uniflorum*, *Discaria toumatou*, *Olearia cymbifolia* or *Podocarpus nivalis* interspersed with *Aciphylla* spp. There is very little completely closed scrub, mainly in steep gullies, but it is the more dense almost impenetrable vegetation that differentiates it from the more open shrubland. Some tree species do exist here though, with heights up to about 3 metres. Tree species include *Hoheria lyallii*, while the shrubs *Coprosma propinqua*, *Aristotelia fruticosa*, and *Brachyglottis cassinioides* were also present. Average species richness is highest (31 ± 4) in grey scrub. Native species consisted of 52 out of 58 species in total.

Group 7 Native mix (28 plots, 81 ha, 4.2% of the study area)

This vegetation type occurs on two blocks at mid altitude (mean altitude 1352 m ±105, range 1090 – 1500 m) on a range of slopes (mean slope 19° ± 9, range 0 - 35°). Native mix is found on a range of north-facing and east-facing slopes, mostly between the brow of the hill and mid-slope. This vegetation type is also often found on stepped slopes or banks where soil erosion is common. Native mix is a mixture of primarily native species, of herbs, shrubs, sub-shrubs and grasses, without one group being dominant.

Sub-shrubs such as *Leucopogon colensoi*, *Pentachondra pumila* and *Dracophyllum pronum* grow well here. Native mix has moderate species richness (mean 21 ± 4). Native species consisted of 49 out of 57 species in total.

Group 8 Tall tussock grassland (27 plots, 756 ha, 40% of the study area)

Chionochloa rigida and *Celmisia lyallii* dominate this vegetation type, found at high altitudes (mean 1419 m ± 138, range 1200 – 1630 m) and is the most extensive vegetation type in the study area. Slopes range from 0 to 36° (mean slope 22° ± 12). On the southern end of Top Block there is very little tall tussock grassland, mainly scattered in higher altitude gullies and other less accessible places, where the tall tussock is not complemented with *Celmisia*. Twin Basins and Tin Hut Blocks have extensive tall tussock grasslands. Tall tussock grassland contains little or no short tussock, *Festuca novae-zelandiae* but the blue tussock, *Poa colensoi* is common. Inter-tussock herb species are *Raoulia subsericea, Oreobulus pectinatus*, *Lycopodium fastigiatum*, *Brachyscome longiscapa*, *Epilobium* spp., other *Celmisia* spp. and the occasional *Aciphylla* spp. Notably, tall tussock grasslands have very little *Hieracium pilosella.* Shrubs and sub-shrubs such as *Dracophyllum* spp. and *Leucopogon colensoi* are also fairly common here. Rock and bare ground typically cover about 10 to 20%. *Chionochloa* species here can be of substantial height (>1m) with many old tussocks well over 30 cm diameter. Average species richness was low in this type with 12 ± 3 species. Native species consisted of 41 out of 45 species in total. Mean percentage cover of major species in the eight communities is shown in Table 1.

Table 1. Mean percentage cover of the major and indicator species in each of the eight vegetated communities. + indicates a mean cover of <1%. Shaded numbers indicate a >70% frequency in plots in each community.

Species	Community							
	EXG	ST/EXG	SAS	ST	AGH	GS	NM	TT
Festuca novae-zelandiae	2	19	23	22	+	7	2	+
Chionochloa rigida	+	1	+	6	+	3	21	41
Hieracium pilosella	63	57	60	63	19	32	21	3
Poa colensoi	21	2	9	10	31	13	10	10
Celmisia lyallii		+	3	+	33	20	15	25
Aciphylla aurea		+	+	+		1	1	+
Dracophyllum pronum	+		1	+	1	9	7	10
Dracophyllum uniflorum			2	+	+	5	3	11
Leucopogon colensoi		+	+	5	+	4	7	+
Celmisia angustifolia	11	+	4	+	10	+	+	
Celmisia haastii	6			+	+	+	+	+
Gaultheria depressa			3	+	7	4	1	+
Poa cita	1	8		+			+	
Agrostis capillaris	33	15	2	2	+	+	+	
Anthoxanthum odoratum	2	7	5	2	+	+	+	
Kelleria dieffenbachii	+	+	+	+	5	+	+	+
Ozothamnus leptophylla		+	3	1	+	5	+	+
Muehlenbeckia axillaris		7	+	2	+	+	+	4
Raoulia subsericea		+	3	7	+	3	7	+
Pimelia oreophila		+	+	+	+	+	+	+
Blechnum penna-marina	+	2	4	+		4	+	+

Note: EXG – exotic grasslands, ST/EXG – short tussock grassland and exotic grass, SAS – sub-alpine shrubland, ST – short tussock grasslands, AGH – alpine grass and herbfield GS – grey scrub, NM – native mix, TT – tall tussock grasslands

These eight vegetation types were visually identified in the field and their borders marked on a map. As the vegetation types would have resulted in a complex mosaic pattern, they were simplified for mapping purposes. Areas designated as tall tussock may contain patches of native mix, for example. Short tussock grassland with and without exotic grass, were merged into one community. See also the GIS Mapping section in Chapter 5. Land cover names were based on the land cover database (www.koordinates.com).

Three other landcover types were identified that were not sampled. These were low producing grassland, alpine gravel and rock and riverbed.

Low producing grassland (0 plots, 37 ha, 1.9 % of the study area)

This vegetation type occurred on a rocky fan on the true left bank, identified by the land cover database and was not sampled as it was assumed to be outside the original study area. On later inspection, it was found to be dominated by rocks frequently interspersed with *Epilobium* spp. and with occasional mat-forming species, mainly *Hieracium pilosella*, *Muehlenbeckia axillaris, Leucopogon fraseri* or the prostrate *Coprosma* or *Raoulia* spp. Grasses present in very low abundance were *F. novae-zelandiae, Chionochloa* and *Poa.*

Alpine gravel and rock (0 plots, 248 ha, 13% of the study area)

This habitat type was not sampled as vegetation is very sparse here but appeared in the land cover database at high altitude. Broken rocks form the steep scree slopes, where sparse *Epilobium* spp. are the main plants. Sheep are likely to utilise this habitat for crossing between grasslands, so was included. The upper altitudinal limit of this habitat type is rather arbitrary, assuming that sheep do not venture far upslope.

Riverbed (0 plots, 302 ha, 15.9% of the study area)

Stones, sand and silt lie on the riverbed adjacent to the water channels. Sheep utilise the riverbed for resting on the warm stones, ruminating and grazing. Sparse vegetation here comprises *Epilobium melanocaulon, Pimelia traversii, Hebe pimelioides, Anthoxanthum odoratum* and *Helichrysum depressum.*

Other

Wetland areas comprised a completely different species composition. However, as the wetlands were so small in area and were linear they were not included in the analysis. The accuracy of the GPS collars at 20 m would not make the location of the wetlands reliable and would therefore be insufficient for mapping. Silver tussock (*Poa cita)* patches were found on moist sites at the bottom of recent small scree slopes. These patches were included in short tussock grassland. Both wetlands and silver tussock patches were sampled for evidence of defoliation and faecal signs.

A summary of environmental attributes for each of the resulting ten communities is shown in Table 2. A landcover map is shown in Figure 10. A full list of vascular species present in the study area appears in Appendix A, while a list of observed fauna is in Appendix B. Photos of each vegetation type appear in Appendix C.

Table 2. Summary of vegetation types in the Glenmore study area

Community	Description	Range of environments
Tall tussock (TT)	CHIrig dominant, CELlya co-dominant	c. 1000 – 1700 m a.s.l. Any slope, any aspect.
Native mix (NM)	Mix of native grasses, sub-shrubs and herbs with few exotics	c. 1200 – 1300 m a.s.l. fairly steep slopes. Any slope, any aspect
Grey scrub (SCRUB)	Dominated by OZOlep, DRA spp. or BRAcas	c. 1000 – 1300 m a.s.l. Any slope, any aspect. Mostly steep gullies.
Sub-alpine Shrubland (SHR)	Dominated by grasses, FESnov and POAcol with some shrubs	c. 1000 – 1300 m a.s.l. Any slope, any aspect.
Short tussock (ST)	Over 20% cover of FESnov with POAcol	c. 950 – 1200 m a.s.l. Any slope, any aspect.
Exotic grass (EXG)	AGRcap, ANTodo, HIEpil	c. 1000 – 1300 m a.s.l. Gentle slopes, any aspect.
Low producing grassland (LP)	Low growing, mainly bare ground, HIEpil and LEUfra	c. 1050 – 1100 m a.s.l. Mainly close to riverbed.
Alpine gravel and rock (AGR)	Broken rock and EPImel	c. 1000 – 2000 m a.s.l. Scree slopes, bluffs and rock.
Alpine grass and herbfield (AGH)	CELlya, POAcol, CELang, CELhaa	c. 1300 – 1600 m a.s.l. Any slope or aspect.
Riverbed (RVBD)	River stones with EPImel, PIMtra, HELdep	c. 950 – 1100 m a.s.l.

Note: AGRcap – *Agrostis capillaris*, ANTodo – *Anthoxanthum odoratum*, BRAcas – *Brachyglottis cassinioides*, CELang – *Celmisia angustifolia*, CELhaa – *C. haastii*, CELlya – *C. lyallii*, CHIrig – *Chionochloa rigida*, DRA – *Dracophyllum* spp., EPImel – *Epilobium melanocaulon*, FESnov – *Festuca novae-zelandiae*, HELdep – *Helichrysum depressum*, HIEpil – *Hieracium pilosella*, OZOlep – *Ozothamnus leptophylla*, POAcol – *Poa colensoi*, PIMtra – *Pimelia traversii*,

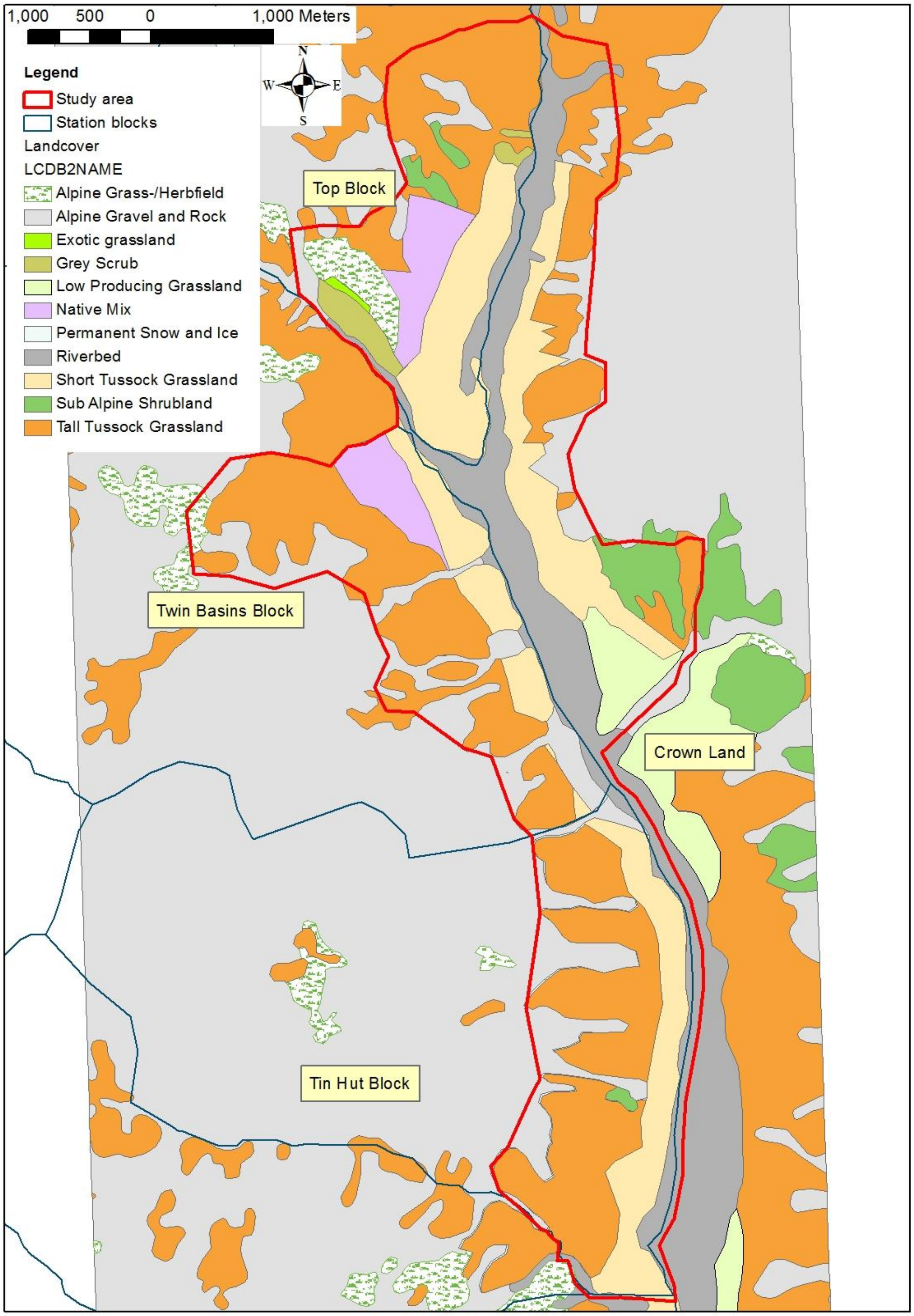


Figure 10. Landcover map of the study area

Vegetation defoliation

Signs of chewed vegetation were common, where some plants had the tips removed (light), some were moderately chewed resulting in about half the leaf remaining. Hard chewing meant that the leaves had been chewed to ground level. Common species that were measured for signs of defoliation are shown in Table 3 below, with comparisons of hare, tahr and possum diet (Flux 1967; Blay 1989; Wong & Hickling 1999; Forsyth et al. 2002; Parkes & Forsyth 2008). Hares were observed in the study area at low density; tahr were present at higher altitudes in summer. No possums were observed but may be present. *Celmisia lyallii* was chewed inside the sheep exclosure plots but not inside the hare-proof section.

Table 3. Common species that showed signs of defoliation

Species	No sign	Light	Moderate	Hard	Hare	Tahr	Possum
Poa cita	Some	Some	Many	Many	Yes	Yes	?
Chionochloa rubra	None	Some	Many	None	Yes	Yes	No
Chionochloa rigida	Some	Some	Some	Some	Yes	Yes	No
Celmisia lyallii	Many	Many	Many	Many	Yes	Yes	Yes
Poa colensoi	Many	Many	None	None	Yes	Yes	Yes
Festuca nz	None	None	None	None	Yes	Yes	?
Anthoxanthum odoratum	Some	Some	Many	Many	Yes	Yes	?
Holcus lanatus	Some	Some	Many	Many	Yes	Yes	?
Agrostis capillaris	Many	Some	Some	Some	Yes	Yes	?

Note: Light is where leaf tips are removed, moderate is where leaf is half chewed and hard is where leaves are chewed to ground level.

Discussion

I could have chosen to describe the vegetation types in broad categories of short tussock grassland and tall tussock grassland but this was deemed too coarse. As the vegetation on the study site was very heterogeneous, it was decided to separate out the two main grasslands, short and tall tussock grasslands, so that a more detailed separation of communities be determined, for the purposes of analysing sheep habitat use, which resulted in 10 vegetation types. As can be seen from Figure 10, tall tussock grasslands (TT), the dominant type in the study area, is largely restricted to higher altitudes. Native mix habitat (NM) occurs in the middle of the altitudinal gradient and on fairly steep slopes. Short tussock grassland (ST) appears at the lower altitudes. The herbfields occur on a more southerly or easterly aspect at medium altitudes, where there appears to be more soil moisture retention. Sub-alpine shrubland (SHRUB) is mostly found in small pockets on mid-slopes and at the bottom of fans, while grey scrub (SCRUB) is found mostly on steep slopes on a more southerly aspect or in steep gullies. Low producing grassland (LPG) occurs only on the large fan on the east bank of the Cass River, while exotic grassland (EXG) appears on a lateral moraine overlooking Ailsa Stream. The resulting 10 mapped landcover types are representative of the area and provide a platform for the analysis of sheep habitat use.

Observations of defoliation signs revealed that some species showed definite evidence, while others were less obvious. Transects on the well-used flats and island showed the most obvious signs. The native grasses *Poa cita, Chionochloa rubra* and *Chionochloa rigida* showed substantial evidence of chewing, while the exotics *Anthoxanthum odoratum* and *Holcus lanatus* also showed clear evidence of being eaten close to the ground, while *Agrostis capillaris* was less evident, maybe because, as an early flowering grass it was reduced to fairly dry stalks by late summer. Of the native herbs, *Celmisia lyallii* showed clear evidence of being eaten but is most likely to be eaten more by hares because defoliation signs were observed inside the sheep exclosure plots but not inside the hare-proof section. Of the less common exotic herbs, *Rumex acetosella* and *Cirsium vulgare* were clearly eaten. Other chewed species noted were: *Carmichaelia monroi, Verbascum thapsus* and *Juncus articulatus.*

Conclusion

Vegetation type is considered highly important for the study of animal habitat use as this may be the main driver of habitat use, particularly with regard to grazing intensity, but also for night camping where they feel safe. The study area contained a mosaic of vegetation types that varied substantially throughout and resulted in the mapping of 10 basic vegetation types: tall tussock grassland, short tussock grassland, short tussock grassland with exotic grass, alpine grass and herbfield, grey scrub, sub-alpine shrubland, native mix, exotic grasslands, alpine gravel and rock and riverbed. Vegetation type varied considerably with respect to altitude, slope, aspect and landform. Vascular species on the whole study area numbered 173 including 153 indigenous species; thus, this is an area with high indigenous plant diversity. Species richness was highest in the grey scrub and the lowest in the tall tussock grassland. Vegetation structure was simple in the exotic and degraded grasslands but most complex in the native mix area, shrubland and grey scrub.

Chapter 4 Sheep habitat use

Introduction

Definitions and designs

Habitat is defined as the resources and conditions in an area that are necessary for the survival of an organism (Hall et al. 1997). In this research, habitat is an all-embracing term that covers several habitat variables, specifically meaning vegetation type, landform, altitude, slope, aspect and distance to water. Habitat use is often compared with habitat availability (Krausman 1986). However, availability or abundance of a habitat does not necessarily mean that the habitat is useful to the animal in question, if it is has the wrong type of food, for example (Johnson 1980). Nevertheless, for the purposes of this research, habitat availability shall be defined the same as abundance, e.g. the percentage of each vegetation type found within the study area.

Three levels of analysis are employed by researchers of animal habitat use (Thomas & Taylor 2006). Design I studies look at the population's habitat use compared with habitats available in the whole study area. Design II studies compare each individual animal's habitat use with the habitats available in the population study area. These two designs will be utilised in this research to determine overall sheep habitat use and explore individual habitat selection. In this research, I have used the limits of vegetation and gullies/rocky bluffs as the borders of the study area, where all the sheep roamed, known as Study Area, which encompasses parts of Top Block, Twin Basins Block and Tin Hut Block.

Domestic sheep are gregarious animals, mobbing together in groups of three to several hundred, which makes understanding individual as well as group dynamics important for better understanding of sheep behaviour. Grouping behaviour has to be taken into consideration in this research. Each collared sheep can represent the behaviour of between 20 and 200 sheep. With the deployment of 16 GPS collars, this represents the behaviour of approximately1000 sheep, so this research is considered to be substantial evidence of sheep behaviour on a high country farm. The stocking rate was approximately 1 sheep per hectare over the two months or a little less than 0.2 sheep ha^{-1} yr^{-1}.

Techniques for assessing habitat use

GPS and radio tracking are well-used, accurate and cost-effective tools for providing information on animal movements (Millspaugh & Marzluff 2001). Radiotelemetry has been the main technique utilised in the past but has disadvantages which GPS can address. GPS records spatial movements at specified time slots, such as every 15 minutes, without the need for human intervention and can be used continuously in fairly rugged terrain, even at night, and is more accurate (Hansen & Riggs 2008). GPS is more expensive than radio-tracking but for long term experiments can actually be cheaper as personnel costs are lower (Recio et al. 2011a). GPS can be used in difficult terrain where observations of many animals would be impossible. It is important to test the GPS units before research begins to test for fix success rate, horizontal accuracy, and logging frequency, (Blackie 2010; Recio et al. 2011b). Stationary and mobile tests on all collars were taken over at least 48 hours.

Materials and Methods

Sixteen Merino ewes were fitted with GPS collars manufactured at the Centre for Geospatial Research, University of Canterbury (see Appendix D for technical details). The collars received GPS signals via satellites every 15 minutes, recording date, time, latitude and longitude, bearing and speed of movement. Data loggers inside the collars recorded data as a text string in NMEA GPRMC format. The collars weighed 620 grams, just over 1% of an average Merino ewe’s body weight at 52 kg.

The GPS collars were tested for fix success rate (how often a location was recorded every 15 minutes) and horizontal accuracy over 48 hours. GPS collars were tested when stationary and on the move (following a defined path). Fix success rate for all tested GPS collars was 100% and were 99% accurate to within 20 metres. For the purposes of this research, the tests were considered highly satisfactory. However, 6 collars were finished late and were tested for one night only.

Merino ewes were released onto Top Block and Twin Basins Block on February 20th 2012 and were mustered out on April 22nd 2012. Due to a series of technical problems and inclement weather, 16 sheep were fitted with collars on March 6th 2012. This should have resulted in six weeks of GPS location data. However, because the batteries performed erratically, the resulting number of records differed for each sheep (Figure 11). Eight sheep were collared on Top Block, where 500 sheep roamed and eight sheep were collared on Twin basins Block where another 500 sheep roamed. Visual observations of sheep were also made over 10 non-consecutive days during daylight hours and activities were defined to the nearest half hour. Different mobs were identified and sheep were regularly counted except during low light.

Sheep locations were explored for patterns in night camping as well as for daytime grazing and resting. All times were recorded in New Zealand Standard Time. Sunrise on March 12 was at 06:21 and sunset at 18:57. By April 21, sunrise was at 07:09 and sunset at 17:47 NZST (RASNZ 2012).

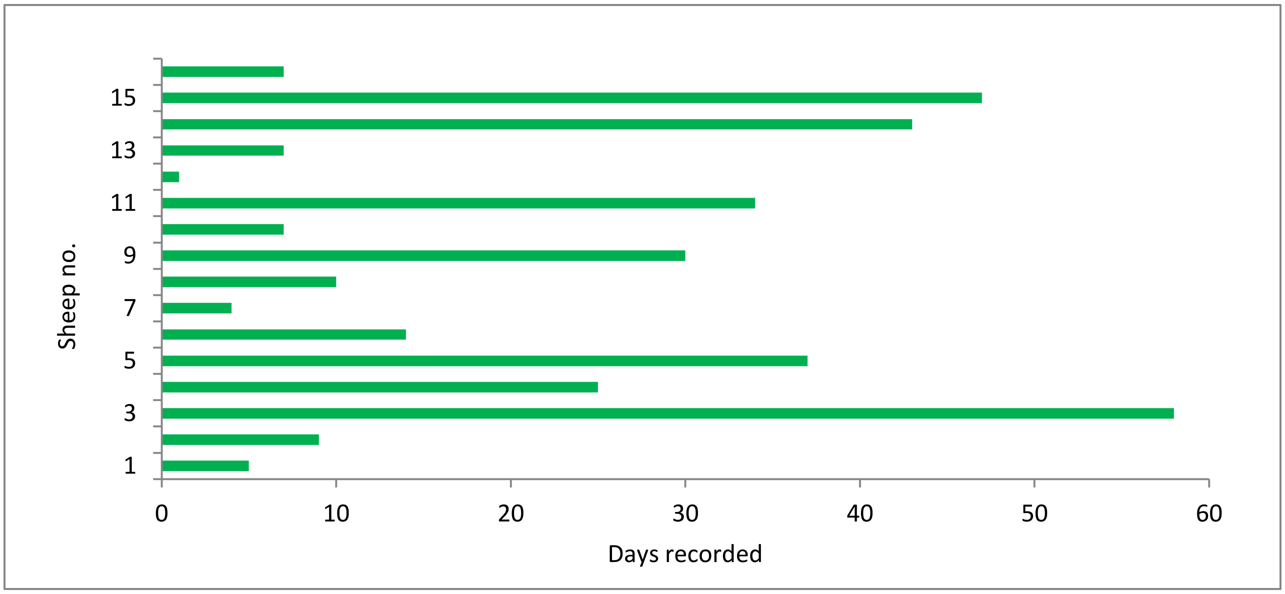


Figure 11. Duration of sheep collars

GIS mapping

In ArcGIS (Environmental Spatial Research Institute, Redwood, California, US), layers were made up using Topomaps, 20m contour files and streams and rivers files downloaded from www.koordinates.com. Ortho-rectified aerial photos were supplied by Terralink International (2004) and block shape files were supplied by David Norton. Rasters of slope, altitude, aspect were derived from the 20m contour file. A raster of distance to water was derived from the rivers and streams layer. All rasters used grids of 25 m x 25 m cell size. The land cover database from Landcare Research, was modified to incorporate the vegetation types derived from field observations and Twinspan analysis to provide a vegetation map (see previous chapter). Raster maps were exported as .asc files for analysis in the R software (R Core Development Team 2011). Finally, the sheep location co-ordinates were entered along with date and time and extreme outliers were subjectively deleted as several inaccurate locations appeared on mountain tops. A composite map was made, where each cell contained values of each habitat variable.

Home range was determined for each sheep, by week and by month, by initially using the 95% minimum convex polygons available in ArcGIS. This was deemed unsatisfactory as polygon edges frequently cut across mountain tops and so was modified by hand to clip closer to the actual locations. Utilising Geospatial Modelling Environment (Beyer 2012) each sheep location was sampled within the rasters of slope, altitude, aspect, vegetation type, distance to water which resulted in an exported table to be later analysed in R for use with the adehabitat package (Calenge 2006) and the Chi square test.

Data analysis

Sheep habitat use was analysed differently for different purposes, with the analysis split into three sections. First, the activity periods were determined from animal movement, backed by observations; second, the data was explored for relationships between activity and the habitat variables for all sheep (Design I), and third, relationships between habitat variables and activity were explored at the Design II level, for individual sheep. Because the GPS collar battery performance was erratic resulting in different lengths of records, data was analysed over two periods, one using data over the first week from 13 sheep, and one using data over the first month from 6 sheep. This split enabled detection of changes over time and sampling effort needed.

It is recognised that the data had inherent spatial and temporal autocorrelation, which could be perceived as pseudo-replication (Fieberg et al. 2010; Hawkins 2012). Sheep are the true replicates, whereas locations are nested within sheep. As sheep locations were measured every 15 minutes, each new location is dependent upon the last location; therefore the data violates the statistical requirement of independent data. As such, data analysis initially follows an exploratory approach using the ecological niche factor analysis (ENFA; (Hirzel et al. 2002; Basille et al. 2008). However, to test for significant differences, Chi-square analyses were performed on counts of sheep locations found within the study area, explained in the following paragraphs.

1. The main aim of this research is to locate areas of intensive use (AIU) both during the day time and at night. Therefore, the first section of the analysis was to determine times when the sheep were active and inactive. Distance travelled in 15 minutes was analysed over 24 hours to identify core activity periods: morning grazing, daytime resting, afternoon grazing and night camping. It was assumed (and clarified through observations) that when sheep travelled more than 50 metres in 15 minutes, they were grazing. With a GPS collar location accuracy of 20 m, this was considered conservative. Daily activities were confirmed by 10 observations days during daylight hours.

2. The second section of the analysis was to explore daily activity patterns of habitat use at the population level to determine which environmental variables influenced habitat use. Overall habitat use (24 hr) was compared with habitat availability, as well as comparing habitat use for each activity with that available. Habitat use for all sheep was compared with that available in the study area (Thomas & Taylor 2006). All factors were explored using the niche-based analysis available in adehabitat package (Calenge 2006). For the categorical habitat variables, vegetation type and aspect, a Chi-square (χ2) goodness of fit test was used to test for differences in the percentage of habitat types used compared to that available. The Chi-square goodness of fit test was chosen as it has been utilised in animal ecological studies worldwide. The Chi-square test measures the difference between the used and available percentages of habitat, where U is percentage of habitat used and A is the percentage of habitat available.

$$\chi^2 = \frac{(U-A)^2}{A} \quad (1)$$

Percentage of vegetation types and aspects available were derived from ArcGIS rasters. Habitat use was determined for vegetation type and aspect by comparing the counts of sheep GPS locations found in each habitat with the counts of available habitat, measured in 25 m x 25 m cell grids. Use and availability of continuous habitat variables, altitude, slope and distance to water are presented as mean ± standard deviation. The overall relationships between used habitat and available habitat for continuous variables were analysed using the ENFA, which defines the ecological space available to sheep and measures the niche used by sheep (Hirzel et al. 2002; Basille et al. 2008). Available habitat is presented as the values of the various environmental variables contained within the study area. In R, a matrix of P cells and V variables was created, where each variable was standardised, so that the mean of each variable was 0 and the variance was 1. After performing the ENFA analysis, a principal components analysis (PCA), produces a biplot diagram. This diagram determines the ecological space available to sheep, where the centroid represents the habitat means. Arrows represent the influence of the environmental variables on the ecological space. The longer the arrows, the more influence they have. The direction of the arrows represents the influence the environmental variables have on the marginality (axis 1) and specialisation (axis 2). Marginality defines the magnitude of deviation from the mean of available space, where μ_a is the available mean, μ_u is the used mean and σ_a is the standard deviation of the available distribution. Marginality values range from 0 to 1, 0 representing no marginality, 1 representing extreme marginality. To test for marginality, 1000 Monte Carlo simulations were calculated on the marginality index and compared with actual results.

$$\mathcal{M} = \frac{(\mu_a - \mu_u)}{1.96\sigma_a}$$

Specialisation measures the narrowness of the niche, or the tolerance of the species; the higher the number the more specialised the habitat use. Specialisation is the ratio of available standard deviation to used standard deviation. Specialisation values range from 1 upwards, where 1 represents no specialisation.

$$\mathcal{S} = \frac{\sigma_a}{\sigma_u}$$

The cloud of points in the biplot defines the ecological niche of the species, where the mean is represented by a white circle. For testing significance (see second paragraph in Data Analysis for explanation), Chi-square analyses were performed on classes of continuous variables and on categorical variables. One compared overall habitat use with available habitat and then each activity was compared with available habitat. Altitude was split into four classes, <1100, 1200, 1300 and >1300 m a.s.l. Slope was split into four classes, <5, 15, 30 and >30°. Distance to water was split into four classes, <100, 200, 300 and >300 m. Significance tests are represented as * when p<0.05, ** when p<0.01 and *** when p<0.001.

3. The third section of the analysis (Design II, individual use in study area) the Outlying Mean Index (OMI) analysis was used (Hirzel et al. 2002; Calenge et al. 2005). Species marginality measures the distance between the mean habitat conditions used by each animal and the mean conditions available in the study area (Dolédec et al. 2000). The OMI is displayed in an ordination diagram, which shows the mean of the habitat variables available in the centre of the diagram and the mean of each sheep's use of those variables placed in relation to the centre, i.e. the marginality.

Results

Defining daily activity periods

Times for night camping and resting were determined based on a lack of movement. Activity started before dawn and finished just after dusk, with a midday rest. All sheep showed this pattern, although there were slight variations. For the purpose of determining different impacts on the environment, sheep habitat use was analysed by activity. Morning grazing (AMG) began about 06:00 and finished at 12:00. Resting (Rest), which included ruminating, occurred between 12:00 and 15:00. Afternoon grazing (PMG) occurred between 15:00 and 20:00, while night camping (NC) occurred between 20:00 and 06:00 (Figure 12). As the results of the morning and afternoon grazing periods differed little in their respective habitat use, they were grouped together as one grazing period (Graze), for improved clarity.

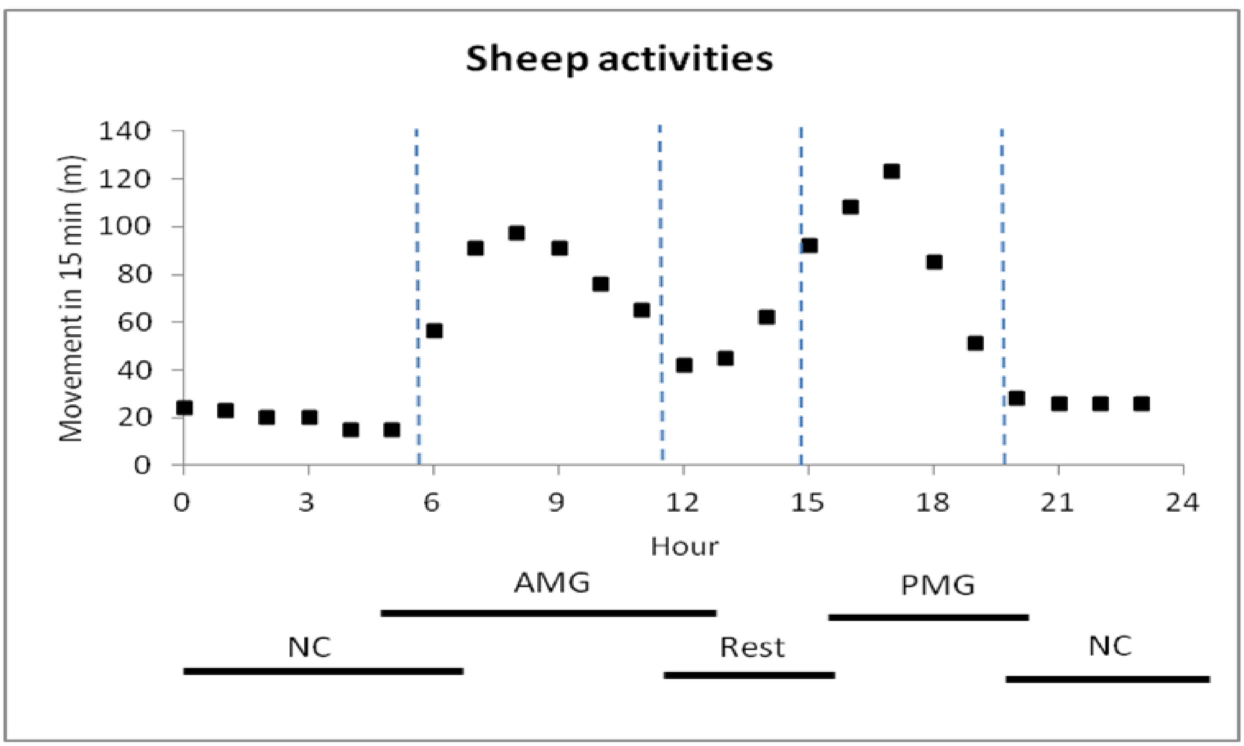


Figure 12. Daily activities defined through distance moved in 15 minutes over 24 hours

Habitat use based on field observations

Merino ewes formed main mobs as well as small groups. Identified through visual observations over 10 days, the main mob in the area just north of Memorial Hut consisted of between 200 and 255 ewes. A mob of about 150 were observed on the true left bank of the Cass River opposite Memorial Hut. At times, these large mobs spilt into smaller mobs and then merged again later, sometimes in the same day and sometimes days apart. This process occurred several times over the course of the observation days. A small group of 12 ewes were observed grazing the patch of exotic grass over 3 days. A group of 60 ewes were observed grazing on the left bank of the Cass River late evening. Other observations included a small group of 12 grazing tall tussock grassland above the flats. Small groups were often observed near the riverbed but were part of the area covered by the collared sheep. The core grazing habitat used by the large mob of ~250 ewes was the lower slopes of short tussock grassland, the riverbed, the lower parts of the big fan, the big island and the hummocks behind Memorial Hut (Figure 2). The riverbed area was most popular for the midday rest for the main mobs and most of the smaller groups. Night camps were popular up side valleys.

Histograms showing the availability of each environmental habitat variable within the study area appear in Figure 13. Mean altitude available is 1238 m, mean slope available is 23°, mean distance to water available is 183 m. Areas of intensive use are portrayed in Figure 14, which are mostly night camps. In Figure 15, the northern half of the study area is shown for clarity; the area north of Memorial Hut was the most intensively used. Resting AIUs are depicted in Figure 16. Note that they are situated mostly along the riverbed.

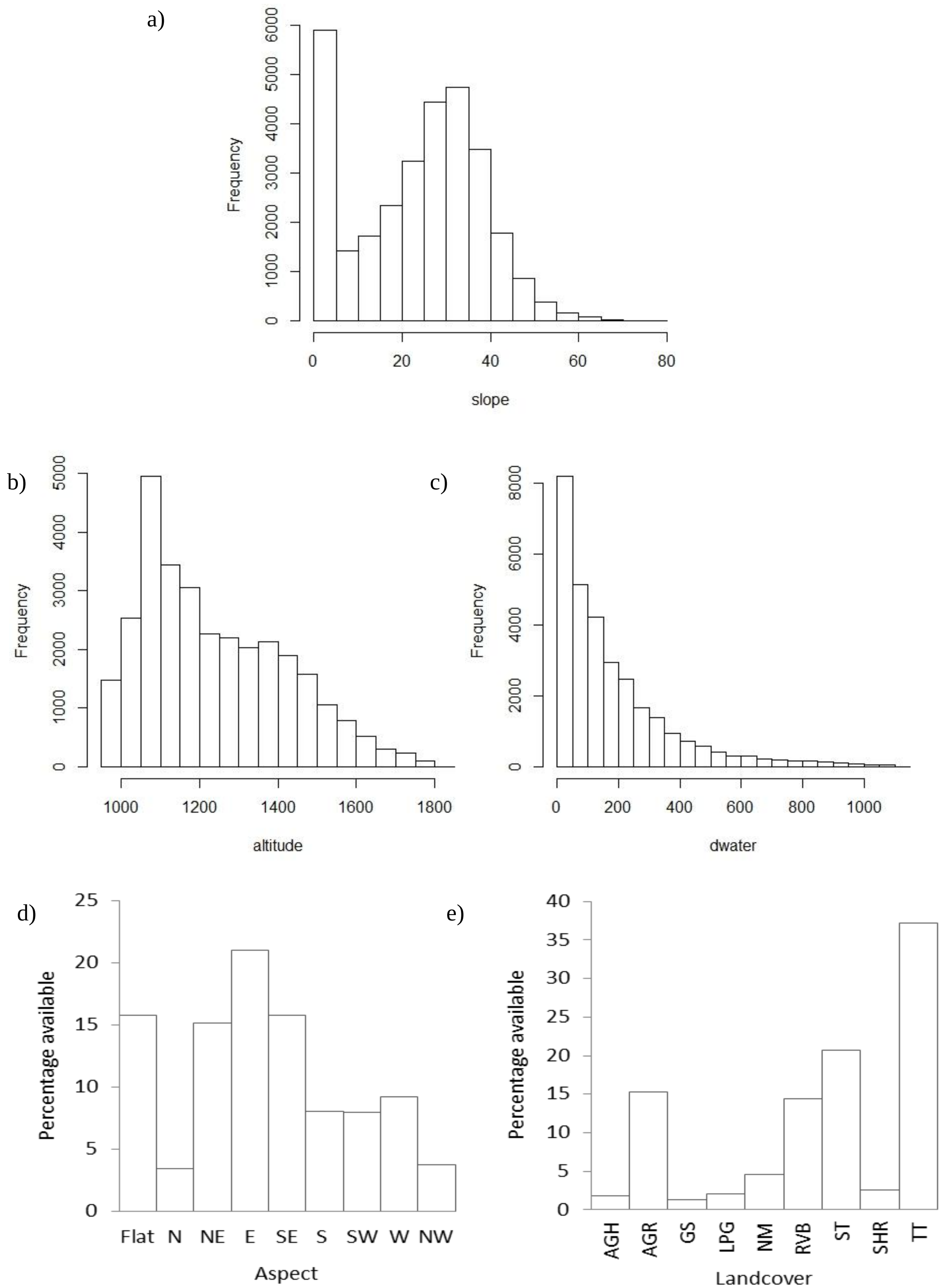


Figure 13. Distribution of habitat variables, within the study area, a) slope, b) altitude, c) dwater, d) aspect and e) landcover.

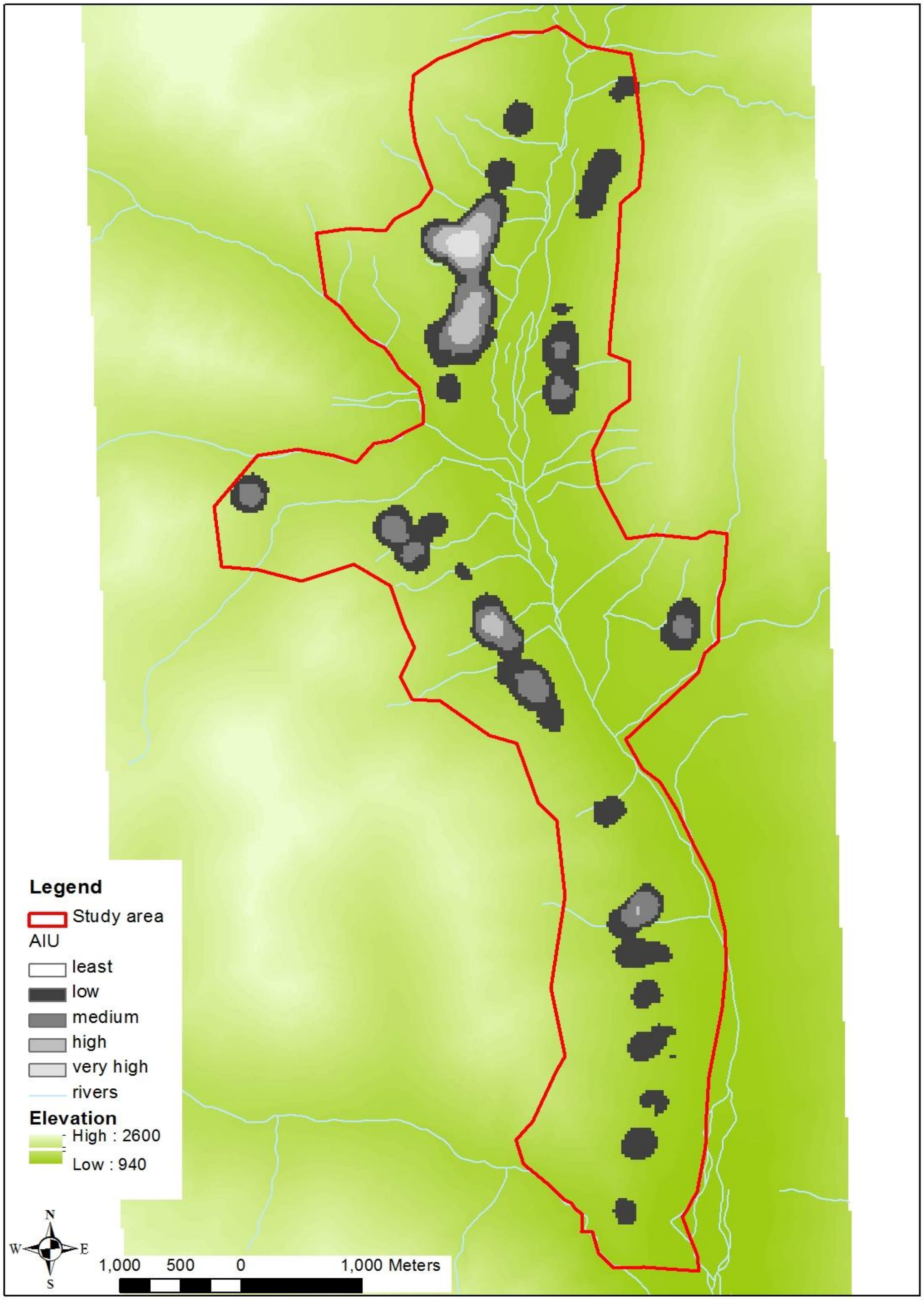


Figure 14. Map depicting areas of intensive use, based on 30 day dataset. Lighter grey areas are more intensive.

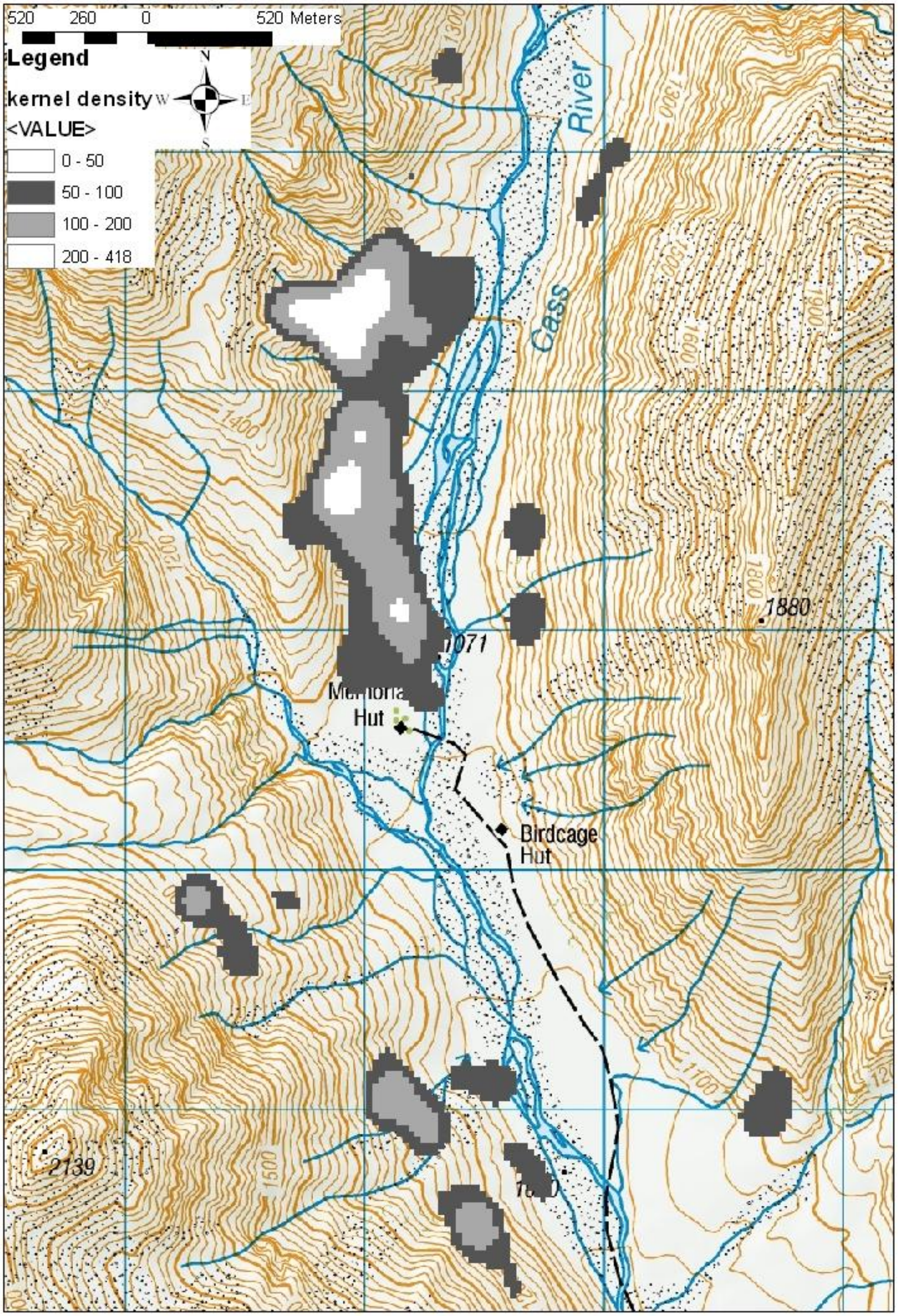


Figure 15. Close-up map of AIUs, mostly night camps.

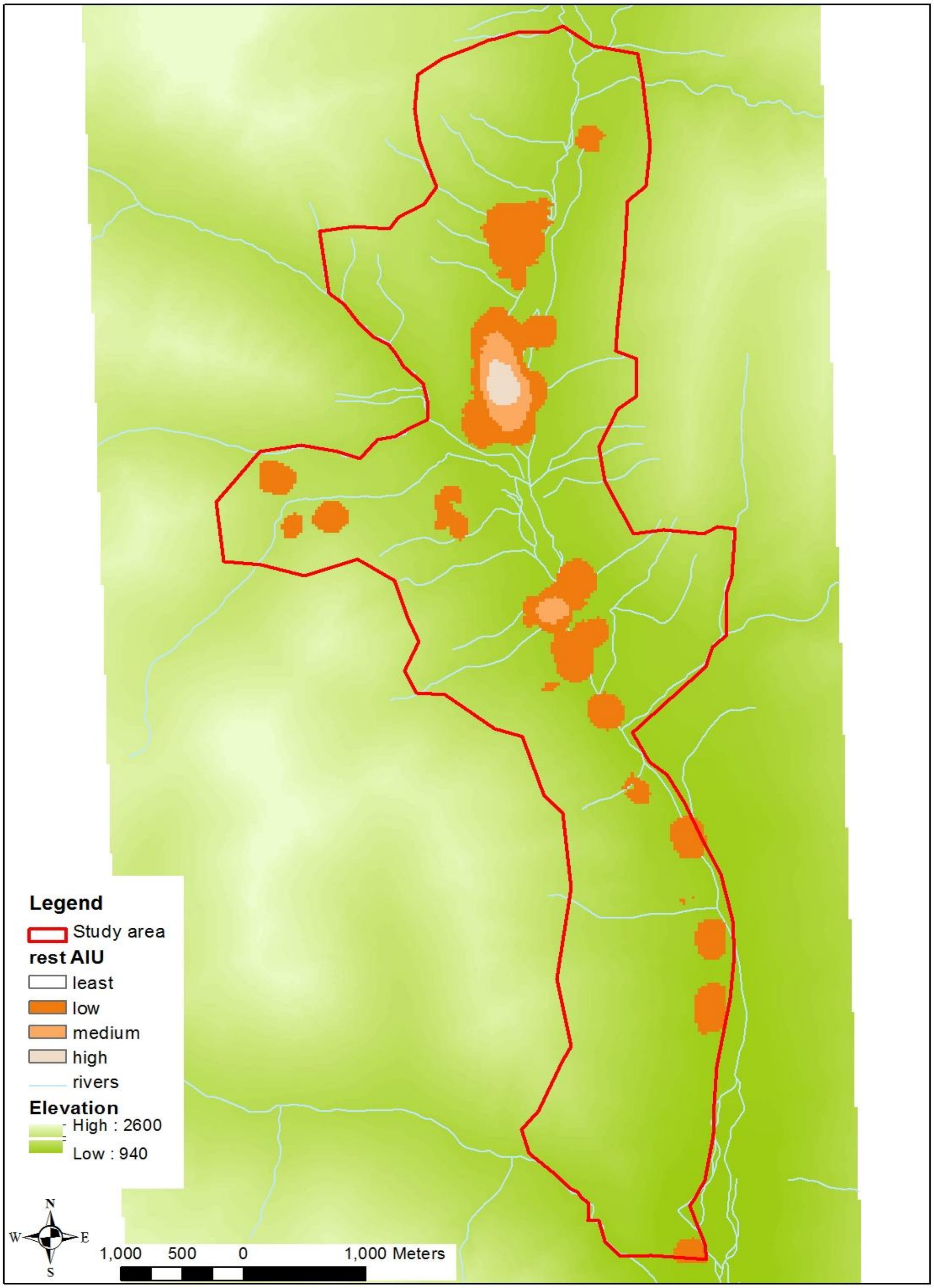


Figure 16. Map of resting AIUs.

Habitat use at the 7 day scale with 13 sheep

Sheep used habitat differently from that available. The habitat niche of the Merino ewes was lower altitude, lower slope and close to water (Figure 18). Species marginality was 0.239, specialisation = 1.44.

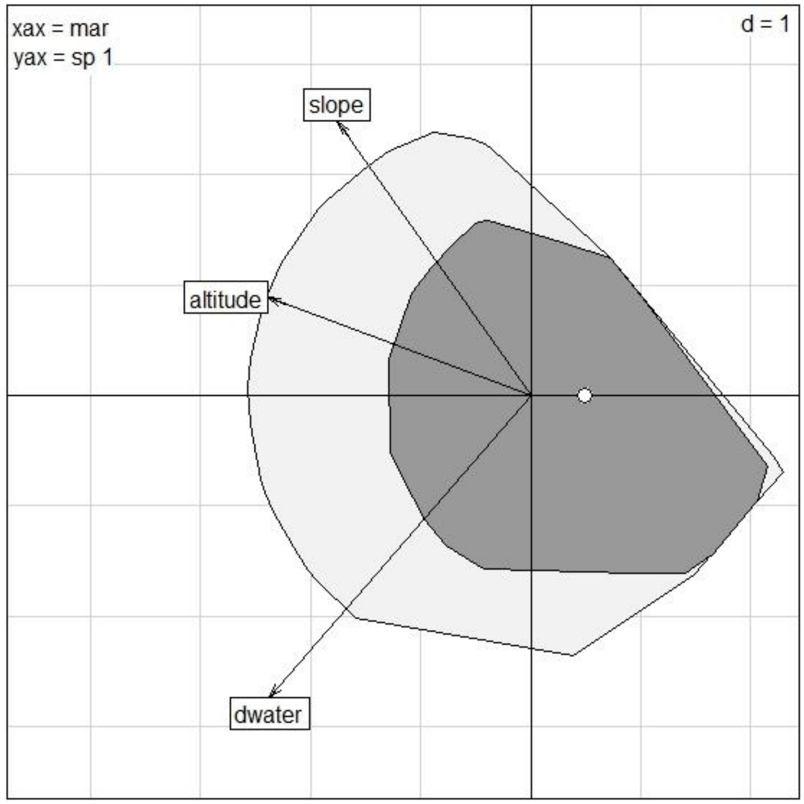


Figure 18. ENFA analysis, weekly data, showing the ecological space available (light grey) and the niche (dark grey). Mean of the niche (white spot) has lower values than the available mean.

Overall sheep habitat use differed from available habitat and each activity differed from that available. Altitudinally, Merino ewes rarely used habitat above 1400 m a.s.l. The majority of the time was spent on or near the riverbed at about 1100 m a.s.l, but sheep moved to higher ground at night. Strong relationships between altitude and activity were evident (Figure 17). Overall, altitude was significantly different from that available (χ^2 = 1470***, df = 3). Mean altitude (resting) = 1117 m ± 112, mean altitude (grazing) = 1155 m ± 110, mean altitude (camping) = 1258 m ± 104, mean altitude (overall) = 1183 ± 134, mean altitude (available) =1238 ± 181.

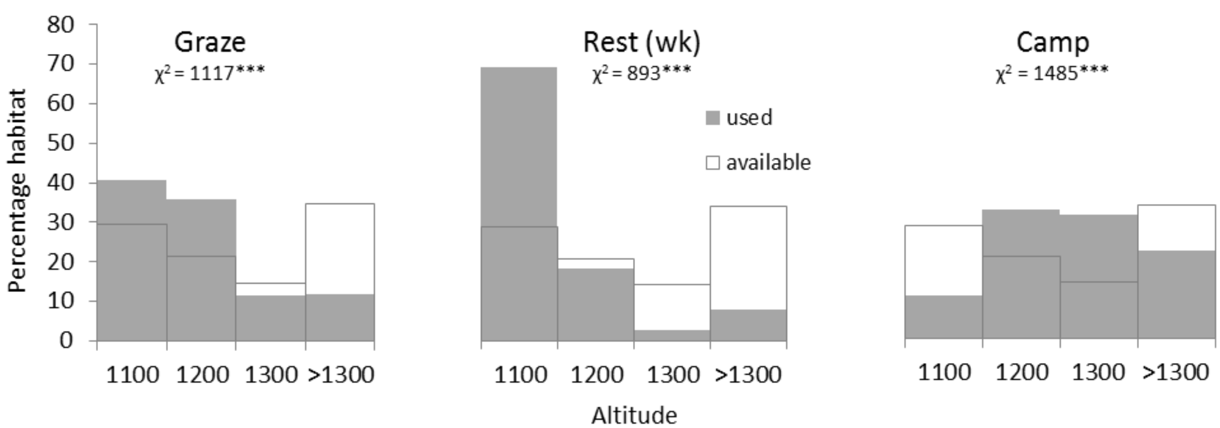


Figure 17. Altitude used (grey bars) and available (white bars) by activity, at the weekly scale

Merino ewes utilised flat land and gentler slopes most of the time, except at night, when they frequently camped on steeper slopes. Although there were very steep slopes in the study area, they largely avoided the steepest slopes, showing a distinct preference for flat and gently sloping land. Overall, there was a significant difference in slope use to that available (χ^2 = 2243***, df = 3). There were also significant differences in slope use between activities (Figure 20). Mean slope (resting) = 8° ± 9, mean slope (grazing) = 16° ± 11, mean slope (camping) = 27° ± 9, mean slope (overall) = 20° ± 13, mean slope (available) =23° ± 14.

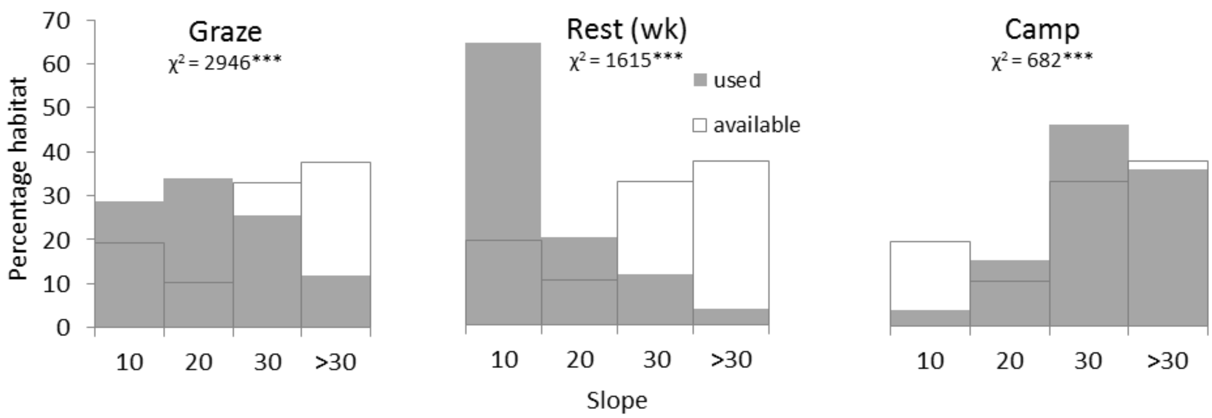


Figure 20. Slope used (grey bars) and available (white bars) by activity, at the weekly scale.

Merino ewes utilised habitat close to water most of the time and rarely used habitat further than 600 metres from a water source (χ^2 = 634***, df =3). Water sources are plentiful in the study area. Differences in distance to water (DW) between activities were evident (Figure 20). Mean DW (resting) = 79 m ± 86, mean DW (grazing) = 114 m ± 64, mean DW (camping) = 162 m ± 112, mean DW (overall) = 129 m ± 127, mean DW (available) = 183 m ±189.

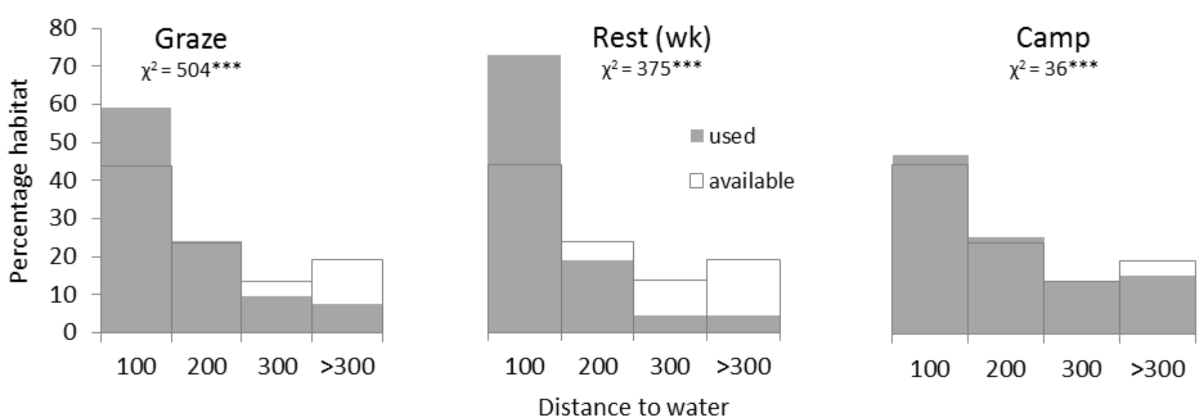


Figure 19. Distance to water used (grey bars) and available (white bars) by activity, at the weekly scale

Merino ewes used different aspects from those available and aspects varied for different activities (Figure 21). Chi-square tests were highly significant between overall aspect use and availability (overall χ^2 = 2512 ***, df = 8). Resting mostly occurred on flat ground (55%). Grazing and night camping mostly occurred on easterly land (34% and 49% respectively). South-west, west and north-west facing land was largely avoided.

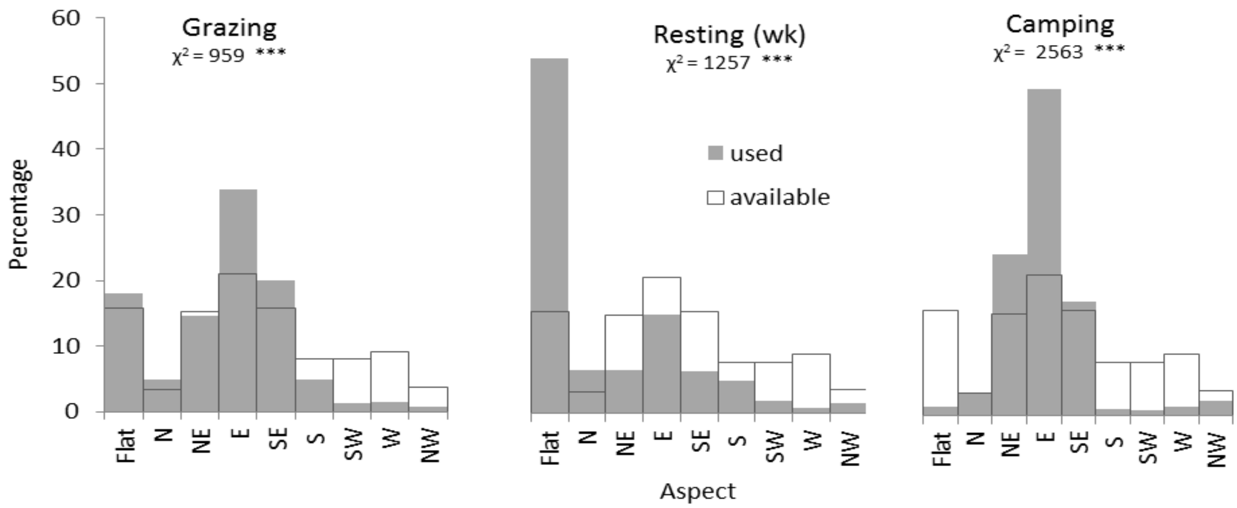


Figure 21. Aspect used (grey bars) and available (white bars) by activity, at the weekly scale.

Merino ewes showed an overwhelming preference for short tussock grassland for grazing (Figure 22). Tall tussock grassland and native mix were utilised mostly for night camping, Grey scrub, alpine gravel and rock and the herbfields were distinctly avoided. There were significant differences in vegetation type used overall and between each daily activities and availability, (overall χ^2 = 5628 ***, df = 9).

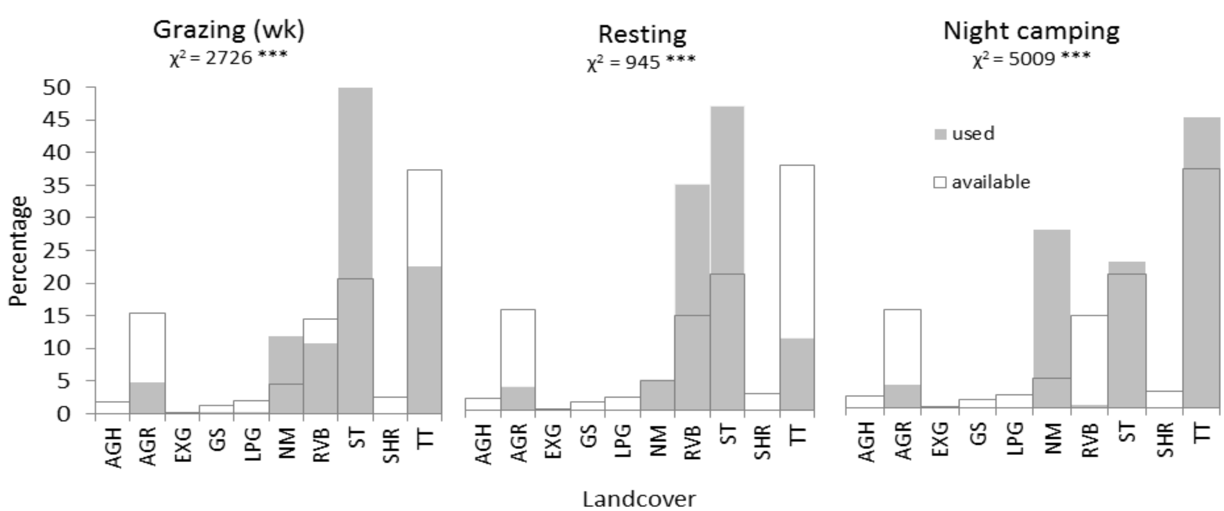


Figure 22. Landcover used (grey bars) and available (white bars) by activity, at the weekly scale.

Habitat use at the monthly scale with 6 sheep

At the monthly scale, sheep used habitat differently from that available. The habitat niche of the Merino ewes was lower altitude, lower slope and close to water (Figure 23). Species marginality was 0.43, specialisation = 2.43, which means that sheep used a narrower niche.

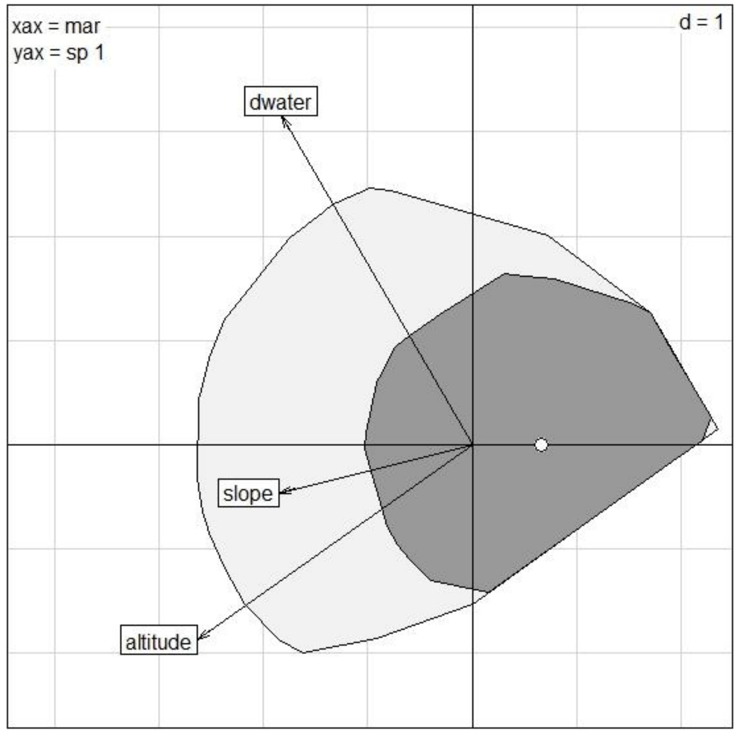


Figure 23. ENFA analysis, monthly data, showing the ecological space available (light grey) and the niche (dark grey). Mean of the niche (white spot) has lower values than the available mean.

At the monthly scale, overall sheep habitat use differed from that available and there were significant differences by activity. Analysis using the 6 sheep over 30 days provided small differences in habitat use from the weekly data. Altitudinal use was similar to the weekly dataset, but somewhat lower over the month (χ^2 = 7542 ***, df =3). Mean altitude (resting) = 1084 m ± 64, mean altitude (grazing) was 1130 m ± 80, mean altitude (camping) was 1208 m ±74, mean altitude (overall) = 1155 ± 93, mean altitude (available) = 1238 m ± 181; (Figure 24).

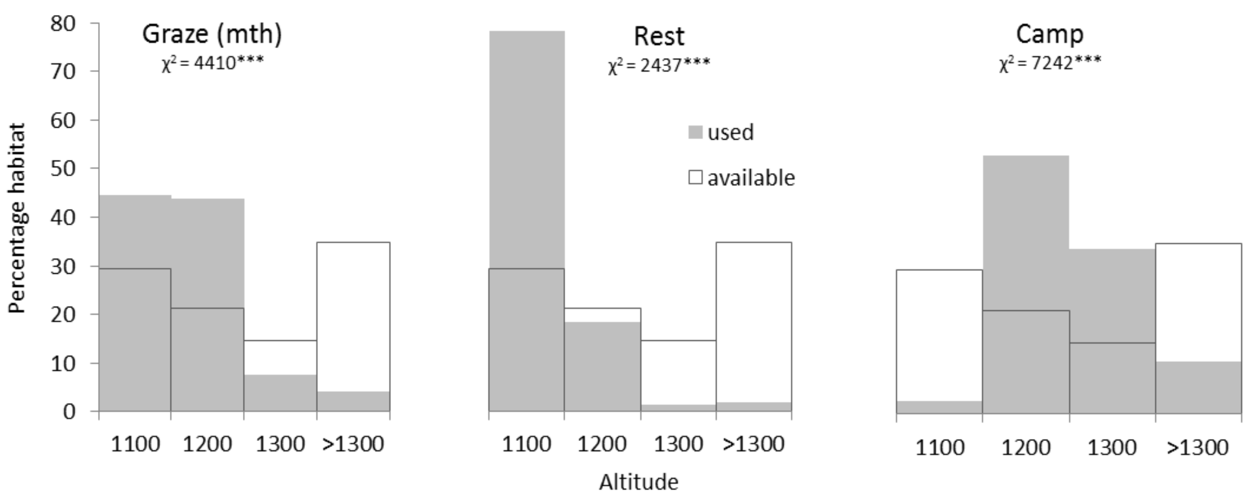


Figure 24. Altitude used (grey bars) and available (white bars) by activity, at the monthy scale

Slope use was very similar to the weekly dataset. There were significant differences in overall slope use (χ^2 = 4656 ***, df =3) as well as by activity (Figure 25). Mean slope (resting) = 6° ± 8, mean slope (grazing) = 15° ± 11, mean slope (camping) = 27° ± 9, mean slope (overall) = 18° ± 13, mean slope (available) =23° ± 14. Differences between activities are evident.

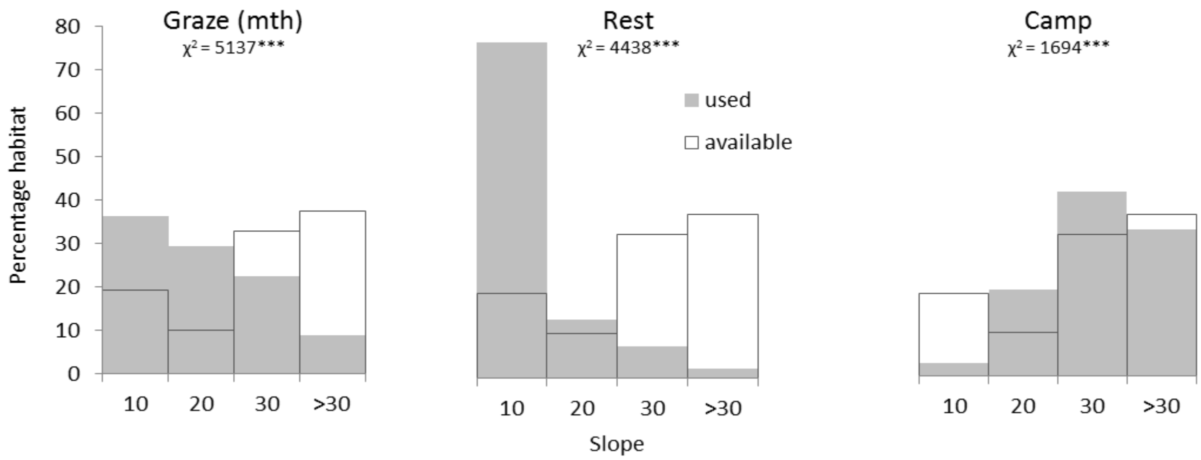


Figure 25. Slope used (grey bars) and available (white bars) by activity, at the monthly scale

Over the 30 days, Merino ewes used similar habitat in relation to distance to water to the weekly dataset; mean DW (resting) = 73 ± 62 m, mean DW (grazing) = 108 ±90 m, mean DW (camping) = 154 ± 116 m, mean DW (overall) =124 m ± 117, mean DW (available) = 183 m ± 189. There were significant differences in overall DW use (overall χ^2 = 1467 ***, df =3) and by activity (Figure 26).

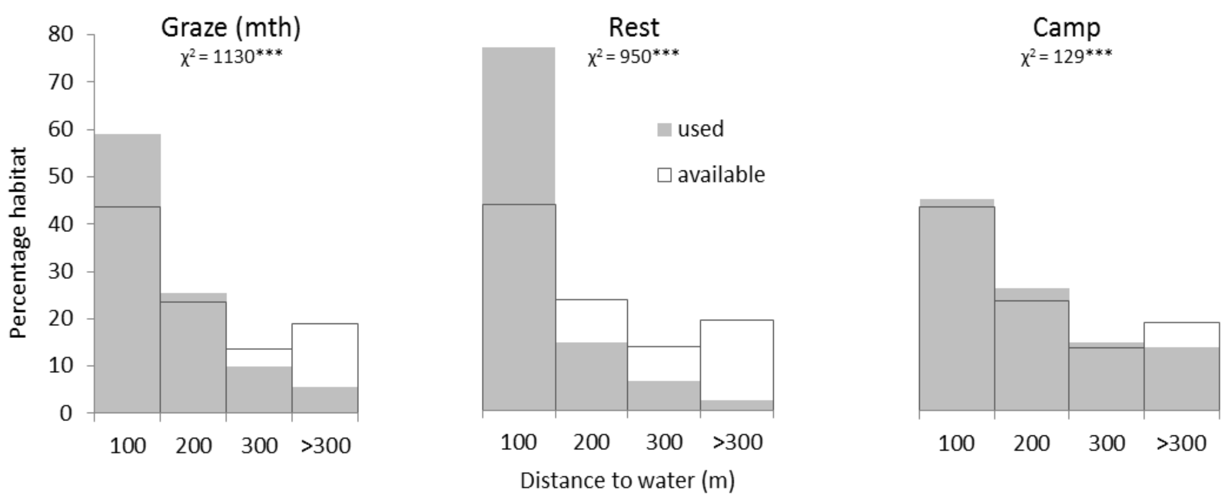


Figure 26. Distance to water used (grey bars) and available (white bars) by activity, at the monthly scale

Aspect use was similar to the weekly data with sheep spending 57% of their resting time on flat land (overall χ^2 = 2319 ***, df = 8). Sheep spent 29% of grazing time on east-facing land and 23% on flat land, while they spent 45% of their night times on east-facing land (Figure 27). Over the month, they did utilise south-west, west and north-west a little more than during the first week.

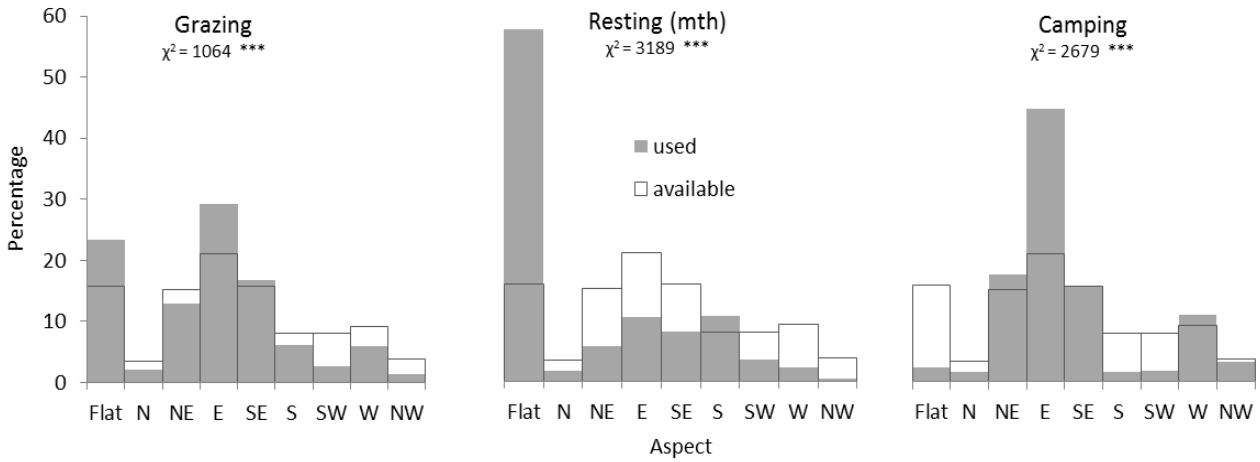


Figure 27. Aspect used (grey bars) and available (white bars) by activity, at the monthly scale

Vegetation type used differed markedly between activities, showing strong preferences for short tussock grassland for grazing, riverbed and short tussock grassland for resting and tall tussock grassland and native mix for night camping (overall χ^2 = 4840 ***, df = 9, Figure 28).

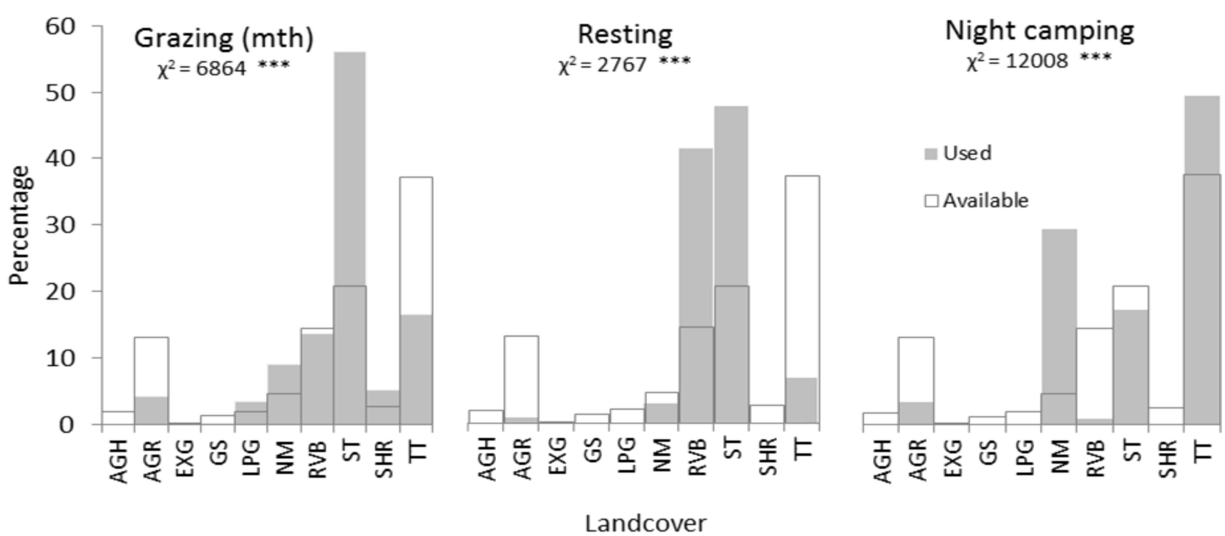


Figure 28. Landcover used (grey bars) and available (white bars) by activity, at the monthly scale

Habitat niche for both weekly and monthly data

The habitat used for both datasets have similar attributes. Both show a strong selection for different habitats between activities. For grazing, sheep show a show a strong selection for flat and gentle slopes, NE aspects, lower altitudes, habitat close to water and short tussock grassland, over both weekly and monthly periods. Resting sites occurred mainly on the riverbed or flat areas of short tussock grassland over both periods. Tall tussock grassland was distinctly avoided both times. Night camping occurred at higher altitudes on steeper slopes throughout the study period. Minor differences that appear in the monthly dataset are the use of slightly lower altitudes and the inclusion of west-facing land, chiefly driven by the two sheep crossing the river. Overall, the monthly dataset showed that sheep used a narrower niche and less tolerance than the weekly dataset.

Design II analysis, analysing individual sheep in the study area

Sheep are gregarious animals that usually mob together in large groups. However, some sheep displayed individual habitat selection. Sheep 3 began the study period on the Twin Basins, but within three days crossed the Cass River and spent the remaining time on the true left bank, on Crown Land. Sheep 9 was also an explorer, beginning on Twin Basins Block but later moving south and moved unexpectedly through a rocky narrow gap in the river. She kept going fast until she reached the fence across the river then spent the remaining time on Tin Hut Block. Sheep 11 began in Top Block with the main mob but crossed the Cass River much later (31 March) to spend the remaining time on Crown Land on the other side of the river.

By examining the following ordination diagrams, it is clear that there were four groups of sheep: sheep 6, 11, 13, 14, 15 and 16 spent the week in more or less the same large mob on Top Block. Sheep 3 was independent, while sheep 2, 4 and 5 were part of a group that ventured as far south as the narrow gap on Twin Basins Block. Sheep 8, 9 and 10 explored further south on Tin Hut block, although 8 and 10 were in a different group to sheep 9. In the diagrams, the centre of the axes represents the mean of the habitat variables. For all these diagrams, axis 1 represents changes in altitude and slope, while axis 2 represents changes in distance to water. The axes run at angles to horizontal.

In the grazing weekly dataset (Figure 29), group selection is evident again; the group on Top Block graze the flattest, lowest altitude land, while the Twin Basin group (2, 4, 5) graze slightly above the mean altitude. The Tin Hut group (8, 9, 10) graze land further from water. Over the month, individual differences weaken. A strong preference for grazing on gently-sloping lower altitude land close to water is shown by all sheep in the monthly dataset.

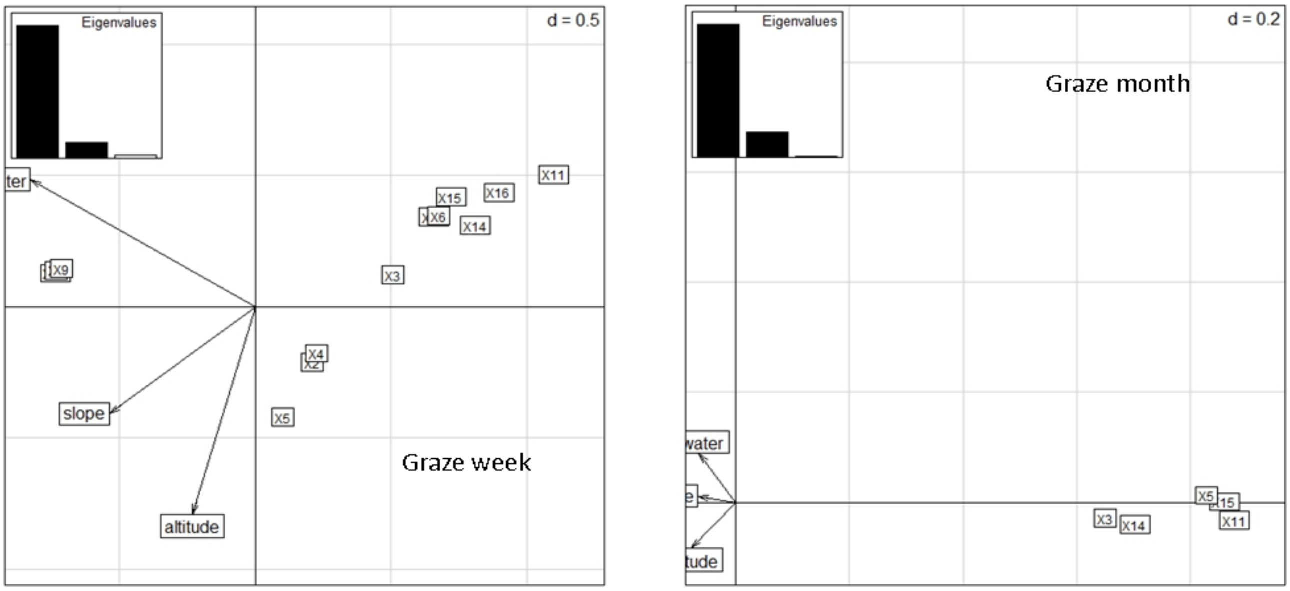


Figure 29. Ordination of Glenmore sheep for the grazing period depicting individual habitat use for weekly data (left) and monthly data (right). Eigenvalues display the importance of the first axis (altitude and slope).

The weekly dataset of resting (Figure 30) clearly shows group selection, where the mob in Top Block is grouped together at the lowest altitudes, lowest slopes and closest to water (the riverbed). The group on Twin Basins (2,4,& 5) occupy habitat closer to the mean, while the Tin Hut mob rest further from water. Sheep 3 appears independent in its own space. In the monthly dataset, sheep 9 has moved to lower altitudes and further from water. Sheep 11, 14 and 15, of the large mob on Top Block, occupied the flat riverbed more than the others. Sheep 3 and 5 occupy different ecological space than the others.

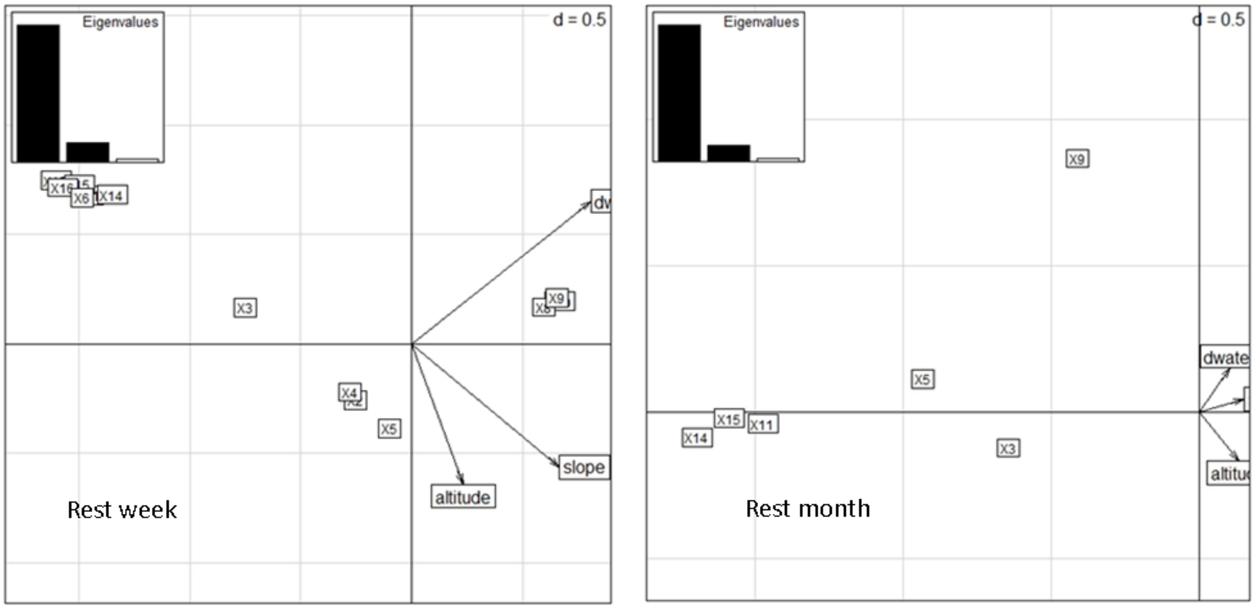


Figure 30. Ordination of Glenmore sheep for the resting period, depicting individual habitat use for weekly data (left) and monthly data (right). Eigenvalues display the importance of the first axis (altitude and slope).

The weekly dataset for night camping depicts higher individual selection (Figure 31), where sheep 8, 9 and10 camped further from water than the mean, sheep 3 has similar selection to sheep 11 and 13, while sheep 5 chooses the higher slopes and altitudes. The monthly dataset retains some individuality, where sheep 9 camps furthest from water and sheep 3 camps on the lowest slopes and lowest altitude.

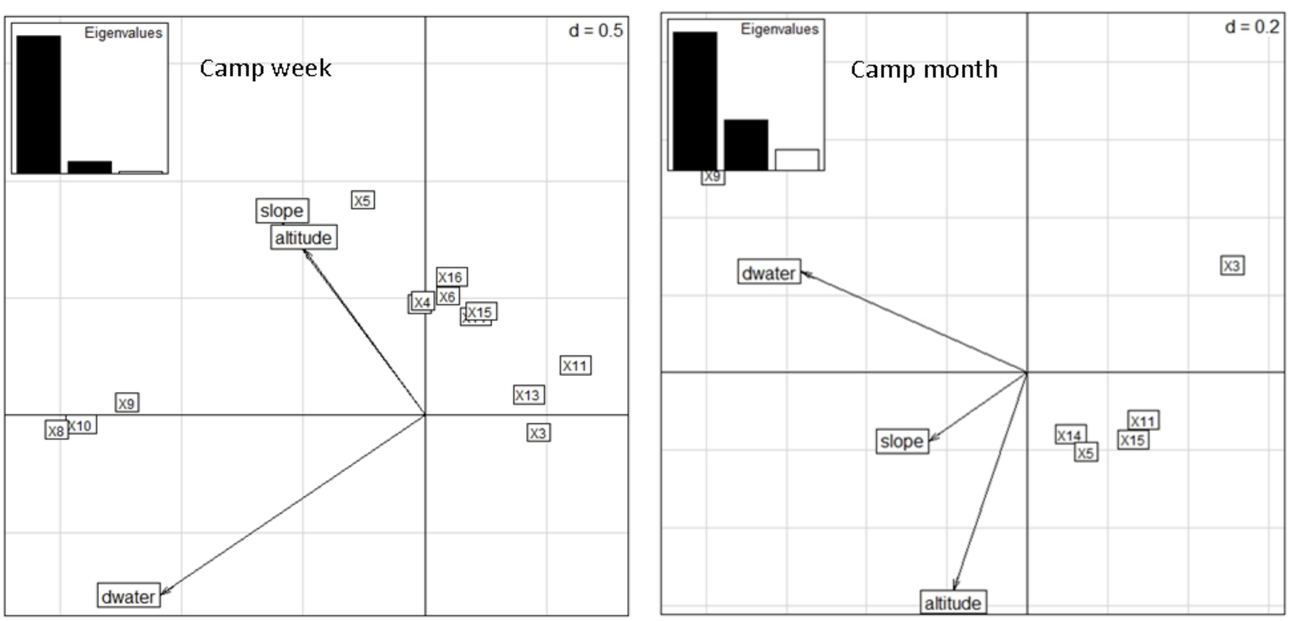


Figure 31. Ordination of Glenmore sheep for night camping, depicting individual habitat use for weekly data (left) and monthly data (right). Eigenvalues display the importance of the first axis (altitude and slope).

Intensively used locations by activity

Some night camping locations were isolated (used only once) while others (popular) were returned to on more than two occasions. Sheep used, on average, 8 popular night camps each, over the study period, ranging from 5 to 15 camps per sheep. The study area contained about 28 popular night camps overall, excluding isolated ones. Popular camps were used between one third and nearly half of the time. One camp was used 20 times in 43 nights (sheep 14). However, camp sites were not necessarily used consecutively. On average sheep spent about 30% of their time using the same camp on consecutive nights. See Appendix D for detailed tables.

Grazing sites also showed some favoured sites and some isolated sites. The most popular grazing site was the area containing the big fan, flats and island just north of Memorial Hut. Sheep on Top Block used this area about 90% of the time. Other sites include the main spur, the area north of the big fan and the hummocks. On the other parts of the study area, popular grazing sites were scattered alongside the riverbed on the lower slopes in short tussock grassland. Grazing sites were more varied on Crown Land, Twin Basins and Tin Hut Block.

Resting sites were predominantly along the riverbed all the way from north to south of the study area, however, on Top Block, the flats, island and surrounding riverbed were distinctively used the most. An example of areas of intensive use for one sheep is shown in Figure 32. Sheep 15 was representative of about 250 sheep, the largest mob in the study area.

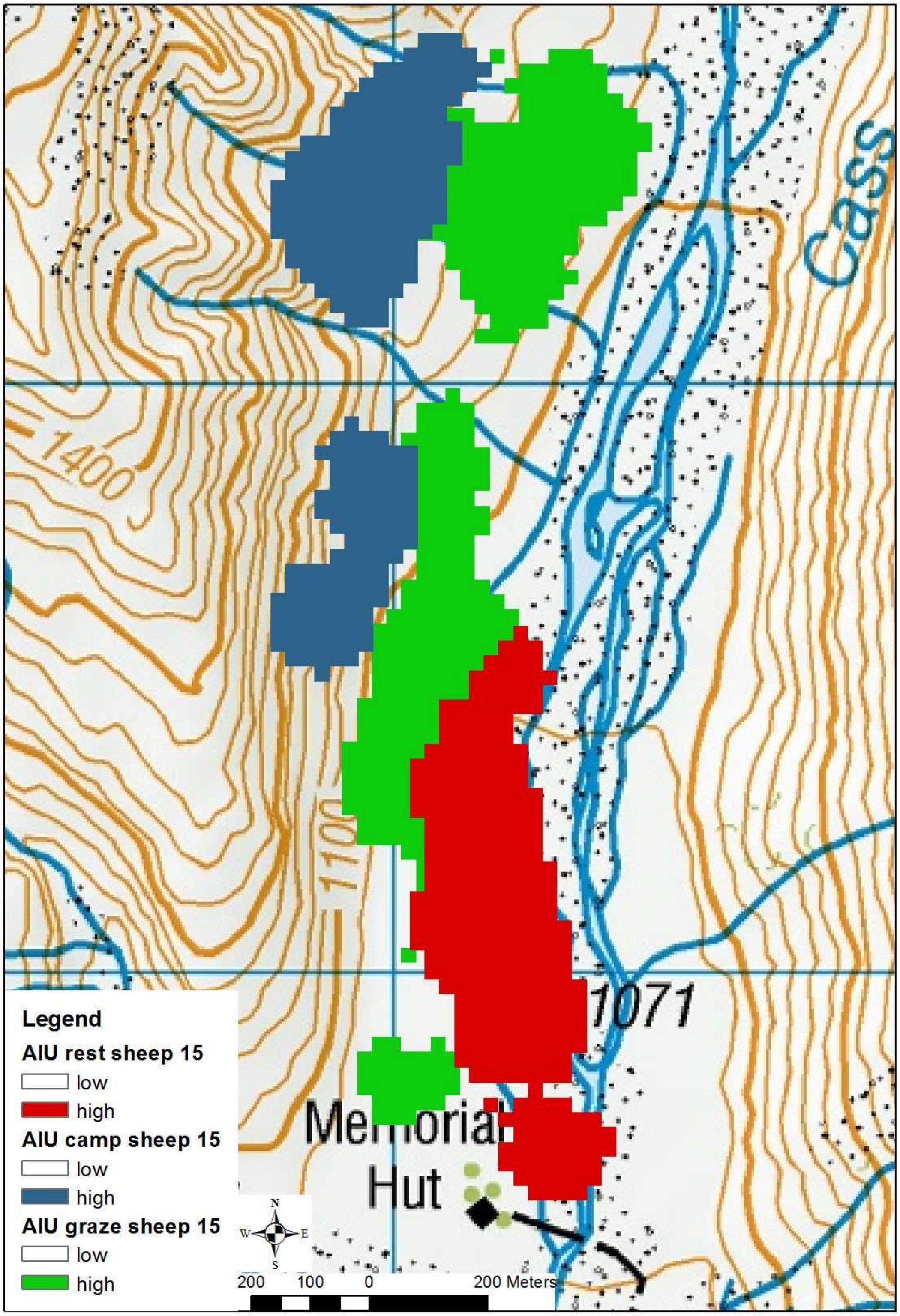


Figure 32. Areas of intensive use for sheep 15, for resting (red), grazing (green) and night camping (blue).

Home ranges and daily distances travelled

Home ranges differed greatly between sheep partly because of the length of time they were monitored. Thus weekly home ranges were calculated for 13 sheep and monthly home ranges were calculated for 6 sheep (Table 4). Notably, the sheep on Top Block have smaller home ranges. Daily distances travelled averaged 5.3 km ± 1.3, ranging from 1.9 to 10 km. Sheep varied in their daily travel, with sheep 3 being the most active, averaging 6 km a day.

Table 4. Home ranges of each sheep for both weekly and monthly data

Sheep	Study days	Home range (ha)		Blocks
		Week	month	
3	47	281	301	Twin & Left bank
9	30	278	303	Twin & Tin
10	7	259	-	Twin & Tin
8	10	227	-	Twin & Tin
4	25	210	-	Twin
5	37	208	241	Twin
11	34	174	278	Top & Left bank
2	9	160	-	Twin
14	43	154	148	Top
6	14	124	-	Top
15	47	116	147	Top
16	7	108	-	Top
13	7	89	-	Top
1	5	-	-	Top
7	4	-	-	Twin

Discussion

The major factor influencing habitat use was daily activity which showed strong relationships with changes in slope use, altitudinal use, aspect use, distance to water and vegetation type. Although sheep showed individuality or group behaviour in their habitat selection, they all displayed the same patterns in daily activities. Daily activity patterns have been documented in other studies (Harris & O'Connor 1980; Champion et al. 1994; Gibb 2007; Mysterud et al. 2007; Pérez-Barbería et al. 2007), but vary at the finer scale. Daily activity patterns are primarily governed by light and the need to optimise their foraging time. Optimal foraging theory (Krebs 1972) states that animals must forage efficiently to maximise their energy intake. Therefore, the daily activity budget for ruminants such as sheep is dominated by the grazing and ruminating cycle during daylight hours. The daily activity budget of all the sheep did show similar patterns; behaviour synchronisation was evident in Soay sheep (Pérez-Barbería et al. 2007). Sheep grazed on average for about 10 hours per day, which agrees with Arnold's (1984) observation but is slightly higher (41%) than with the Soay sheep at 36% (Pérez-Barbería et al. 2007). Therefore, the need for on the ground observations are vital to understanding sheep habitat use, as merely collecting remote data can lead to misinterpretations. Sometimes the sheep grazed intensely, moving very slowly, while other times they moved quite fast and were frequently observed running (mostly the ones at the back of the mob trying to catch up).

The overall habitat niche of the 16 Merino ewes in the study area was not unexpected. About 50% of daylight hours were spent in short tussock grasslands, with the remainder on the riverbed and on the lower reaches of tall tussock grassland. The popularity of the area just north of Memorial Hut, the flats, hummocks, island and lower parts of the fan meant that the largest mob spent their daytimes within a140 hectare space. Sheep on a high altitude summer grazing block are limited by quality forage. As sheep are an alien species in the New Zealand landscape, they have to forage among unfamiliar indigenous plants. So, when they find large patches of familiar introduced grasses and herbs, it is no surprise that they choose to stay in these patches. The riverbed and surrounding short tussock grassland were popular for the daytime resting activity, no matter which part of the study area the different sheep occupied. Night camping was definitely on higher ground, on slopes above the riverbed for all sheep for almost all nights. Night camping on higher altitude land was also noted by Taylor and Hedges (1984). It is important to know which areas are utilised the most so that vegetation changes can be monitored closely for signs of deterioration. It is also important to know the location of popular night camps, for the same reason, as sheep density may be higher on night camps, with a higher concentration of faeces, which may alter community composition (Betteridge 2010).

The grazing habitat niche of the sheep was short tussock grassland at lower altitude, on gentle slopes and fairly close to water. The night camping habitat niche was tall tussock grassland or native mix at higher altitude (average 100 metres above the riverbed) on steep slopes. The resting habitat niche was on the riverbed, islands or flat areas of short tussock grassland. The ewes may have returned to the same area because of higher quality forage (Krebs 1977) and familiarity (Hewitson et al. 2005). It is worth noting here, that altitude and vegetation type are somewhat correlated, as tall tussock and native mix were at higher altitude and short tussock grassland at the lower altitudes. To some extent, altitude and slope are also correlated, (0.5) because of the U-shaped nature of the valley.

The night camping niche of the sheep was on higher ground. Higher altitudes and steeper slopes are warmer at night in U-shaped valleys, due to the well-known cold air drainage effect at night. Sheep may also be more alert to predators at night higher up through smell as well as by sound. Admittedly, limited flatter land at higher altitude may confound these findings. On the other hand, it may be vegetation type that drives sheep to prefer these habitats at night as they provide better shelter and protection. Native mix and tall tussock grasslands have a more complex structure than the short tussock grasslands, so may provide better protection from the wind and cold. It was surprising that the shrubland areas were under-utilised for night camping. Other studies found that sheep camp at higher altitudes even when the changes are small (Taylor et al. 1984). The frequent change in night camp location remains a mystery. Maybe they choose various camps to foil perceived predators as build-up of faecal evidence would be obvious. Taylor and Hedges (1984) also observed several night camps, but no other studies mention this. They also noted that most night camps were on north-east facing land, presumably to catch the early morning sun, but the night camps on Glenmore were on a variety of aspects. Note that night camping is not restricted to resting; sheep do include short bouts of grazing (Pérez-Barbería et al. 2007).

Overall, sheep showed a preference for altitudes between 1100 and 1200 m a.s.l., distinctly avoiding the highest altitudes. If the study area had contained even higher altitudes, this avoidance would be even more obvious. As with many animal habitat use studies, the area delineated to the study has no finite borders. Sheep may have preferred these altitudes and gentler slopes because this was where the best forage was. Incidentally, sheep did cross scree slopes, contrary to expectation.

Overall, slope use was interesting. As expected, the sheep avoided the steepest slopes but utilised the gentler slopes more than what was available, although they utilised flat land similar to what was available. Slopes over 45 degrees would be uncomfortable and have little vegetation, so would be of little use to the sheep, although they would be ideal for tahr. As slope was somewhat correlated with altitude in the Glenmore study area, it was difficult to tease apart the strength of the relationships of sheep habitat use.

Sheep were expected to stay reasonably close to water and did spend much of their time within 200 metres of a water source. This coincided with the flat riverbed and short tussock grassland. The study area contained many water sources and so sheep were unlikely to stray far from water. The furthest places from water were mountain tops; not really sheep habitat. Unexpectedly, sheep did cross the river, as sheep do not like crossing water of their own free will. However, it is important to note that the river was low this year due to a lack of rainfall/snowmelt in the area.

The use of vegetation type was interesting. Tall tussock grasslands were used much less than expected while sheep showed a strong preference for short tussock grassland, especially for grazing. Short tussock grasslands encompass much of the introduced grasses and herbs. The preference for tall tussocks and native mix for night camping makes sense: they provide some protection. Not surprisingly, they did not use the herbfield or the grey scrub, both of which contained dense herbs or shrubs. This makes sense as sheep prefer introduced grasses for grazing (Harris & O'Connor 1980; La Morgia & Bassano 2009). Use of the riverbed for the resting period is interesting as the stones would be warm by midday for sitting on, but surely would also be uncomfortable.

Aspect was a difficult variable to quantify, as most habitat available was either east or west facing. Sheep showed some preference for north-east-facing land as well as flat land but used south-facing land very little, despite much of it being of gentle slope in short tussock grassland. Use of aspect may not be conclusive as there was not an even amount of variation available. Ideally, to test aspect use, a study area containing a conical hill would be best. South-facing land holds more moisture, so should be better for grazing.

Sheep clearly displayed individuality in their choice of habitat. Sheep 3 showed initiative in crossing the river to occupy Crown Land. Sheep 11 also crossed the river but joined them later on in the month, while sheep 9 was the first to explore south towards Tin Hut. It is interesting to note that even though eight sheep each started on either Top Block or Twin Basins Block, they generally followed similar patterns but were not always a tight mob. The sheep on Top Block were part of a large mob but were well spread out. Overall, they stayed in the same area, maybe because they felt more secure in a large mob and and/or the forage quality was better. The Top Block mob often spread out and split into two or more groups and then remerged later. Splitting into sub-groups may depend on breed, sociability and individual boldness (Arnold et al. 1981; Michelena et al. 2009).

The Twin Basins mob (sheep 2, 3, 4, 5, 7, 8, 9 and 10) left the basins area within three days. Did they leave because they were disturbed or did they leave because they had eaten all the most palatable plants? There was low abundance of exotic species in the basins area, so the tall tussock, *Chionochoa rigida*, would have been the major food item. A change in phenology is also likely to have been the driver of altitudinal change as La Morgia (2009) found. Phenological changes in alpine plants mean that sheep can move up the altitudinal gradient as plants recover from winter and put on new growth (Mysterud et al. 2007). The early stages of plant growth are known to be more nutritional (Van der Wal et al. 2000). Clearly, they moved down slope towards the riverbed and the lower slopes of short tussock grassland. Sheep 4 and 5 only ventured as far as the narrow gap, despite them being monitored for over a month. Sheep 3 quickly decided that the grass was greener on the other side of the river, while sheep 9 was another explorer, quickly heading south to Tin Hut. A fence right across the Cass River stopped her moving further south, so she stayed to occupy the slopes between the narrow gap and Tin Hut. Sheep 8 and 10 also followed the same route as sheep 9 but at different times.

Home ranges were calculated out of curiosity, as there is little information on home ranges for domestic sheep. It is interesting to note that the largest home ranges were on the Twin Basins Block and Tin Hut Block. This might indicate that Top Block (at least the area containing the popular spots) has better quality forage, and/or provides all the needs of the sheep over the summer period. The home ranges on Top Block were about half that of home ranges on Twin Basins and Tin Hut Blocks. This complements the optimal foraging theory where it is expected that home ranges on better quality pasture would be smaller than on poorer quality pasture. Therefore, sheep in the less than optimal areas would need to forage wider.

Apparently, animal density appears to have little effect on overall home range size at this scale (Kausrud et al. 2006). Daily movements were very varied; maybe they reflect how much searching for good quality forage is needed.

As for high country sheep diet, the species eaten generally agree with other studies (Harris & O'Connor 1980). The exotic grasses *Anthoxanthum odoratum* and *Agrostis capillaris* were probably the main species eaten. *Poa cita* and *Chionochloa rubra* showed the most substantial evidence of being chewed. Although *Chionochloa rigida* showed clear evidence of being chewed, sheep did not stay long in the tall tussock grassland on Twin Basins Block, despite there being plenty of tussocks available. The fact that there was plenty of evidence to show that old and young *Poa cita* were well chewed, this contrasts with earlier studies (Cockayne 1919b; Croker 1958; Connor et al. 1970; Lord 1990). Grazing selection changes when preferred items are in short supply (Augustine & McNaughton 1998). This was evident in the patch where *C. rubra* was more abundant than *P. cita*. Tall tussocks (*Chionochloa* spp.) were also well chewed, where *C. rubra* appeared to be most popular, possibly because it was only found near the riverbed. Connor et al (1970) thought *Chionochloa* spp. were generally unpalatable, but there is plenty of evidence here that they were eaten in abundance and close to the ground. Herbivores affect plant community composition through grazing, trampling and nutrient cycling. Plants that offer resistance to grazing, such as through short stature, unpalatability, chemical or physical defences or tolerance through rapid regrowth, will survive better than those with little resistance (Augustine & McNaughton 1998).

Conclusion

Sheep definitely showed daily activity patterns of night camping, grazing and midday resting. Sheep utilised different habitats according to activity. The majority of Merino ewes spent the greater part of the day at the lowest altitudes available, while there was ample evidence that they select higher elevations on steeper slopes for night camping. Merino ewes showed an overwhelming selection for short tussock grassland for grazing, tall tussock grassland and native mix for night camping and short tussock grassland and the riverbed for resting. Habitat close to water was preferred in the daytime while they moved away from water at night. Night camping occurred at different locations throughout the study period but some camps were used on several occasions. Sheep displayed individuality in their choice of habitat use in terms of both vegetation type and altitudinal use. Merino ewes do cross rivers, streams and scree slopes. Observations showed that small groups of Merino ewes occupied different territory than the main mobs, where patches of exotic grass and some shrubland were utilised. Merino ewes were also observed to form sub-groups, splitting off from the main mob and remerging some time later.

Chapter 5 Influence of weather

Introduction

The climate in the high country of the South Island of New Zealand typically has hot dry summers and cold moist winters with about 3 months of deep snow above 1000 m a.s.l. Mean annual air temperature in the study area ranges from 6.1°C on the upper slopes to about 7.9°C on the riverbed (LENZ 2011). Mean March 2012 temperature was 8.9°C. Mean annual solar radiation is estimated to be about 13.8 MJ m^2 day ((LENZ 2011). Mean annual rainfall is estimated to be about 3000 mm at the highest peaks declining to about 2000 mm at Memorial Hut. Lake Tekapo Weather Station (37 km SSE from the study area) records mean annual rainfall as 515 mm and mean annual air temperature as 8.8°C (NIWA, 2012). Mt Cook Weather Station (22 km WSW from the study area) records mean annual rainfall as 4305 mm and mean annual air temperature as 8.8°C (NIWA 2012). Both these NIWA stations are at altitude ~750 m a.s.l.

When the ewes are grazed on the high country summer blocks, between February and April, the weather is highly variable, when air temperatures can range from – 6°C to 27°C. Rainfall at this time is generally low and although prolonged heavy storms are unlikely, rainfall events can be intense. The Southern Alps provide an orographic barrier to the moist westerlies, where high rainfall (up to 6000 mm per year) falls on the western slopes of the Alps. The study area is located just east of the Alps in the rain shadow. Mountain winds are notoriously strong, sometimes as cold southerlies and sometimes as hot dry Norwesters.

Weather variables can affect animal behaviour. Extremes of air temperature, snow, rain and wind compels animals to seek shade and shelter. Heat stress, wind chill and soggy coats can make the sheep uncomfortable. Altitudinal use of habitat is a recognised response to one or more weather variables (Mysterud et al. 2007). Different habitat types present a variety of vegetation composition which in turn offer different types of shade and shelter for animals. In this part of the study, the response of sheep habitat use is analysed in relation to different types of weather.

Location of Weather Stations

Weather stations were set up at two locations on the study site and one reference station on a hill near Lake Murray overlooking Lake Tekapo. A summary of the attributes of the three weather stations is given in Table 5. The Hill weather station was situated inside an exclosure plot on a broad spur between two waterfalls, above a tributary of Ailsa Stream. Immediately to the north is a steep-sided valley and the weather station is surrounded by large mountains on three sides, to the south, west and north. To the northeast is a gentle slope leading down the hillside. The vegetation here is low stature tall tussock grassland with herbs. The weather station on the riverbed site is situated alongside Ailsa Stream, on open ground with a small hummocky area immediately to the north and a large spur to the north-west. The vegetation surrounding the weather station is short tussock grassland. The station at Lake Murray is on a small hill overlooking Lake Tekapo.

Table 5. Attributes of each weather station on Glenmore

	Hill site	Riverbed site	Lake Murray
Altitude (masl)	1380	1070	720
Aspect/Slope	Flat	Flat	Flat
Habitat type	Tall tussock/herbs	Short tussock	Exotic grass

Materials and Methods

Weather variables recorded at 30 minute intervals were: average air temperature and relative humidity at one metre height, average and maximum wind speed and average wind direction at 1.7 m height and average solar radiation at 1.6 m height. Weather variables recorded at hourly intervals were: average soil temperature at 10 cm depth, average ground temperature (tucked into a tussock) and total rainfall. Equipment used is summarised in Table 6. Campbell Scientific CR10X data loggers were used to store the data.

Table 6. Summary of weather variables measured on Glenmore

Weather variable	Equipment used	Units
Wind direction	Vector 200P wind vanes	degrees
Wind speed	Vector A101M 4 cup anemometer	m/s
Air temperature/Relative Humidity	Vaisala Humitter 50Y	Deg C/%
Rainfall	Tipping bucket raingauge	mm
Soil and ground temperatures	Thermistor probes	Deg C
Solar radiation	LI-COR 200 pyranometer	W m^{-1} s^{-1}

Data Analysis

Weather variables were explored initially for descriptive purposes, to determine patterns in the three locations and to identify adverse weather days. The relationships between weather variables and sheep habitat use were analysed in two sections using each sheep's averaged daily data for each activity separately, in an attempt to avoid temporal autocorrelation. First, because there were only three days of rain, most of which occurred in the latter half of the study period when only 4 collars were still active, rain days were compared with no-rain days, while attempting to keep all other weather variables constant using a simple paired t-test. Second, a linear mixed effects model was used to analyse the effects of weather variables, air temperature and maximum wind speed, on habitat use, where animal ID and day were the random effects and weather variables were the fixed effects, in an attempt to account for pseudo-replication (Gillies et al. 2006; Mysterud et al. 2007). The second analysis was performed for each activity separately on a 30 day dataset using 6 sheep, where each sheep's altitude and movements were averaged out on a daily basis by activity.

Results

Summarising weather conditions during the study period at the hill site (1380 m a.s.l.), there was little rain, air temperatures were mild and there were few windy days. Rainfall of 2.8 mm, 5.6 mm and 15.8 mm fell on 19, 24 March and 10 April, respectively, (Figure 33). Daily average air temperatures ranged from 3°C to 14°C fluctuating throughout the study period (Figure 34). Lowest night time temperatures reached -2°C, while the highest daytime temperature reached 20.5°. In March, average temperature on the riverbed site was 11.3˚C, on the hill site 10.1˚C. Air temperature follows a daily pattern with minimum air temperatures about 06:00 and maximum air temperatures around 15:00. Daily average wind speed also fluctuated, ranging from less than 1 m/s to almost 3 m/s (Figure 35). Hourly average wind speed ranged from 0 to 4.6 m/s. Over the summer months, average wind speed is lowest at night (~1 m/s), picks up in the morning and reaches maximum speed around mid-afternoon (~4 m/s). Wind direction varies daily with the synoptic system but patterns did emerge. On the riverbed, the wind was often NNW overnight (katabatic winds from the large spur) then SSE during the day (up-valley winds). At the hill site, wind direction was often SW overnight (katabatic winds from the mountain) then often easterly during the day (anabatic winds). During the day, wind speed was often higher on the riverbed than on the hill, averaging about 2 m/s.

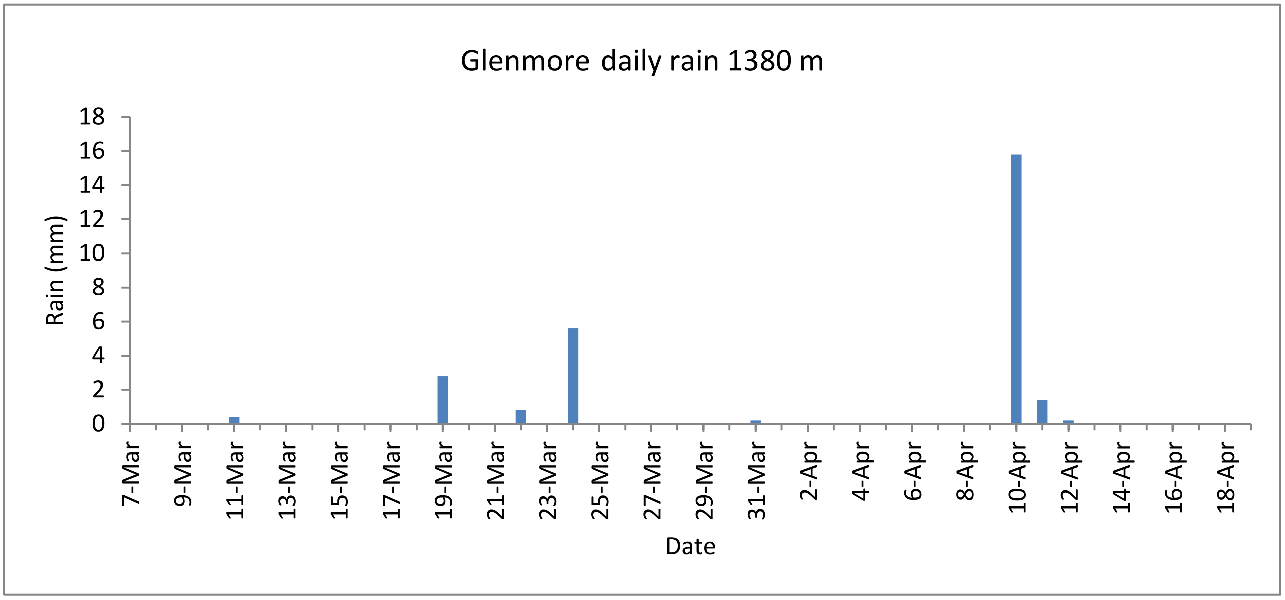


Figure 33. Daily rainfall Glenmore at 1380 m a.s.l. on Twin Basins Block

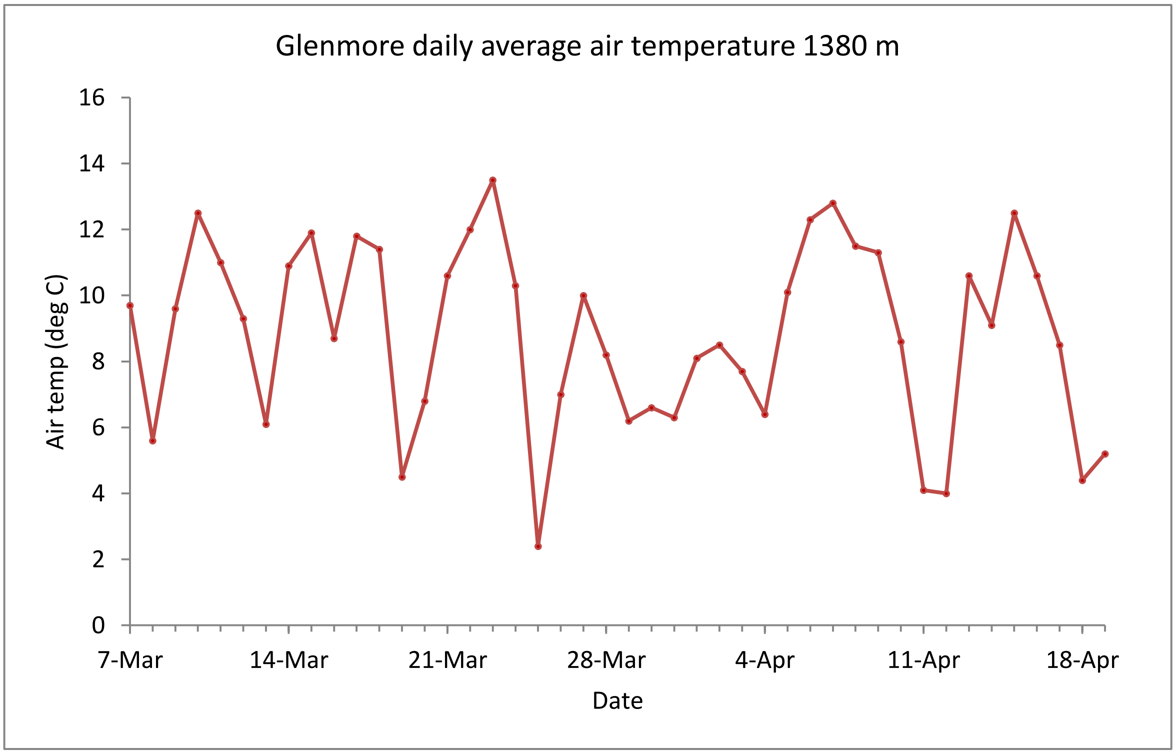


Figure 34. Daily average air temperature Glenmore at 1380 m a.s.l. on Twin Basins Block

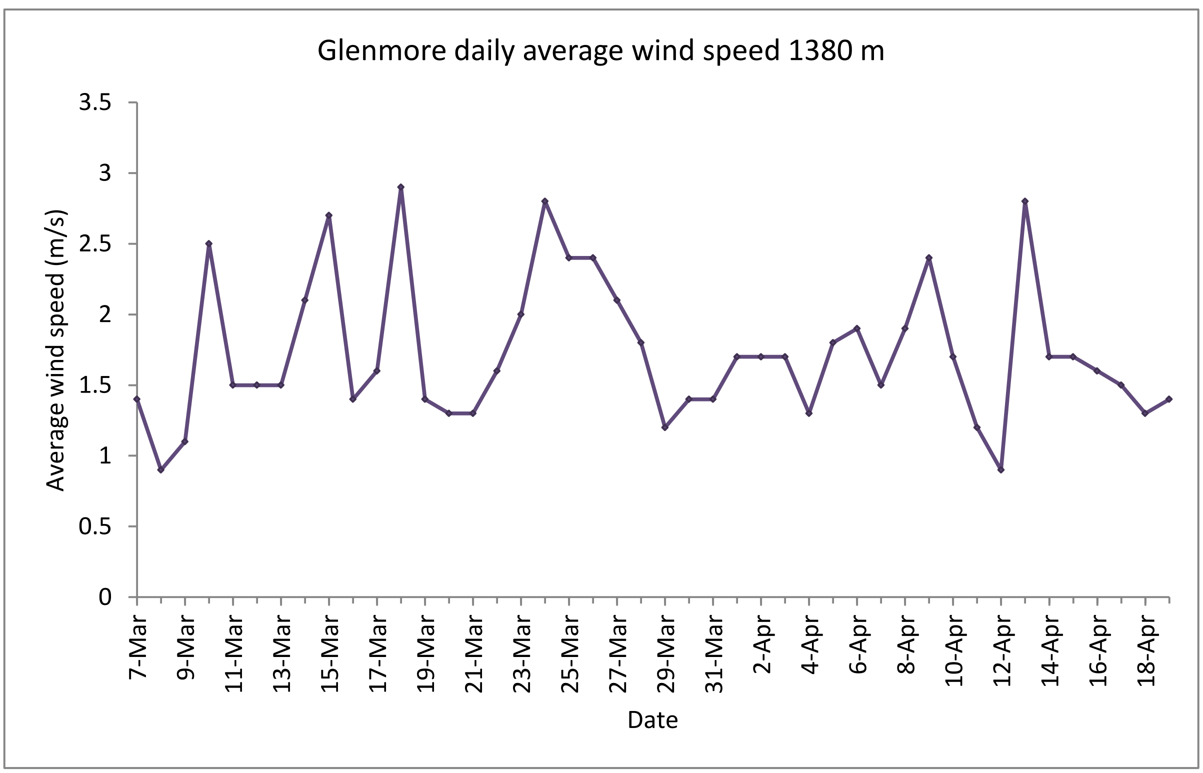


Figure 35. Daily average wind speed Glenmore at 1380 m a.s.l. on Twin Basins Block

Rainfall

Of all the weather variables, rain affected sheep behaviour the most, resulting in less active sheep grazing and resting at higher altitudes but camping at lower altitudes than when not raining (Table 7). By comparing rain days with no-rain days, while keeping air temperature and wind speed similar, differences in habitat use were evident. On rainy days, mean altitude used during the day time was 60 metres higher than on non rainy days. Movement on rain days was about half that of no-rain days, 160 metres per hour as opposed to 240 metres per hour. Sheep also camped at lower altitude during rain. On rainy days sheep preferred tall tussock grassland and native mix during the day and distinctly avoided the riverbed, particularly during the resting period (Figure 36).

Table 7. Influence of weather variables on sheep habitat use by activity (paired t-test)

Activity	Response variable	Explanatory variable	Rain or cool	No rain or warm	Diff (m)	T	P
Graze	Altitude	Rain	1150	1121	31	2.58	0.024
Rest	Altitude	Rain	1167	1074	93	12.03	<0.001
Camp	Altitude	Rain	1163	1201	-38	-2.04	0.048
Graze	Movement	Rain	51	96	-45	-6.35	<0.001
Rest	Movement	Rain	20	52	-35	-8.94	<0.001
Graze	Altitude	Temp	1139	1098	41	5.7	0.001
Rest	Altitude	Temp	1117	1064	53	2.86	0.017
Graze	Movement	Temp	87	104	-17	-2.11	0.044
Rest	Movement	Temp	58	47	11	4.7	0.002

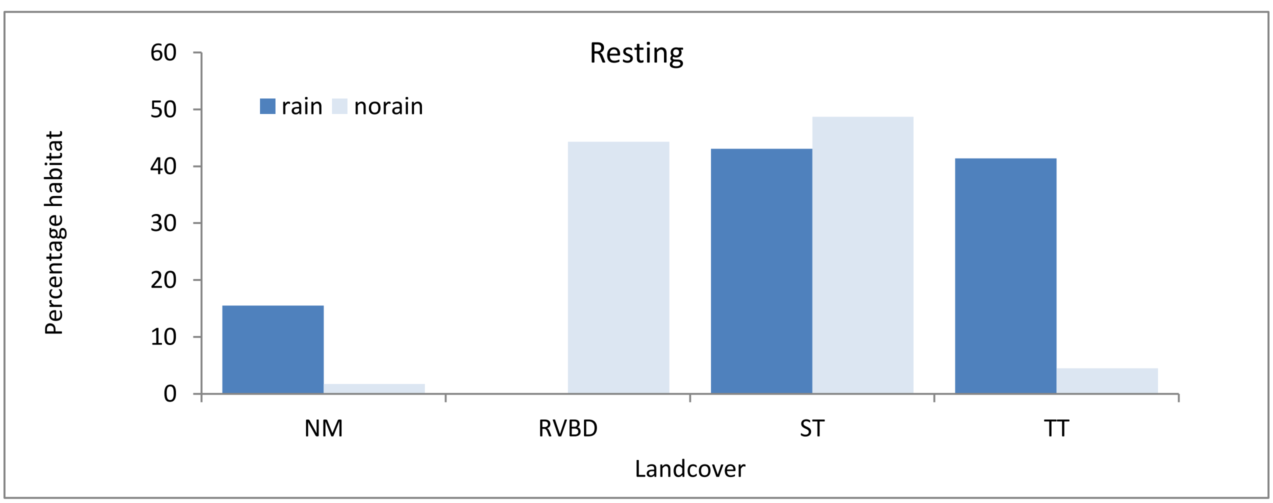


Figure 36. Influence of rain on vegetation type used during resting

Air temperature and wind

There were no clear signs that air temperature had much influence on sheep habitat use, as there was much variation on both warm and cool days using the 30 day dataset. However, using the paired t-test on the balanced dataset, grazing occurred on slightly higher ground on cool days than on warm days (Table 7). Wind appeared to have a relationship with altitudinal use during grazing and resting where sheep used higher ground on windy days (Table 8). During the grazing period only, sheep were also less active on windy days (Table 8). All other relationships were non-existent, mixed or very weak because of much variation.

Table 8. Parameter estimates of the effects of wind using a linear mixed effects model on the 30 day dataset

Activity	Weather variable	Habitat variable	Intercept	Estimate	T	P	df
Rest	wind	altitude	1032	14	3.3	0.003	25
Graze	wind	altitude	1084	11	4.0	<0.001	25
Graze	wind	movement	116	-6	-2.2	0.034	25

Discussion

Rain forced sheep to graze and rest on higher ground but camp at lower altitude than normal. They spent more time in tall tussock grassland and native mix during the day and distinctly avoided the riverbed for resting. They were also much less active during the day, probably huddling together. It is not surprising that rain had the most effect on sheep behaviour, as wet fleece can be uncomfortable, as well as increasing heat loss (Stafford Smith et al. 1985). Rain may not only inhibit visibility for the sheep but also the sound of rain disguises any predator approach, therefore sheep may band together in tight groups to reduce predation risk, as observed by (Rutter 2002). April 10 was the most interesting day as it was cold, wet and windy. Clearly, the large mob stayed together on the fan and moved about very little. Sheep on the other blocks also displayed little activity on rain days and stayed higher up slope all day, avoiding the riverbed. Rain distinctly influenced their choice of vegetation type, where they preferred to stay among vegetation that offered some shelter, rather than coming down to the exposed riverbed.

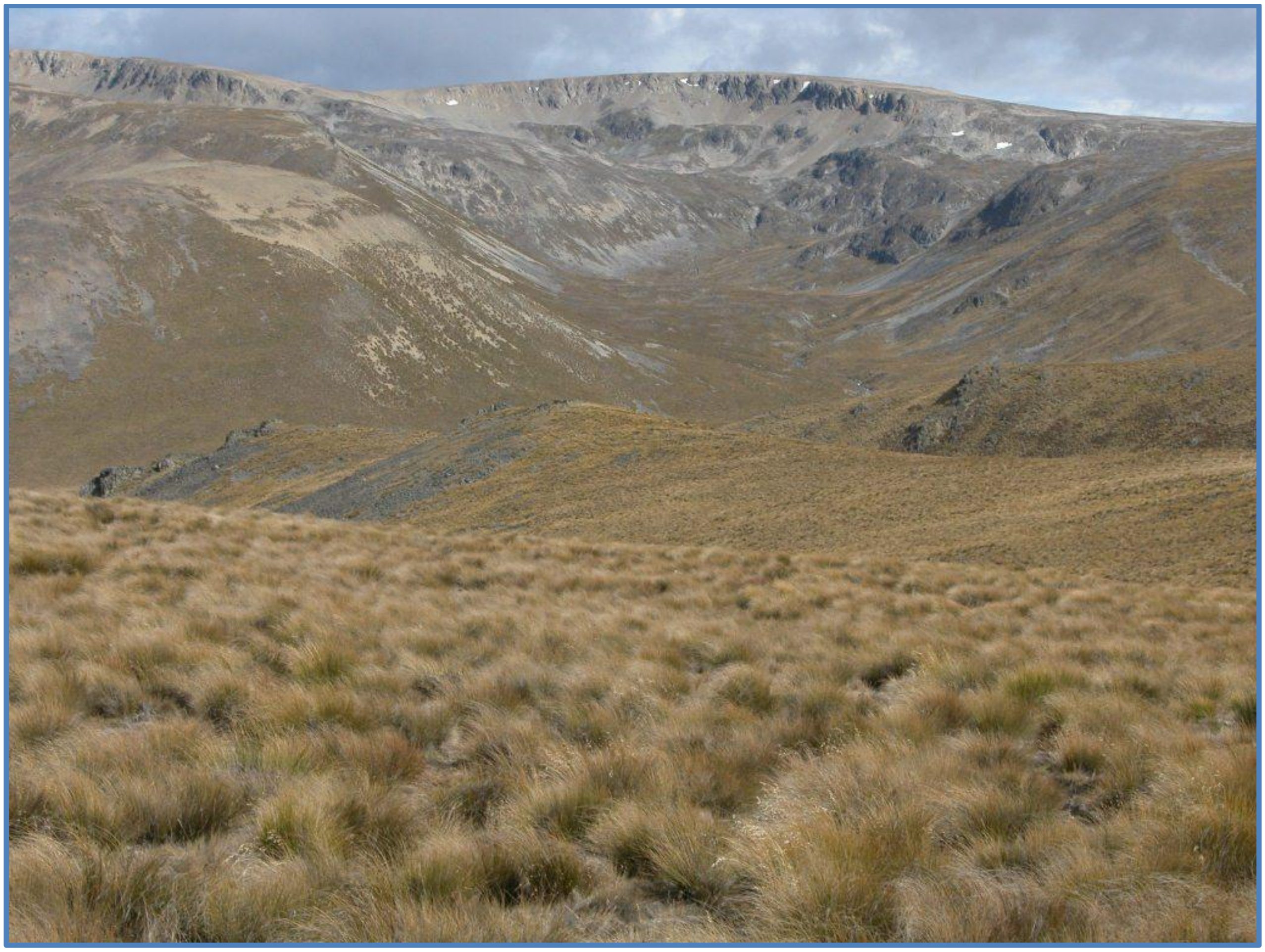
Rain and to a lesser extent, wind, had a profound effect on habitat use for reindeer (Cuyler & Øritsland 2010). While sheep on Glenmore were less active in rainy weather, Powell (1968) found that wind and air temperature, but not rain, influenced movement; on Glenmore, sheep were marginally less active in windy weather during the grazing period. Sheep used marginally higher ground on windy days but these were not cold winds, which could increase body heat loss (Mount 2012). Air temperatures appeared to have no influence on either altitudinal use or movement, as the large mob came down to the riverbed on cool and warm days. Sheep in Norway displayed contrasting evidence, where they used higher altitudes in fine and windy weather but lower altitudes in cloudy cool weather (Mysterud et al. 2007). Other ungulates were also affected by air temperatures. Beier and McCulloch (1990) found that deer activity was highest at moderate air temperatures, but were less active when temperatures were low or high.

Depending on the dataset used, trying to keep the dataset balanced and the type of analysis used can produce different results. Therefore, only the clear relationships were given.

Conclusion

Weather stations on the study site were established to monitor weather variables: temperature, relative humidity, wind, solar radiation and rainfall. This research quantified the effects of weather variables on sheep behaviour, the first in New Zealand. Sheep habitat use is influenced by the weather. Rain had the most influence on habitat use, where, on average, sheep spent the daytimes at higher altitude than normal, and spent the night times at lower altitudes than normal. Sheep preferred to stay in the shelter of the tall tussock grasslands and native mix during rainy days rather than graze down towards the riverbed as usual, which was completely avoided. On rainy days, sheep were much less active; their movements on rainy days were about half that of non-rainy days. Air temperatures had weak mixed effects on sheep habitat use with no clear evidence of a relationship. Windy weather had a small influence on sheep habitat use, when sheep spent the daytimes on slightly higher ground than on calm days. Sheep also moved slightly shorter distances in windy weather. Experimental research on the influence of weather on Merino sheep habitat use could be undertaken over a shorter timescale using observations on a small mob in a more confined area.

Chapter 6 Sheep habitat use on Otematata Station, S. Canterbury



Study area

This study was undertaken on Otematata Station situated southeast of Omarama in South Canterbury, New Zealand (Hawkdun Ecological District, 44.74° S, 169.99° E, c. 800 - 1800 m a.s.l.). Otematata Station lies between the Waitaki Valley in the east and the Hawkdun Range in the west. The landforms were carved by glaciers resulting in cirques, deep wide basins, steep-sided ravines, along with gentle rolling hills. Geology is greywacke sandstone and argillite from the Torlesse Supergroup alongside Haast Schist (GNS Science (N.Z.) & Forsyth 2008). Otematata Station has warm dry summers and cold winters, where the rainfall on the western part of the property is in the region of 1600 mm per year. Average annual temperature is about 4.2 °C, and annual solar radiation is about 14 MJ m^2 s^2 (2009) Land Environments of New Zealand database (LENZ 2011). Soils are similar to the Glenmore soils: Brown. Otematata Station is a 39,370 (26,582) hectare high country sheep station with 20,000 Merino sheep and 500 cattle. In the summer months, the sheep are moved from the lowland blocks to high altitude blocks to allow the pasture to recover. The study area (2,284 ha) is set within the Basins and Wether Range, which is a block located in the southwest of the property, on the Hawkdun Range, adjacent to Crown Land managed by the Department of Conservation. Altitudes in the study area range from 1200 m a.s.l. to 1876 m a.s.l. The Basins and Wether Range contains many flat to low slopes (<20 deg) with broad spurs in an easterly direction (Figure 37).

Landcover type in the block is dominated by tall tussock grasslands (57.5%), alpine gravel and rock (31.5%) and alpine grass and herbfield (9.2%). The lower altitude short tussock grasslands were not present in the Basins and Wether Range. Tall tussock grasslands consisted of the dominant species, *Chionochloa rigida*, with the native grass, *Poa colensoi* being sub-dominant. No surveys were undertaken of the vegetation so habitat types were derived from the Landcover Database available on-line at www.koordinates.com (Figure 38).

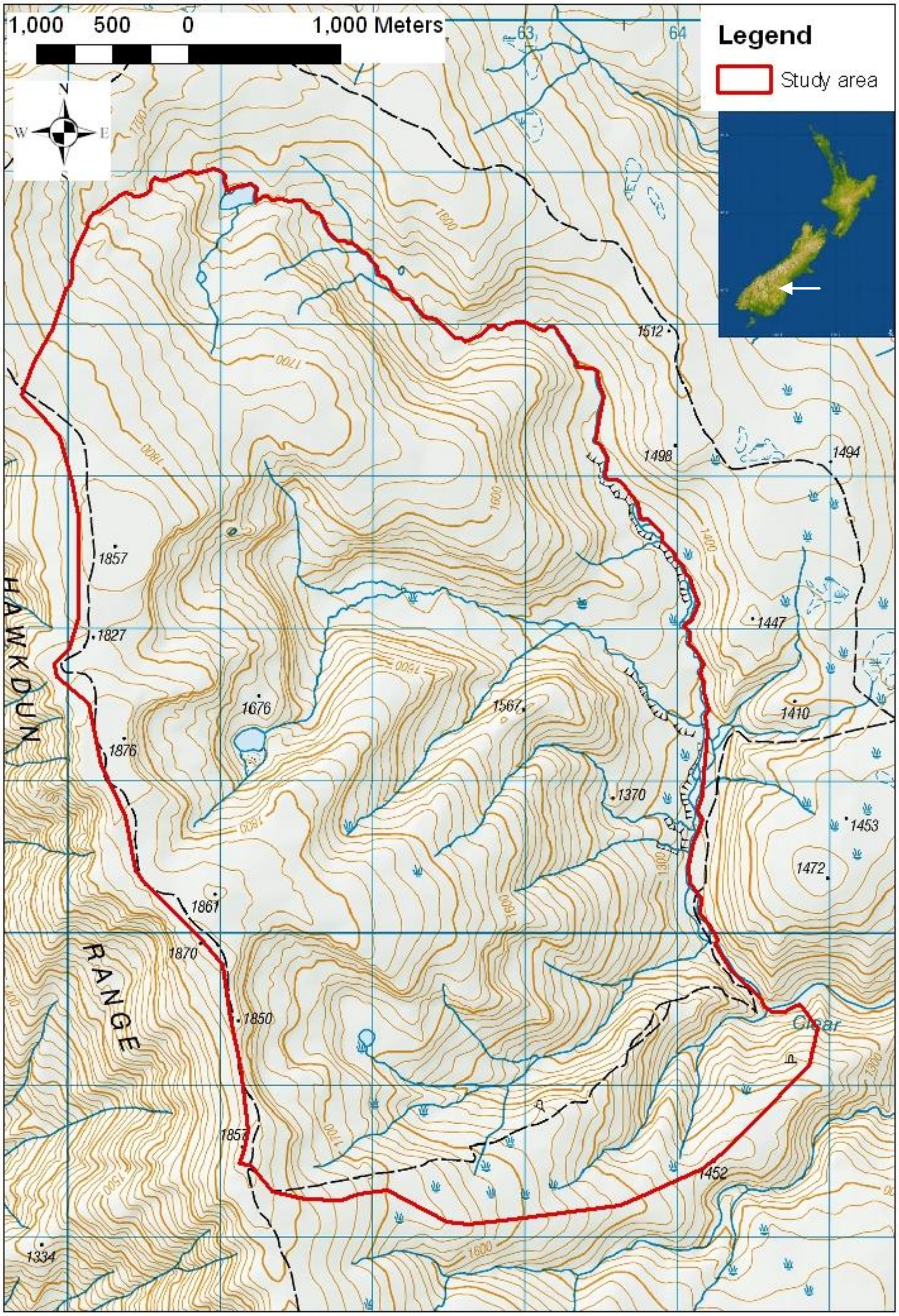


Figure 37. Topographic map of the study area, Otematata

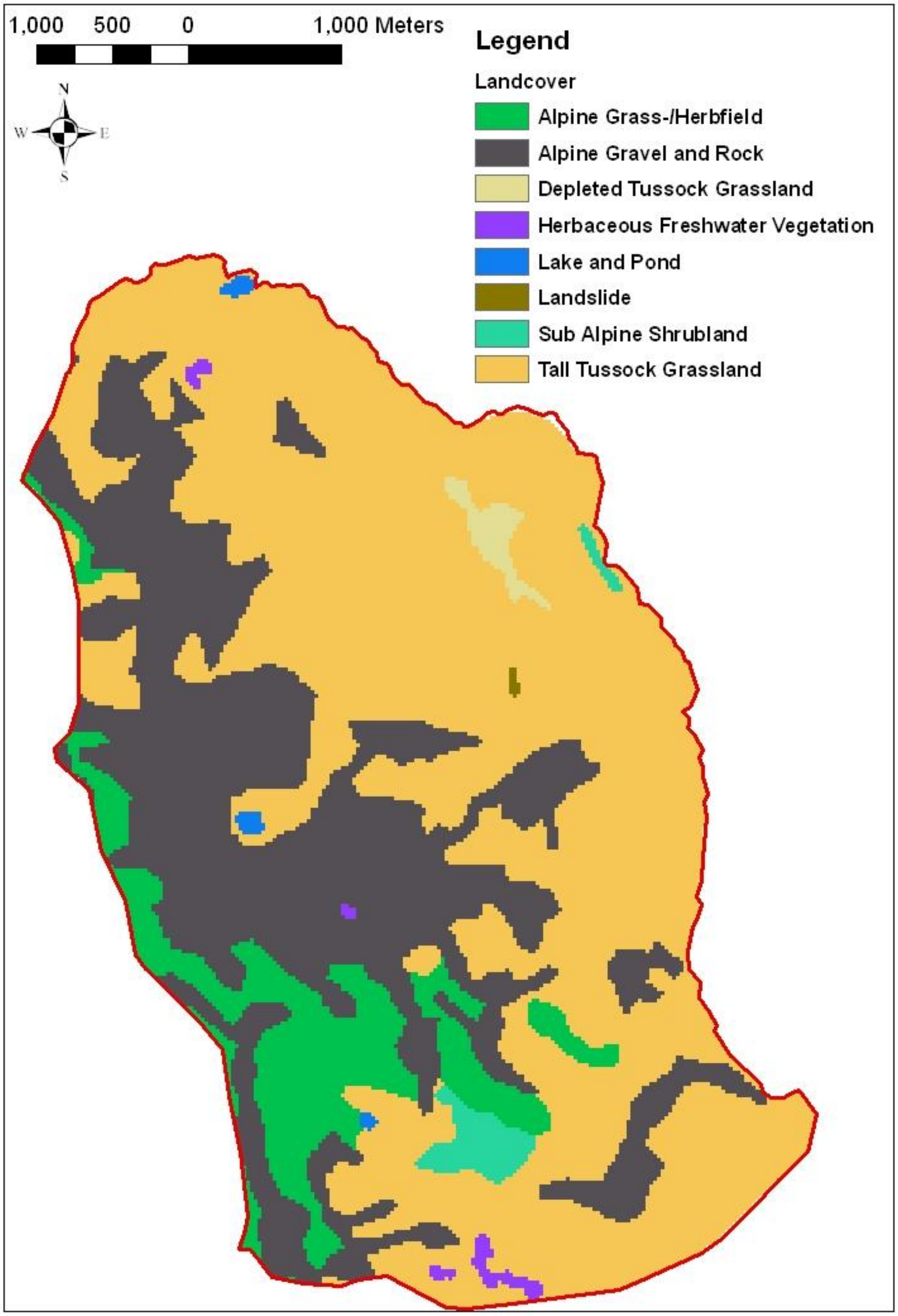


Figure 38. Land cover type Otematata

Materials and Methods

Four merino wethers were fitted with Televilt GPS collars and were released onto the Basins and Wether Range on Otematata Station in the summer of 2005/2006. The main block of interest was the Basins and Wether Range which is a high altitude mountainous area, consisting of mainly tall tussock vegetation and alpine gravel and rock. The block consists of 5,332 hectares. With 5,700 wethers on the block, this equates to a stocking density of approximately 1 sheep per hectare for four months or 0.2 stock units ha^{-1} yr^{-1}. Three of the sheep monitored were confined by Clear Stream, flowing south east, which offered a natural boundary within the block. This sub-block comprised 2,250 hectares. One sheep (no. 2) roamed Crown Land managed by the Department of Conservation to the south of the fence, as it found a gap in the snow-damaged fence. Land available to sheep 2 was 4,344 hectares and it is unknown how many sheep accompanied it, but stocking density is assumed to be very low. A pilot study of the four GPS-collared Merino sheep on Otematata Station (Haddon 2008) was re-analysed with respect to activity.

Sheep location data in table format was re-analysed using ESRI's ArcGIS, Microsoft Excel and R. Tables recorded latitude and longitude in decimal degrees, altitude, date and time. Data was recorded every 20 minutes, for five months but for the purposes of this thesis, only the data from Mar 1st to April 8th was analysed for comparison with the Glenmore data. The data was inspected for extreme outliers, which were removed. Although the data recorded every 20 minutes, due to inaccurate satellite fixes, some data had already been removed.

Home range was initially determined using the minimum convex polygon method in Hawth's Tools but was deemed to be too coarse, so hand-drawn home range polygons were used for a more accurate measurement. Patterns in sheep movements by time of day were analysed using distance travelled in 20 minutes. Sheep locations were explored for patterns in night camping as well as for daytime grazing. All times are recorded in New Zealand Standard Time (NZST). On March 22nd 2006, sunrise was at 06:42 and sunset was at 18:47 (Royal Astronomical Society).

Altitude, slope, aspect and distance to water were derived from the 20 metre contour shape file and streams and rivers shape file available from www.koordinates.com and created in ESRI's ArcGIS. Landcover database was also supplied by www.koordinates.com. Landcover types are alpine grass and herbfield (AGH), alpine gravel and rock (AGR), herbaceous freshwater vegetation, (HFV), shrubland (SHR) and tall tussock (TT).

Data analysis

Data analysis follows the same as in Chapter 4: ENFA and Chi-square goodness of fit test. For the purposes of this analysis, the three landcover types less than 10 hectares were not included. For the ENFA analysis, altitude was divided into four classes of >1300, 1500, 1700 and >1700 m a.sl. Slope was divided into <5, 15, 30 and >30°, while distance to water (DW) was divided into <100, 200, 300 and >300 m. P-values for significance tests are depicted as * <0.05, ** <0.01 and *** <0.001.

Results

Defining activity periods from animal movement

Hourly distances travelled by all sheep depicted the same pattern although there were minor differences between sheep. The morning grazing period was considered to be between 07:40 to 12:00 NZST, the midday resting period between 12:20 and 14:00, the afternoon grazing period between 14:20 and 20:00; night-time was between 20:20 to 07:20. For comparison with the Glenmore data, days were also split into grazing, resting and camping

Overall habitat niche

Overall, sheep on Otematata study area used the broad easterly spurs at middle altitudes on gentle slopes in tall tussock grassland. They were never far from water as this study area has several streams, tarns and wetland areas. Sheep used habitat differently from that available, with a marginality index of 0.22 and a specialisation index of 1.88, meaning that they used about 80% of available ecological space, with a narrower niche (Figure 39). Mean altitude available was 1596 m a.s.l., mean slope was 14°, mean dwater was 279 m.

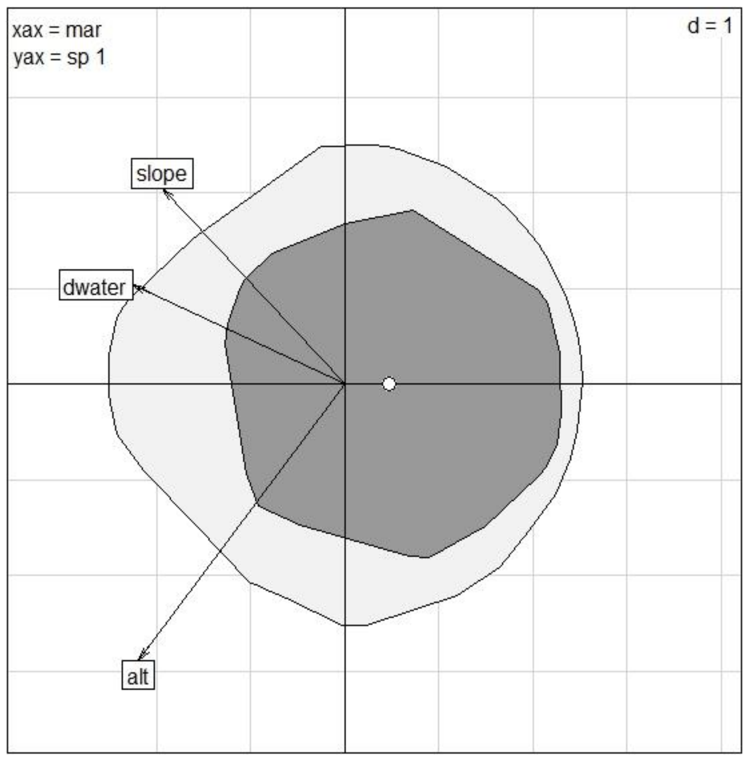


Figure 39. ENFA of Otematata sheep habitat use (dark grey) and habitat availability (light grey). Mean habitat use has lower values (white spot) than the available mean (centroid).

Habitat use over one month (Design I)

Habitat use differed significantly from available habitat and use by each activity also differed from that available. Landcover use was significantly different to that available (χ^2 = 1324 ***, df =4). Tall tussocks were strongly favoured in all activities, while alpine gravel and rock and alpine grass and herbfield were used much less than available (Figure 40). Differences between activities are chiefly on the selection of herbaceous freshwater vegetation (HFV) for grazing and resting and the avoidance at night. Alpine gravel and rock (AGR) was used more at night.

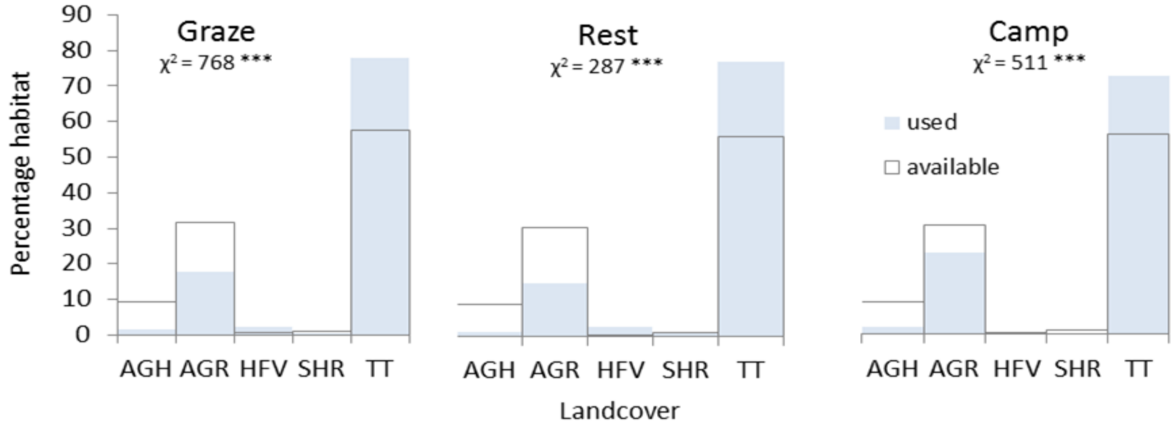


Figure 40. Landcover use (grey bars) and availablity (white bars) for each activity on Otematata.

Aspect use was also different from that available (χ^2 = 2886 ***, df = 8) and varied by activity (Figure 41). Overall, flat land was used more than that available. North and north-east facing land was used more at night, while east to south-east land was used much less.

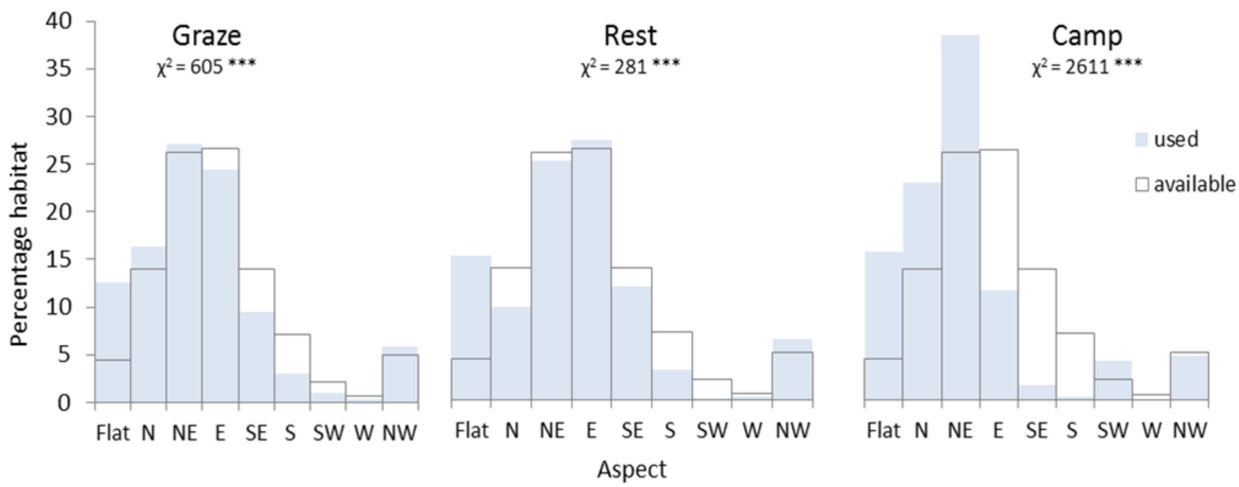


Figure 41. Aspect use (grey bars) and availability (white bars) for each activity on Otematata

Altitudinal use varied between activities (Figure) when night camping sites were on average 36 metres higher than grazing sites, which in turn were lower than resting sites (mean grazing altitude = 1537 m ± 101, mean resting altitude = 1548 m ± 106, mean night camping altitude = 1573 m ± 104. Overall use of altitude was significantly different from available altitude (χ^2 =2395***, df = 3).

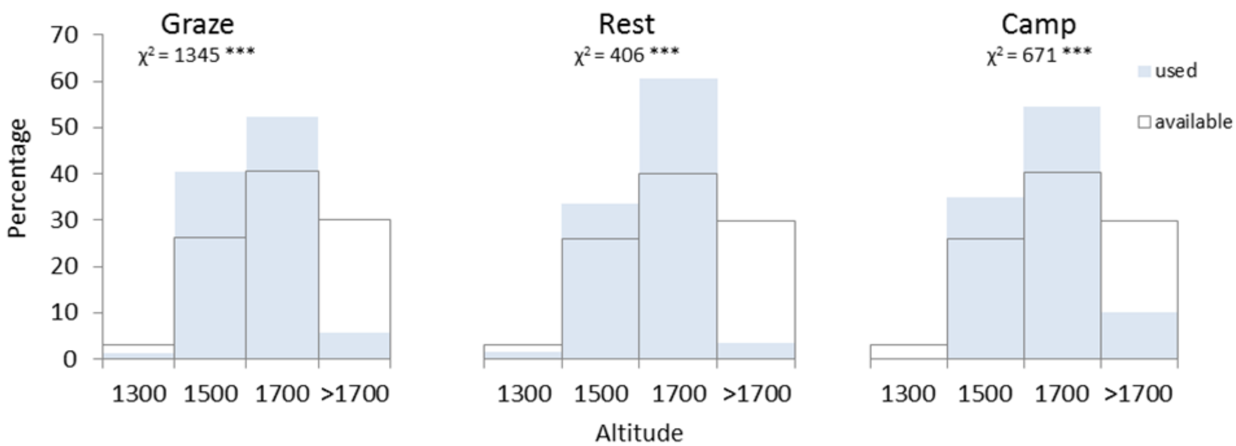


Figure 42. Altitude use (grey bars) and availability (white bars) for each activity on Otematata

Distance to water also differed from that available (χ^2 = 1959***, df = 3) and by activity (Figure 43). Mean dwater grazing = 142 m ± 115, mean dwater night camping = 245 m ± 99, mean dwater resting = 119 m ± 107. Night camps were much further from water than resting sites.

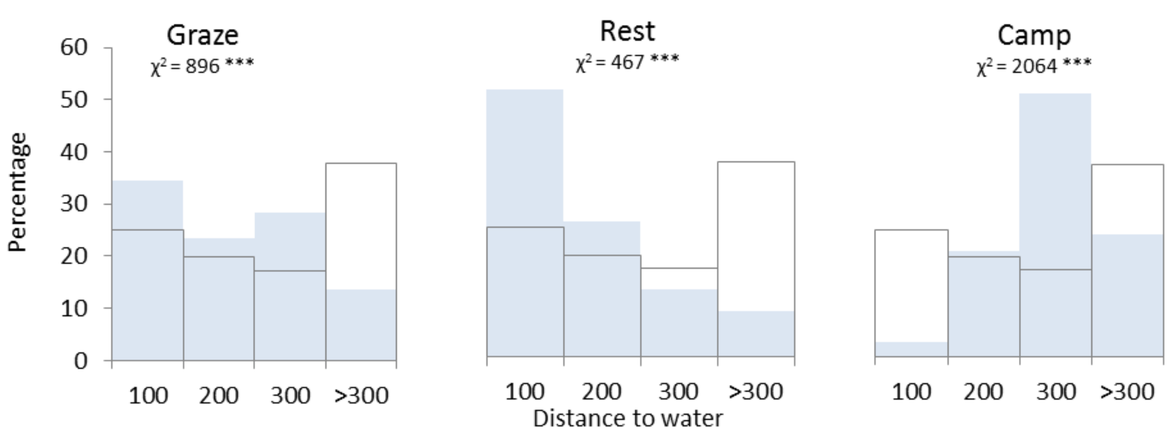


Figure 43. Distance to water use (grey bars) and availabilty (white bars) for each activity on Otematata

Mean slope use for all activities averaged 12°, but sheep showed further selection for slopes less than 15° for night camping (Figure 42). Differences of slope use between activities was, therefore significant ($\chi^2 = 59$ ***, df = 6). Overall slope use differed from that available ($\chi^2 = 727$ ***, df=3).

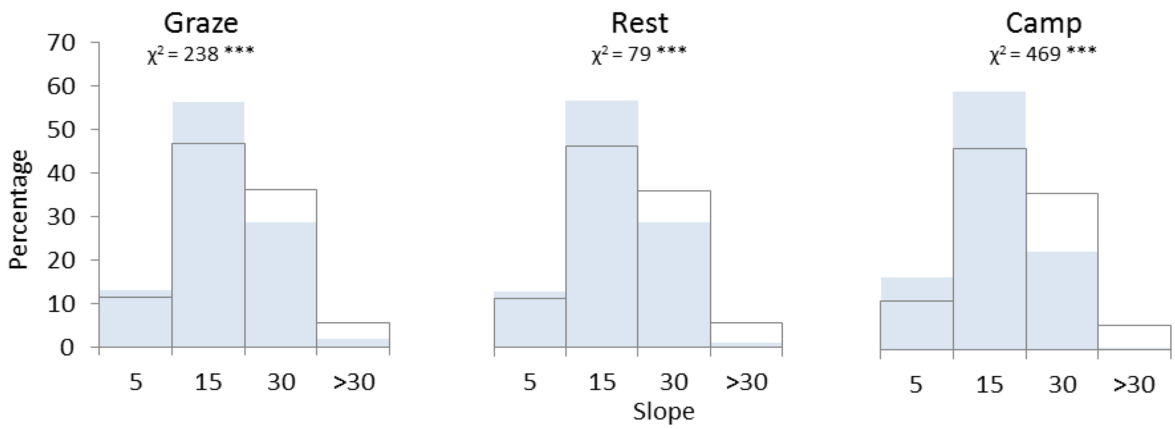


Figure 42. Slope use (grey bars) and availability (white bars) for each activity on Otematata

Design II, habitat use by individual sheep

The similarity in habitat use between sheep during the March period was quite noticeable. Tall tussock was strongly preferred in March and alpine gravel and rock was used much less by all sheep. Use of altitude, slope and distance to water were all fairly similar between all three sheep on the same block, although sheep 1 was slightly different as she occupied different part of the study area (Figure 43). Sheep 3 and 4 used higher slopes for grazing; sheep 4 used highest altitudes and slopes for camping.

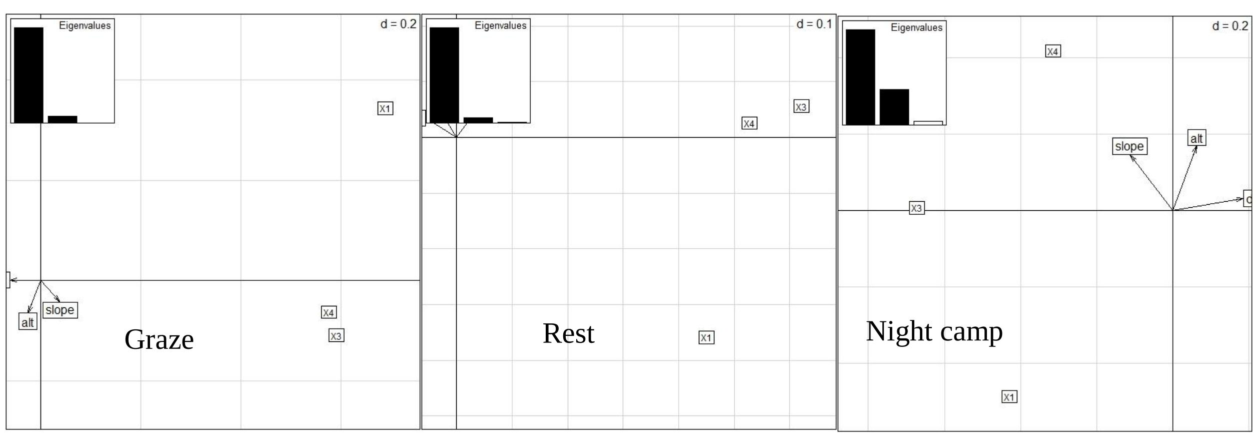


Figure 43. Ordination of Otematata individual sheep habitat use by activity

Location of night camps and daytime grazing sites

The locations of night camps were a mixture of popular re-used sites and isolated (used only once) sites. Each sheep had 4 or 5 favourite night camps; used 70% of the time, but of these, only 29% were used on consecutive nights.

Home ranges

Sheep home ranges for March ranged from 197 ha to 1025 ha. Sheep 1, which roamed south of the study area, had a home range of 197 ha. Sheep 2 which occupied Crown Land had the largest home range at 1025 ha. Sheep 3, which roamed the northern part of the study area, had a home range of 506 ha, while sheep 4, which occupied middle territory, had a home range of 385 ha. . Average daily distance travelled was about 3.5 km, ranging from 2 km to 5 km.

Discussion

Habitat use

Habitat use differed between the two study areas because of differences in vegetation type and landform. However, patterns that were similar were the use of higher altitude at night in both areas. Although at Glenmore the night camps were on steeper slopes, on Otematata, they were not. This suggests that altitude is the main driver of habitat use at night. Because the Glenmore study area was in a U-shaped valley, the higher altitudes would have been correlated with steeper slopes. However, although there were few broad spurs at Glenmore to compare with Otematata, the spurs on Glenmore were under-utilised. Sheep on both study areas used habitat further from water at night too. This suggests that they like to camp on a slope not in gullies. Both study areas had more easterly land available and so this was used more. Use of aspect, therefore, was similar. The Otematata sheep avoided the lowest altitudes probably because they were only accessible down steep slopes. Taylor and Hedges (2010) also found that sheep used higher altitudes at night.

Variation in use of landcover type suggests that the requirements of the sheep differ according to forage availability, climate and social grouping. As the Otematata sheep used alpine gravel and rock about 20% of the time, much more than the Glenmore sheep, this landcover type could be further investigated on the ground. This is where the need for ground surveys can improve the research as this habitat may well include far more vegetation than it sounds. Variation in habitat use by activity is logical. Daytime grazing sites would likely be where the best forage is available, in the valleys and closer to water sources, whereas night camps are located high up where the sheep feel most comfortable in terms of protection and shelter. Overall, forage quality and phenological changes influence grazing distribution the most (Harris & O'Connor 1980).

Daily activities

Sheep on both Otematata and Glenmore followed a similar daily activity pattern, when movement started just before sunrise, assuming grazing, and continued until just after dark, with a rest around midday. One study on mixed breed sheep found that grazing started just after sunrise and increased in intensity until just before sunset (Betteridge 2010), while another study on Soay sheep suggested that grazing and ruminating occur successively all day (Champion et al. 1994). There could be slight differences in activities between breeds but also gender. There may be slight differences in habitat use between Merino wethers on Otematata and Merino ewes on Glenmore, as Pérez-Barbería et al (2007) found that the gender of Soay sheep marginally affected their habitat use.

Location of night camps and daytime grazing sites

The most striking feature of this analysis is the range of locations for night camps. Night camps were well spread out and although there were clusters of camping locations, there were still quite a few that were only used once. Several night camps were observed in Australia (Taylor & Hedges 1984). Night camps are generally places that the sheep return to most nights, a site that is familiar to them and offers safety from predators (perceived or real) mostly at higher altitude (Betteridge 2010). This study shows that sheep do not camp in the same spot all the time. About a third of the nights were in different locations, but of the locations that they did return to, a third of those were used on consecutive nights. As the land is at reasonably high altitude, mountainous with fairly steep slopes in places, the sheep may have preferred to camp out at different locations for various reasons. They may have just happened upon a site depending on their location prior to the night-time. With 3700 sheep on the block, a stocking density of 1 sheep per hectare, night-time locations may be also depend on the movements of other mobs, as it can be clearly seen that the four sheep were part of different mobs. Preferred night camps on Otematata were frequently located on top of spurs, presumably for their predator detection properties, by sound or smell. This contrasts with the night camps on Glenmore, where preferred campsites were tucked into narrow side valleys, or on steep slopes. Night camps on Otematata showed a strong selection for NE facing land, likely to catch the early morning sun; this preference was strongly noted in Merinos in Australia (Taylor & Hedges 1984).

It is also of distinct note that in both study areas, the sheep were not completely still at night. They did tend to wander around at night albeit at short distances; night-time grazing was also observed by Betteridge (2010).

Daytime grazing sites on Otematata did show 33% site fidelity, where certain sites were preferred and returned to for several days. On Glenmore favoured sites were utilised 90% of the time on Top Block but less so on the other blocks. Grazing clusters on Otematata showed a tendency to accumulate around water sources, whereas on Glenmore this was less obvious. Harris and O’Connor’s (1980) observations also found that sheep grazed more often in swampy areas.

Distances travelled

Animal movements on both study areas were very similar over a 24 hr period. Although we are comparing Merino wethers with Merino ewes, there appears to be little difference in their daily rituals in summer. Daily distances travelled (~3.5 km) are similar to another study (Putfarken et al. 2008) but GPS inaccuracies may have overestimated daily travel, so the real figure could be a little lower. We had no way of testing the accuracy of the GPS collars used on Otematata, as they were no longer available.

Comparison of home ranges

The differences between home ranges in the two study areas suggests that forage availability may have been the deciding factor, as there was assumed to be more palatable feed in the short tussock and exotic grassland at Glenmore. Monthly home ranges on Glenmore were smaller. There is little information available on domestic sheep home ranges.

Conclusion

Habitat use for four Merino wethers on Otematata station were re-analysed following a pilot study in 2005 (Haddon 2008). Merino wethers (castrated male sheep) utilised the broad spurs and wider valleys for the four month study. Analysing a similar period to the Glenmore study, from March to April, Merino wethers preferred the middle altitude valleys close to water for the midday resting period. Merino wethers selected higher altitude broad spurs for night camping. They grazed widely in the morning and afternoon across the broad spurs. Individually they showed slight selection for different vegetation types but combined there was no difference between the availability and use of vegetation types. About 14 different night camps were used during the March/April period, but camps were used on consecutive nights only 28% of the time. Daytime resting sites, on the other hand, occurred in tighter clusters.

Chapter 8 General Discussion

The earlier chapters have explored habitat use of Merino ewes on the vegetation in high country summer grazing blocks. This chapter discusses the key findings of the research and the contribution these findings make to improve our knowledge. Implications for management are provided based on these findings. Suggestions are also made for future research in sheep habitat use.

First and foremost, biodiversity is declining in New Zealand. Tall tussock grasslands in the high country are receding and giving way to increasing amounts of short tussock grassland that comprises many exotic species. It is debateable whether sheep grazing is one of the major factors contributing to the decline. Invasive species such as *Hieracium pilosella* are increasing in abundance, frequency and altitudinal range and are invading tall tussock grassland at ever higher altitudes (see Appendix D; (Allen et al. 1995; Duncan et al. 1997; MacDougall & Turkington 2005; Day & Buckley 2007; Mark et al. 2011). Exotic grass species present in the area are also contributing to the decline in native plant diversity. Although they are favoured for grazing by sheep, exotic grasses are well-adapted to regrow and reproduce, enabling their spread. So, how do we best monitor the condition of summer grazing blocks in relation to sheep grazing? We need to know where and when sheep use specific habitats and what they are doing there. By exploring the main drivers of sheep habitat use and the type of habitat most affected by sheep use, we can better target monitoring of vegetation change in the areas of intensive use, to determine what changes are caused by sheep.

Merino ewes exhibit a strong daily activity pattern. These patterns were exhibited in all sheep on both Glenmore and the Otematata study areas, despite slight variations in timing. Activity is mainly driven by daylight, as grazing starts at first light and finishes after dark. Generally, the day is split into four activities, morning grazing, midday resting, afternoon grazing and night camping. Resting occurs around the middle of the day in summer, to allow sheep to ruminate, although this may also occur in short bouts throughout the day. These daily activity patterns agree with other research on mammalian herbivores (Harris & O'Connor 1980; Champion et al. 1994).

Habitat use is not random. Habitat use differs from that available and differs between activities. The major factor influencing habitat use is the daily activity pattern. Merino sheep on Glenmore strongly selected for short tussock grassland for grazing, with its array of exotic species while on Otematata sheep were more restricted in their choice of available vegetation type and grazed mainly tall tussock grassland. Some of the sheep on Glenmore also grazed tall tussock grassland in the early part of the study period but moved down slope to the short tussock grassland as the period studied progressed. This suggests that changes in phenology may also be a driver of habitat use which could be further explored in detail. Resting occurred on and around the riverbed on Glenmore and on and around water sources on Otematata. Although none of the observed sheep were seen drinking, this may have been the reason for using this resting habitat. Although the land cover types were different on the two study areas, all the sheep showed the same resting pattern, as defined by lack of movement. Resting occurred mostly on flat land, presumably for comfort. However, on Glenmore, sheep rested on the lowest altitude land, while on Otematata sheep often rested on land slightly higher than the grazing sites (reflecting the presence of broad ridges with gentle tops and steeper side slopes).

Night camping, which occurs during darkness, is situated at higher altitudes than the grazing sites, often on ridges, or up side valleys, where accumulation of faeces is an obvious sign of such camps. On Otematata, sheep preferred to camp in tall tussock grassland or alpine gravel and rock, while on Glenmore, they preferred to camp in tall tussock grassland or native mix, both of which have a complex vegetation structure, offering some protection, comfort or cover. Numerous night camps were used on both study areas, suggesting that Merino sheep like to vary their camping locations, probably to reduce predation risk. Variation in night camps was also noted by Taylor et al (1987).

Merino ewes showed some evidence that they altered their behaviour in response to weather conditions. Rainfall forced the sheep to keep away from the riverbed on Glenmore, taking refuge among the short tussock grassland on the large fan or slopes. A distinct lack of activity during rain was also evident. The rain may have kept the mob closer together to reduce perceived predation risk and for warmth. Although there were only three days of rain to analyse, there was a clear change in habitat use on these days. The most obvious change came on the third day of rain, which had 15 mm of rain. Wind and air temperatures showed a slight relationship with sheep habitat use, but this was difficult to clarify as there was much variation. Because shrubland was used very little, shelter from the elements may not be so important for Merino sheep over summer, or the habitats used (tall tussock grassland during rain) provided sufficient protection. Visual observations suggested that there was a distinct lack of shade-seeking behaviour during hot sunny weather, where the sheep appeared to prefer standing together with their heads hanging down or were sitting on the stones in full sun.

Daily movements varied from 2 km to 10 km for no discernible reason, other than rain limiting movement during wet periods. The fact that the daily movements on Glenmore were consistently longer than on Otematata (mean Glenmore = 5 km, mean Otematata = 3.5 km) may actually relate to the accuracy of the GPS collars than any other reason, although gender differences may be the reason (ewes were studied at Glenmore while wethers were studied at Otematata. Measuring ewe and wether movements at the same time on neighbouring blocks could shed some light on the reasons why they are different. Windy days also decreased daily movements but to a much lesser extent than on rainy days. Air temperature appeared to have no effect on daily movements. Home ranges on Glenmore varied from 150 ha to about 300 ha, while on Otematata home ranges varied from 200 ha to 1000 ha. The difference within Glenmore appeared to be related to which part of the study area sheep occupied, where the smaller home ranges were possibly on better quality land. Because the short tussock grassland on the fans had gentler slopes than the side slopes, the fans may hold more moisture and so have a higher abundance of exotic grass species. The difference between average home ranges on Glenmore (250 ha) and Otematata (500 ha) may also be related to different landforms, where Otematata had more expansive broad spurs compared to the steeper slopes on Glenmore.

Areas of intensive use were identified and marked by activity. Grazing sites were commonly on lower slopes and fans in short tussock grassland. Grazing sites were used over and over again. Site fidelity, therefore, may be driven by forage quality. Night camps were scattered along the higher altitude slopes and were more varied than the grazing sites. Intensively used resting sites also showed a high return rate but as most of them were on the riverbed, which frequently gets flooded, there would be many vegetation changes not attributed to sheep use.

The expansion of hawkweed species in summer grazing blocks is a concern to farmers as these species are unpalatable and highly invasive, with a reputation of replacing native species. Hawkweeds are unlikely to reach a high abundance in tall tussock grasslands, because of the denser taller vegetation cover. Recognising the changes in vegetation over the years is important to try and stem the tide of declining native plant diversity. Therefore, the siting of exclosure plots and monitoring sites is paramount to tracking changes.

The results from the Glenmore research compare well with the results from Otematata. Sheep on both study areas showed the same activity patterns, similar grazing site fidelity and the use of higher altitudes at night. These results complement the understanding of Merino sheep habitat use. The differences are also interesting. Sheep on Otematata appeared to have less choice in vegetation type and so had to utilise whatever was available. However, because an on-the-ground vegetation survey was undertaken on the Glenmore study area, the vegetation types available were more detailed. Had the survey not been undertaken, vegetation types on Glenmore would have been delineated mostly as tall tussock grassland. This is an important point that suggests that good vegetation survey data is important for our understanding of sheep habitat use.

Vegetation change in the high country is a dynamic process because of natural progressions such as succession through several different disturbances. Grassland ecosystems often move towards a shrubland ecosystem. If sheep were removed from the area, tall tussocks and shrubs may predominate. However, there is still the problem of hares and tahr. Also, wilding pines have appeared lower down the valley and would be expected to spread up the valley, given time, if not removed.

Implications for management

In order to establish whether sheep grazing is sustainable in the high country, it is very important to continue monitoring vegetation changes. The location of monitoring sites and exclosure plots is paramount. They would be best located in areas of intensive use by sheep, in the most popular night camps and in the most popular grazing sites as this is where the impacts will be highest. This would allow recognition of two types of impacts, one on changes in forage quality and one on changes in vegetation providing shelter. This could be achieved by measuring not only species and their abundances, but also measuring changes in vegetation structure and function. Monitoring the receding line of tall tussock grassland could also be a priority, as we know that this is a major concern and may well be a result of sheep habitat use.

For each type of site, it may be beneficial to establish indicator species as well as measuring the less common species. At the grazing sites, monitoring the response of *Chionochloa rubra, Poa cita* and *Festuca novae-zelandiae* would be valuable because the first two are declining and palatable, while the latter is unpalatable but still declining. At the night camps, indicator species could be *Chionochloa rigida,* a shrub species and a soft herb such as *Acaena* spp. However,

Future research needs

Future research could provide more information on sheep habitat use if phenological changes were measured, as many sheep are grazed on summer blocks for 4 or 5 months. On the ground vegetation surveys are also important for analysing sheep habitat use on other high country farms, as whether the results here can be used to predict habitat use on other farms is debateable. It is likely that a smaller number of plots would have been sufficient to determine vegetation type, but a larger area could have been included, so this is important to bear in mind in future projects.

A comprehensive evaluation of the influence of weather variables on sheep habitat use could also be undertaken as one survey is not enough to study cause and effect. This could be established using a weather-protected video camera or using visual observations from a hide. Choosing days when the forecast is predicting bad weather would focus the research on collecting useful data rather than collecting weeks of fine weather. This type of observational research would best be undertaken on a small hillside where the whole study area can be viewed from one position.

Ideally, any future research on sheep habitat use would use more animals over the same time frame. This would require using reliable GPS collars with reliable batteries and using as many collars as can be afforded. Counting the number of sheep in the same mob as the collared sheep would also give a good indication of how many sheep are using the same habitat. For a longer term study and if battery reliability is a problem, it may be useful to collect data for a week, bring them in, recharge the batteries and then put the collars back on for another week, say in the next month and so on. Of course, this would only be viable if you have a small mob in a more confined area and an understanding and patient shepherd.

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Appendix A
Plant species list

Botanical Name	Common name
Native grasses	
Chionochloa macra	slim snow tussock
Chionochloa rigida	narrow-leaved snow tussock
Chionochloa rubra	red tussock
Deyeuxia avenoides	
Elymus scabra	wheat grass
Festuca novae-zelandiae	hard tussock
Poa cita	silver tussock
Poa dipsacea	
Poa lindsayi	
Poa colensoi	blue tussock
Rytidosperma pumilum	
Rytidosperma setifolium	
Native shrubs and trees	
Aristotelia fruticosa	
Brachyglottis cassinioides	
Carmichaelia monroi	native broom
Coprosma decurva	
Coprosma dumosa	Mikimiki
Coprosma fowerakeri	
Coprosma propinqua	mikimiki
Corokia cotoneaster	
Discaria toumatou	matagouri
Dracophyllum longifolium	
Dracophyllum uniflorum	turpentine bush
Hebe lycopodioides	
Hebe odora	
Hebe pimelioides	
Hebe subalpina	
Hebe tetrasticha	
Hebe traversiii	
Hoheria lyallii	Mountain ribbonwood
Melicytus alpinus	Porcupine shrub
Olearia cymbifolia	
Olearia nummularifolia	
Olearia odorata	
Ozothamnus leptophyllus	

Native shrubs and trees cont.

Pittosporum divaricatum	
Podocarpus nivalis	snow totara

Native sub-shrubs

Acrothamnus colensoi	
Coprosma atropurpurea	Mat coprosma
Coprosma petriei	Mat coprosma
Coprosma perpusilla	
Dracophyllum kirkii	
Dracophyllum pronum	
Gaultheria crassa	
Gaultheria depressa	snowberry
Gaultheria parvula	
Hebe buchananii	
Pentachondra pumila	
Pimelia oreophila	Native daphne
Pimelia pseudolyallii	
Pimelia traversii	

Native herbs

Acaena caesiiglauca	Glaucus bidibid
Acaena inermis	Bronze bidibid
Acaena profundeincisa	
Aciphylla aurea	Yellow speargrass
Aciphylla montana	Mountain speargrass
Aciphylla scott-thomsonii	Giant speargrass
Anaphalioides bellidioides	
Anisotome aromatica	
Anisotome imbricata	
Anisotome flexuosa	
Argyrotegium mackayi	
Brachyglottis bellidioides	
Brachyglottis haastii	
Brachyscome longiscapa	
Cardamine sp.	
Celmisia alpina	
Celmisia angustifolia	
Celmisia gracilenta	dainty daisy
Celmisia haastii	
Celmisia laricifolia	
Celmisia lyallii	false speargrass
Celmisia semicordata	
Celmisia sessiliflora	
Celmisia verbascifolia	

Native herbs continued

Colobanthus apetalus	
Craspedia lanata	White woollyhead
Craspedia uniflora	Green woollyhead
Epilobium alsinoides	
Epilobium brunnescens	
Epilobium glabellum	
Epilobium komarovianum	
Euchiton lateralis	
Euphrasia monroi	
Euphrasia zelandica	
Forstera sedifolia	
Forstera tenella	
Galium perpusillum	
Gentianella corymbifera subsp. corymbifera	
Gentianella corymbifera subsp. gracilis	
Geranium microphyllum	Hairy cranesbill
Geranium sessiliflorum	cranesbill
Geum cockaynei	
Gunnera monoica	
Helichrysum filicaule	
Huperzia australiana	
Hydrocotyle hydrophila	
Hydrocotyle novae-zeelandiae	
Kelleria dieffenbachii	
Lagenifera petiolata	
Lagenifera strangulata	
Leucopogon fraseri	
Lobelia angulata agg	
Lobelia linnaeoides	
Luzula crinita	
Luzula rufa	Red woodrush
Lycopodium fastigiatum	
Muehlenbeckia axillaris	
Neopaxia australasica	
Nertera balfouriana	
Nertera ciliata	
Ophioglossum coriaceum agg.	Adders tongue
Oreobolus pectinatus	
Chaerophyllum novae-zelandiae	
Ourisia caespitosa	
Plantago novae-zelandiae	
Ranunculus cheesmanii	
Ranunculus multiscapus	
Ranunculus gracilipes	

Native herbs continued

Raoulia eximia	
Raoulia grandiflora	
Raoulia hookeri	
Raoulia parkii	
Raoulia subsericea	
Raoulia tenuicaulis	
Scleranthus brockiei	
Scleranthus uniflorus	
Stellaria gracilenta	
Taraxacum magellanicum	Native dandelion
Viola cunninghamii	
Wahlenbergia albomarginata	harebell

Native sedges and ferns

Blechnum penna-marina
Carex bergrennii
Carex breviculmis
Carex buchananii
Carex comans
Carex gaudichaudiana
Hypolepis millefolium
Isolepis aucklandica
Isotoma fluviatilis
Juncus distegus
Juncus edgariae
Juncus novae-zelandiae
Juncus pusillus
Schoenus pauciflorus
Uncinia divaricata

Native orchids

Prasophyllum colensoi	
Pterostylis venosa	
Thelymitra longifolia	sun orchid

Native climbers

Clematis marata
Muehlenbeckia complexa

Exotic grasses

Anthoxanthum odoratum	sweet vernal
Agrostis capillaris	browntop
Festuca rubra	chewings fescue
Holcus lanatus	yorkshire fog
Juncus articulatus	

Exotic herbs

Cerastium fontanum	
Cirsium vulgare	Scotch thistle
Crepis capillaris	
Hieracium aurantiacum	Orange hawkweed
Hieracium caespitosum	
Hieracium lepidulum	tussock hawkweed
Hieracium pilosella	mouse-ear hawkweed
Hieracium praeltum	king devil hawkweed
Hypochoeris radicata	catsear
Linum catharticum	Purging flax
Myosotis discolor	
Rumex acetosella	
Spergula rubra	
Taraxacum officinale	dandelion
Trifolium dubium	suckling clover
Trifolium repens	white clover
Verbascum thapsus	

Mosses

Breutelia pendula
Drepanocladus aduncus
Marchantia berteroana
Polytrichum juniperum

Scree/riverbed plants

Epilobium crassum
Epilobium melanocaulon
Helichrysum depressum
Myosotis traversii
Stellaria roughii

Appendix B

Fauna observed around study area

Native Birds

Falcon	*Falco novaeseelandiae*
Pipit	*Anthus novaeseelandiae*
Black fronted tern	*Sterna albostriata*
S.I. pied oystercatcher	*Haematopus ostralegus*
Silvereye	*Zosterops lateralis*
Warbler	*Gerygone igata*
Banded dotterel	*Charadrius bicinctus*
Paradise shelduck	*Tadorna variegata*
Kea	*Nestor notabilis*
Black backed gulls	*Larus dominacanus*

Exotic birds

Yellowhammer	*Emberiza citrinella*
Blackbird	*Terdus merula*
Skylark	*Alauda arvenis*
Chukor	*Alectoris chukor*
Starling	*Sturnus vulgaris*

Native invertebrates

Tree weta	*Hemideina maori*
Ground weta	*Hemiandrus maculifrons*
Black carabid beetle	
Brown cricket	
Green cricket	

Exotic mammals

Hare	*Lepus europeus*
Tahr	*Hemitragus jemlahicus*

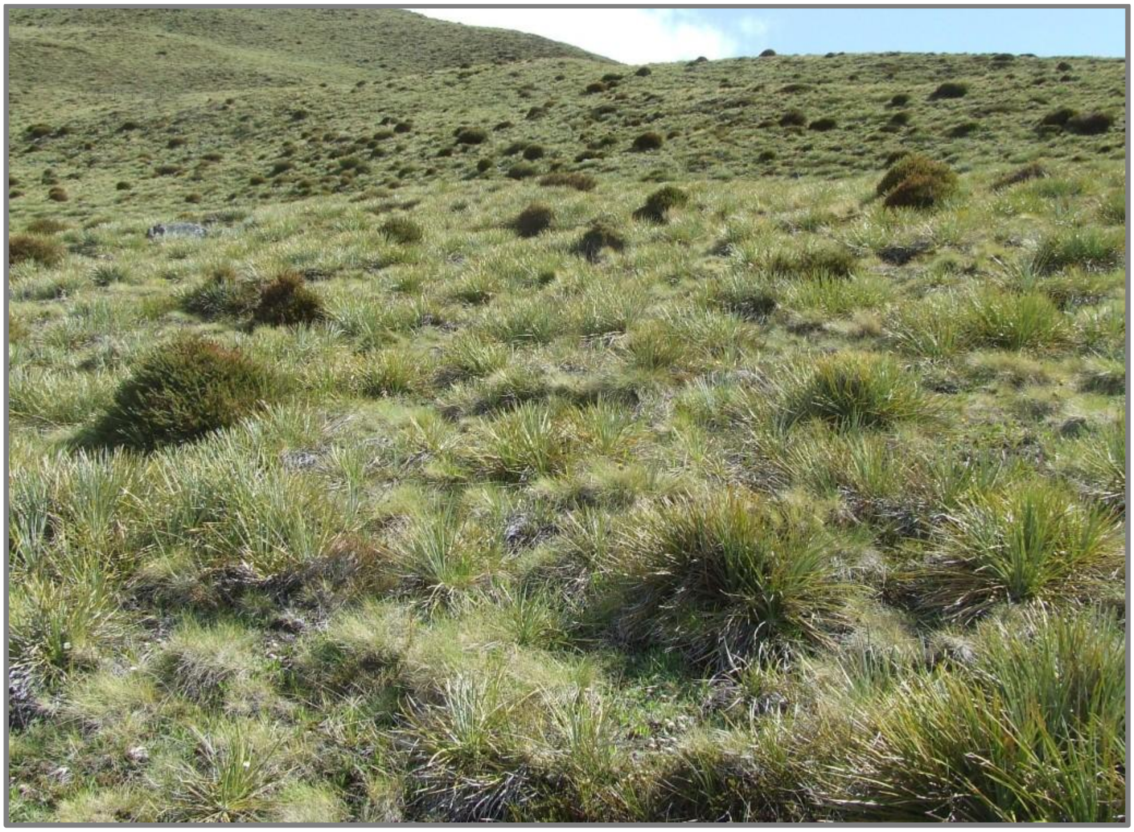
Appendix C

Photos of vegetation types on Glenmore

Tall tussock grassland (TT)

Short tussock grassland (ST)

Native mix (NM)



Alpine grass and herbfield (AGH)

Sub-alpine shrubland (SHR)

Exotic grass (EXG)

Grey scrub (GS)

Low producing grassland (LPG)

Riverbed (RVB)

Appendix D
Hawkweed invasion

Introduction

Hawkweeds (*Hieracium* species; Asteraceae*)* are environmental weeds with serious impacts on biodiversity and agriculture in New Zealand grasslands as they displace native species and reduce pasture quality (Espie et al. 2001). *Hieracium pilosella* L. (also known as *Pilosella officinarum* Vaill.) is an aggressive rosette plant that has been widely recorded invading native vegetation, particularly in the low-rainfall hills and basins of the eastern South Island (Treskonova 1991; Duncan et al. 1997; Meurk et al. 2002; Rose et al. 2004; Day & Buckley 2007; Mark et al. 2011). Other *Hieracium* species have also been documented invading eastern South Island grasslands including *Hieracium praealtum* (*Pilosella piloselloides* subsp. *praealta*) and *Hieracium lepidulum* (Wiser & Allen 2000; Day & Buckley 2007; Radford et al. 2010; Day & Buckley 2011; Mark et al. 2011). *Hieracium* species invasion, especially *H. pilosella*, has resulted in widespread and dramatic changes in the composition and structure of lower-elevation grasslands to the extent that many areas that were previously dominated by native short tussocks (especially *Festuca novae-zelandiae*) are now *H. pilosella* dominated herbfields (Scott et al. 1990; Duncan et al. 1997; Rose et al. 1998; Norton et al. 2006).

The reason for the invasion of *Hieracium* species is a matter of some debate, although a series of ecological and environmental factors have been proposed including high stress tolerance, rapid vegetative, sexual and asexual reproduction, high competitiveness and allelopathy, all accelerated by land management practices (Treskonova 1991; Duncan et al. 1997; Rose et al. 1998; Rose & Frampton 1999; Meurk et al. 2002; Day & Buckley 2007; Day & Buckley 2009; Diez et al. 2009; Day & Buckley 2011; Mark et al. 2011). What is clear is that *Hieracium* species were present in New Zealand grasslands for many years before they became dominant. For example, *H. pilosella* was first recorded in New Zealand in 1878 (Murphy 1878) while *H. praealtum* was first recorded in 1924 (Allan 1924), while *H. lepidulum* was first recorded in 1946 (Wiser & Allen 2000). The various *Hieracium* species show ecological differences in both their invasion patterns and the systems in which they invade, reflecting differences in their basic biology (Makepeace 1980, 1985b, a; Espie et al. 2001). *H. pilosella* is most abundant in lower elevation sites that were previously dominated by short tussock grasslands, while the more shade-tolerant *H. lepidulum* appears more abundant in higher altitude tall tussock (*Chionochloa* dominated) grasslands as well as in forests. *H. praealtum* appears more common in low-rainfall short tussock grasslands but is generally at low abundance.

All the *Hieracium* species appear to be very effective competitors with native species. They have high stress tolerance, being able to withstand a wide range of temperatures, moisture, nutrient and light levels, which makes them good competitors. They are good colonisers of both bare ground and low stature vegetation, taking advantage of the altered disturbance regimes provided by modern agricultural practices. Once established they spread easily as they are wind pollinated and wind dispersed. All three *Hieracium* species can reproduce both sexually and asexually by apomixis. *H. pilosella* and *H. praealtum* can also reproduce vegetatively by producing daughter plants at the end of stolons. Genetically, *Hieracium* species are readily evolving and hybridising thus enabling rapid adaptation (Chapman et al. 2000; Chapman et al. 2003; Morgan-Richards et al. 2004). *Hieracium* species appear to benefit from land management practices such as burning, grazing and fertilising but are deterred when land is irrigated and oversown (Scott et al. 1990). *Hieracium* species also have allelopathic properties that alter the soil chemical balance that inhibit surrounding vegetation (McIntosh et al. 1995; Scott et al. 2001).

Hieracium species are generally less invasive in tall tussock grasslands than in short tussock grasslands. As the tall tussock grasslands are at higher altitude and therefore cooler, lower temperatures may be a limiting factor, although there is also less human disturbance here. *H. pilosella* and *H. praealtum* are fairly common in tall tussock grasslands but *H. lepidulum* appears to be more abundant in Otago (Connor 1992; Rose & Platt 1992; Rose et al. 1995; Wiser & Allen 2000; Mark et al. 2011). *H. pilosella* is far more abundant in Canterbury than Otago where it is still in the early stages of invasion (Mark et al. 2011). *H. praealtum* is generally at low abundance in both Canterbury and Otago. *Hieracium* species are generally unpalatable to farm stock although there is some evidence of them being palatable to hares (Blay 1989). *H. pilosella* is an exotic invasive weed that has spread to become a dominant species in the dry hills of the Canterbury high country. Since the 1960s *H. pilosella* has spread rapidly across the short tussock grasslands of the South Island of New Zealand (Hunter 1992; Groves 2006).

In this study we assessed the extent of invasion by *Hieracium* on the Glenmore study area. Specifically we wanted to know how widespread different *Hieracium* species were, what were the main environmental correlates of their distribution, and if there were any differences between *Hieracium* species.

Methods

Two sets of vegetation plots have been independently established at the study site over the last five years. The first set was established in February 2009 specifically for monitoring the spread of *Hieracium pilosella* and *Hieracium praealtum*. These 60 plots were stratified altitudinally (1100-2028 m a.s.l.), in proportion to the available area of tussock grassland in different altitudinal bands in the Twin Basins Block south of the confluence of Ailsa Stream and Cass River. Each plot consisted of ten contiguous 1m x 1m quadrats. The second set of 159 plots comprising 5m x 5m quadrats were measured as part of this sheep habitat use study and were established in the 2010/2011 summer. These plots were located in Top Block, north of Ailsa Stream and the Twin Basins Block, as well as on adjacent public conservation land (1080 - 1600 m a.s.l.).

For both sets of vegetation plots, percentage cover of each species present was recorded, as well as bare ground and rock. Average vegetation height in the quadrats was also recorded, as were the environmental variables altitude, aspect and slope. A moisture index was derived from aspect, slope and topography (Duncan et al. 1997). As the plots and quadrats sampled different areas, they were aggregated to give similar sizes for analysis, as sample size can affect species composition. In the 60 plot dataset, ten quadrats of 1m x 1m were averaged out to give each plot a size of $10m^2$. The 5m x 5m plots were not aggregated and had a plot size of $25m^2$. We felt that this was the best way to accommodate the different sized plots and only the potential explanatory variable, species richness, is most likely to be affected, so was not included in the analysis.

Data Analysis

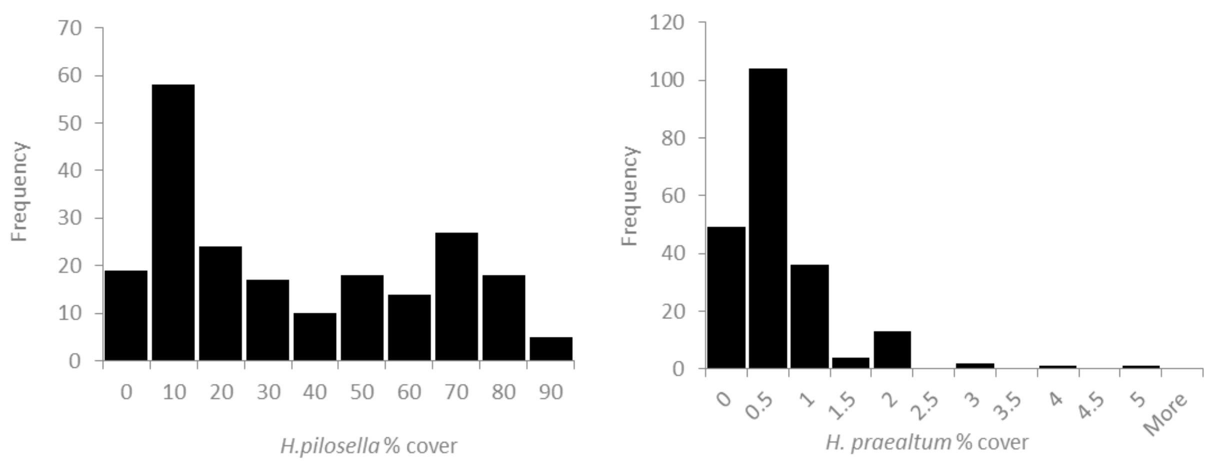
Correlations between environmental variables and hawkweed abundance were examined first and multiple linear regressions were performed in R 2.11.1 (R Core Development Team 2010). Each linear model was checked for normality and constant variance. Both response variables, *H. pilosella* and *H. praealtum* were arcsin squareroot transformed to meet these assumptions. Each species was first modelled using the maximal model and was gradually reduced to the most parsimonious model based on model fit and best explanation, using the Akaike Information Criterion. Correlations between explanatory variables were considered and the most influential variable was kept in the analysis. Analysis was undertaken on the 60 plots and 159 habitat plots separately. Explanatory variables entered into the model were altitude, aspect, slope, tall tussock cover (TT), short tussock cover (ST), bare ground/rock cover, large herbs cover (LGHRB), shrub cover, sub-shrub cover, vegetation height, total vegetation cover, vegetation cover over 10cm (CVR10) and moisture index.

Vegetation cover represents the abundance of all the vegetation in the quadrat other than *Hieracium* species. Regressions were arranged in order of strength of relationship. Presence and absence of both hawkweeds were then analysed in R in generalised linear models (GLM) using the binomial error structure and the logit link function.

Results

Hieracium pilosella was present in 89% of the total 219 plots, while *H. praealtum* was present in 76%. At altitudes below 1800 m a.s.l. *H. pilosella* was present in 91% of the plots (n = 207) but was still found in half of the plots over 1800 m a.s.l. (n = 12). Both hawkweed species were present at the highest altitude plot at 2028 m a.s.l. *H. lepidulum* only appeared in three plots.

In all plots, *H. pilosella* cover ranged from 0 to 90% (mean = 31 ± 1.9 SE, median = 22). Percentage cover of *H. praealtum* ranged from 0 to 5% (mean = 0.62 ± 0.06 SE, median = 0.5). Thirty four percent of *H. pilosella* cover values were < 10%, but showing a bimodal distribution with a major peak at 1-10% and a minor peak at 61-70% (Appendix D.1). Mean *H. pilosella* cover was 60% at altitudes < 1200 m, 29% at 1200 - 1400 m. 14% at 1400 - 1600 m, 5% at 1600 - 1800 m a.s.l. and 0.5% at over 1800 m. Mean *H. praealtum* cover was consistently about 0.5% in each altitudinal band.



Appendix D.1. Abundance of the two hawkweed species, *H. pilosella* and *H. praealtum* (using the combined data).

For the first set of 60 plots, abundance of *H. pilosella* significantly decreased with increasing altitude, subshrubs, tall tussock cover, large herbs and litter, where 76% of the variation in abundance was explained by these variables (Appendix D.2). Likewise, abundance of *H. praealtum* decreased with increasing altitude (p=0.001), which explained 23% of the variation. Presence or absence of *H. pilosella* was mostly influenced by altitude and tall tussock abundance. Slope had no influence on abundance and there was insufficient variation in aspect for analysis.

Appendix D.2. Linear model variables influencing abundance of arcsine square root transformed *H. pilosella*, using the 60 plot dataset

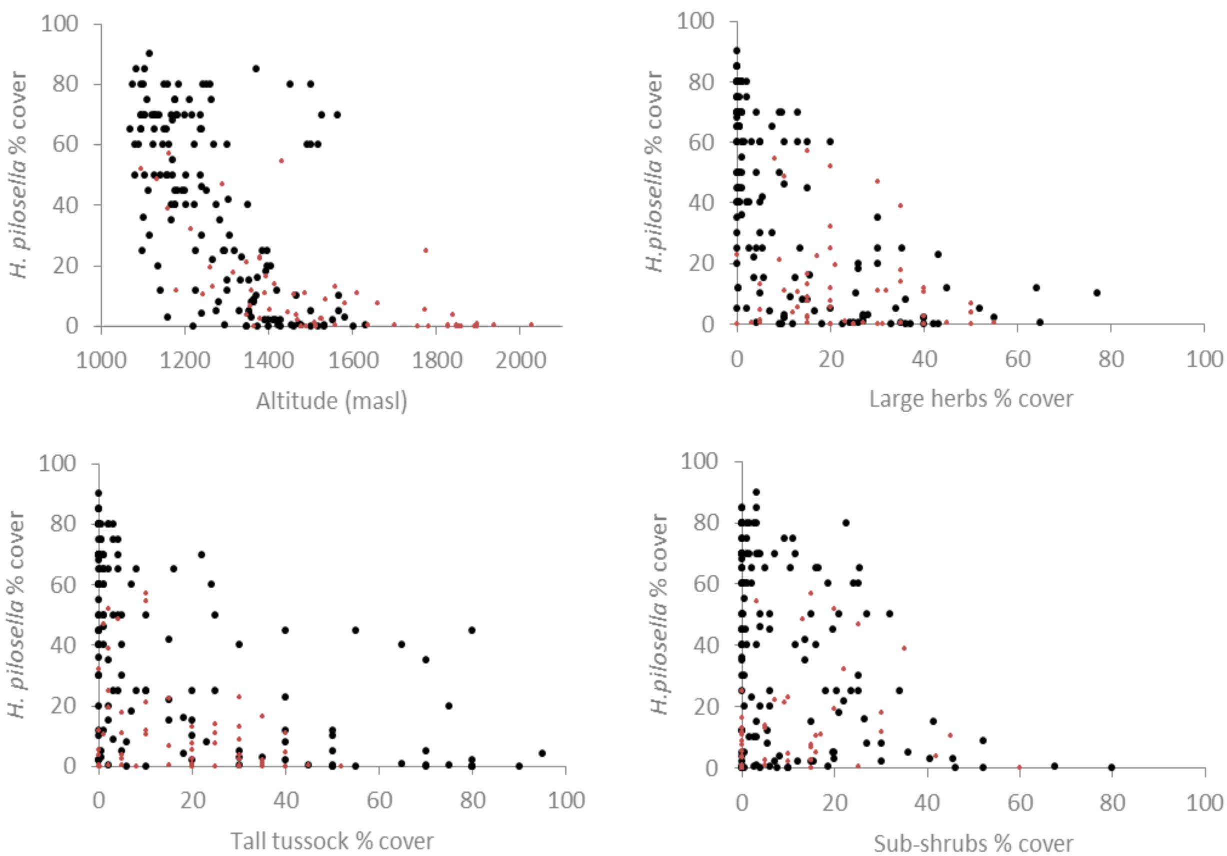
Variable	Estimate	SE	T	*P*	R^2
Intercept	1.41600	1.2000	11.795	<0.001	0.76
Altitude	-0.000558	0.000076	-7.326	<0.001	
Subshrubs	-0.006872	0.001454	-4.725	<0.001	
Tall tussock	-0.005022	0.001139	-4.410	<0.001	
Large herbs	-0.004025	0.000924	-4.354	<0.001	
Litter	-0.006599	0.001780	-3.708	<0.001	

For the second set of 159 plots, abundance of *H. pilosella* decreased with increasing large herbs, tall tussock and altitude but decreasing short tussock where 66% of the variation was explained by these variables (Appendix D.3). Vegetation height was also influential but was correlated with large herbs and tall tussock cover. Abundance of *H. praealtum* had no significant relationship with any of the variables, perhaps due to its very low abundance. The presence or absence of *H. pilosella* also showed no significant correlation with any of the variables. Slope, aspect and moisture showed no influence on hawkweed abundance.

Appendix D.3. Linear model variables influencing abundance of arcsine square root transformed *H. pilosella*, using the 159 plot dataset

Variable	Estimate	SE	T	*P*	R^2
Intercept	1.17749	0.14759	7.978	<0.001	0.66
Large Herbs	-0.00624	0.00095	-6.586	<0.001	
Tall tussock	-0.00323	0.00570	-5.666	<0.001	
Altitude	-0.00461	0.00011	-4.025	<0.001	
Short tussock	0.00183	0.00076	2.379	0.018	

Altitude was the most influential variable in both models, explaining most of the variation in *H. pilosella* abundance. As can be seen from Appendix D.4a, *H. pilosella* is present right up to the highest plot at 2028 m a.s.l. The anomalies of high altitude and high abundance of *H. pilosella* shown in Appendix D.4a are on broad open ridges. Overall, abundance of *H. pilosella* decreases with increasing cover of large herbs, tall tussock and sub-shrubs (Appendix D.4b, c and d respectively).



Appendix D.4. Scattergraphs showing relationships between explanatory variables and *Hieracium pilosella* in both the 159 plot set (black dots) and the 60 plot set (brown dots), for a) altitude (masl), b) large herbs (% cover), c) tall tussock (% cover) and d) sub-shrubs (% cover).

Discussion

Both *H. pilosella* and *H. praealtum* show widespread distribution within the study site, appearing in the majority of plots, suggesting that they are in the latter stages of the invasion process. Abundance of *H. pilosella* is high in the lower altitude short tussock grasslands, as expected, but is also moderately abundant in the tall tussock grasslands at higher altitude. Although *H. praealtum* is widespread, it has very low abundance (<2%) in the majority of plots. The high occurrence of both species was noted as a mark of the latter stages of invasion when range expansion occurs (Radosevich et al. 2003). With this in mind, abundance was found to be a better measure of invasion as both species were present at well over 70% of the plots (Buckley & Freckleton 2010). *H. lepidulum* only appears in only three plots at low cover, so would be in the early stages of invasion here.

The main environmental correlates with *Hieracium* species distribution are altitude and surrounding vegetation structure. The relationship of altitude with *H. pilosella* cover is strong, appearing in the regression models of both sets, but the relationship with *H. praealtum* is much weaker although statistically significant. Altitude is related to temperature, which is one of the main drivers of community composition. Clearly, abundance of *H. pilosella* is affected then, by cooler temperatures, which may explain why it is less abundant in Otago. Although higher altitudes had lower *H. pilosella* cover, the broad ridge at the top of the main spur was an anomaly with over 50% cover. This area is easily accessible from the valley floor and with its gentle slopes and is attractive to sheep, possibly as a night camp. A strong relationship with altitude was also noted by Duncan et al (1997) where the highest abundance was at about 1000 m.a.s.l. which is where our highest abundance was found. Our study is the first recording that *H. pilosella* has spread well into high altitude country at over 2,000 m a.s.l. Alan Mark recorded *H. lepidulum* presence on Treble Cone, Wanaka at 2000 m a.s.l. (Hunter 1992).

The correlation between *H. pilosella* abundance and tall tussock and large herbs is understandable as they limit the amount of light available, have stout basal areas and generally form a dense canopy. Tall tussock grasslands may have resisted invasion through greater canopy cover, higher rainfall, lower fertility and less human impacts such as burning and grazing (Treskonova 1991; Rose & Frampton 1999). Rose and Frampton (1999) also concluded that abundance of *H. pilosella* was influenced by vegetation composition and structure. They found most *H. pilosella* seedlings growing amongst low vegetation, litter and bryophytes, rather than in bare ground.

Abundance of *H. pilosella* was lowest or absent from areas that had abundant tall grasses or herbs, or a good continuous cover of dense shrubs and sub-shrubs at higher altitudes (>1400 m). Where it is already abundant, it is on open ground with low stature vegetation at lower altitudes. Where *H. pilosella* can be shaded out, other species have a chance to exist. The amount of vegetation cover that is tall enough to shade out the hawkweed is most important, i.e. dense cover of sub-shrubs that may only be 10 cm high appear to be enough. Tall tussocks, large herbs and shrubs obviously make a difference too but they can have large spaces between them where hawkweeds can grow. For example, even old large snow tussocks of about 30 cm basal diameter, that are far apart, have a long drooping habit that allows enough light to infiltrate under the overhang for hawkweeds to prosper.

There was little correlation between *H. pilosella* abundance and the moisture index, indicating that at this scale, either the differences in soil moisture were minor or that the species has adapted to grow in a range of soil moisture conditions. Although Duncan et al (1997) found moisture index to be a good predictor of *H. pilosella* abundance at lower altitudes, we did not.

Differences between *Hieracium* species were evident. *H. pilosella* was the most common and most abundant species, both in the whole study site and in the tall tussock grasslands only. *H. praealtum* was very common but a very low abundance both in short and tall tussock grasslands. *H. lepidulum* was very sparse and at very low abundance.

Conclusion

Hawkweed species are unpalatable to sheep and are encroaching on indigenous plant communities. In lower altitude short tussock country, hawkweeds have become the dominant species, thereby degrading pasture. In higher altitude tussock grassland, hawkweed species are less abundant but frequently present. This research looks at the extent of three *Hieracium* species around the study area on Glenmore Station. *H. pilosella* and *H. praealtum* are widespread throughout the study site, whereas *H. lepidulum* is rare. Major factors influencing abundance of *H. pilosella* and *H. praealtum* are altitude and dense vegetation cover such as tall tussocks, large herbs and sub-shrubs. Both *H. pilosella* and *H. praealtum* were present at high altitude, 2,028 m a.s.l. Differences in the invasion stage of *Hieracium* species are evident. Mean abundance of *H. pilosella* ranged from 0.5% cover in high altitude herbfield, to 6% cover in tall tussock grassland to 60% in short tussock grassland. *H. praealtum* averaged 0.5% cover in both short and tall tussock grasslands. Slope, aspect and a moisture index had little influence on hawkweed abundance. To stem the invasiveness of hawkweeds on the high altitude summer grazing blocks, abundance of tall tussocks, large herbs and sub-shrubs should not decline.

Appendix E

Additional tables and information

GPS collar technical specifications

GPS data was collected using custom data acquisition collars designed by the Geospatial Research Centre at the University of Canterbury. Each collar contains a 20-channel SIRFStarIII GPS receiver module, two thermistor temperature probes, an LIS302DL three-axis accelerometer, an NXP LPC2103 ARM microcontroller, 4 megabytes of flash storage, and a Lithium-Ion battery pack. A patch GPS antenna was installed within the collar strap.

Under normal operation, the microcontroller would wake at a fixed interval (15 minutes in this case), and acquire data from the GPS unit, the temperature sensors and the accelerometer. The microcontroller would then record the data to the internal flash storage and return itself and the GPS receiver to a sleep state. As the GPS receiver executed a warm start at each wake up, time to acquisition was variable from ~10 to ~120 seconds, depending on satellite visibility and signal quality. Data was retrieved from the collars via a serial connection after putting the collar in a data retrieval mode. Due to a manufacturing flaw, the accelerometer was disabled in the final design.

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Geospatial Research Group
University of Canterbury

Records of GPS collars on Glenmore

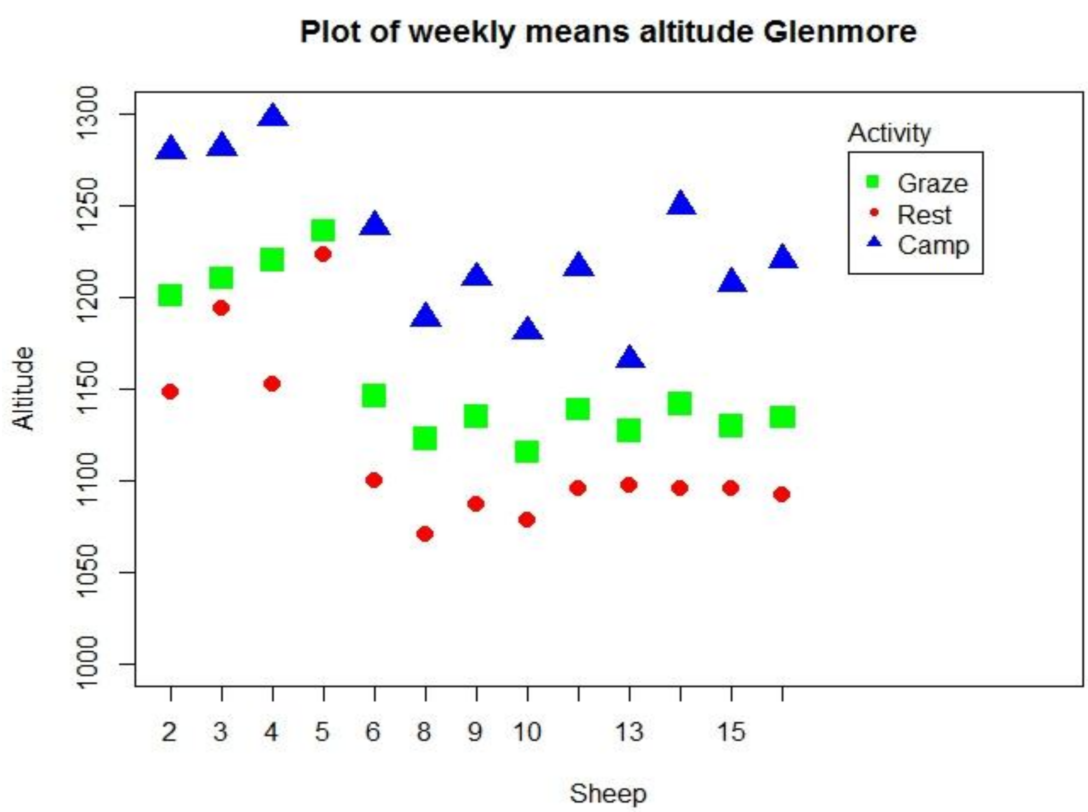
Sheep no.	FSR	Days	No. of records	Notes	Block
1	100	5	543	Not used in the analysis	Top
2	100	9	825	Week	Twin
3	99	58	4403	Week and month	Twin
4	99	25	2386	Week	Twin
5	84	37	2896	Week and month	Twin
6	100	14	1303	Week	Top
7	100	4	426	Not used in the analysis	Twin
8	92	10	874	Week	Twin
9	100	30	2831	Week and month	Twin
10	99	7	764	Week	Twin
11	64	34	2458	Week and month	Top
12	100	1	81	Not used in the analysis	Top
13	100	7	758	Week	Top
14	99	43	4020	Week and month	Top
15	99	47	4396	Week and month	Top
16	99	7	775	Week	Top

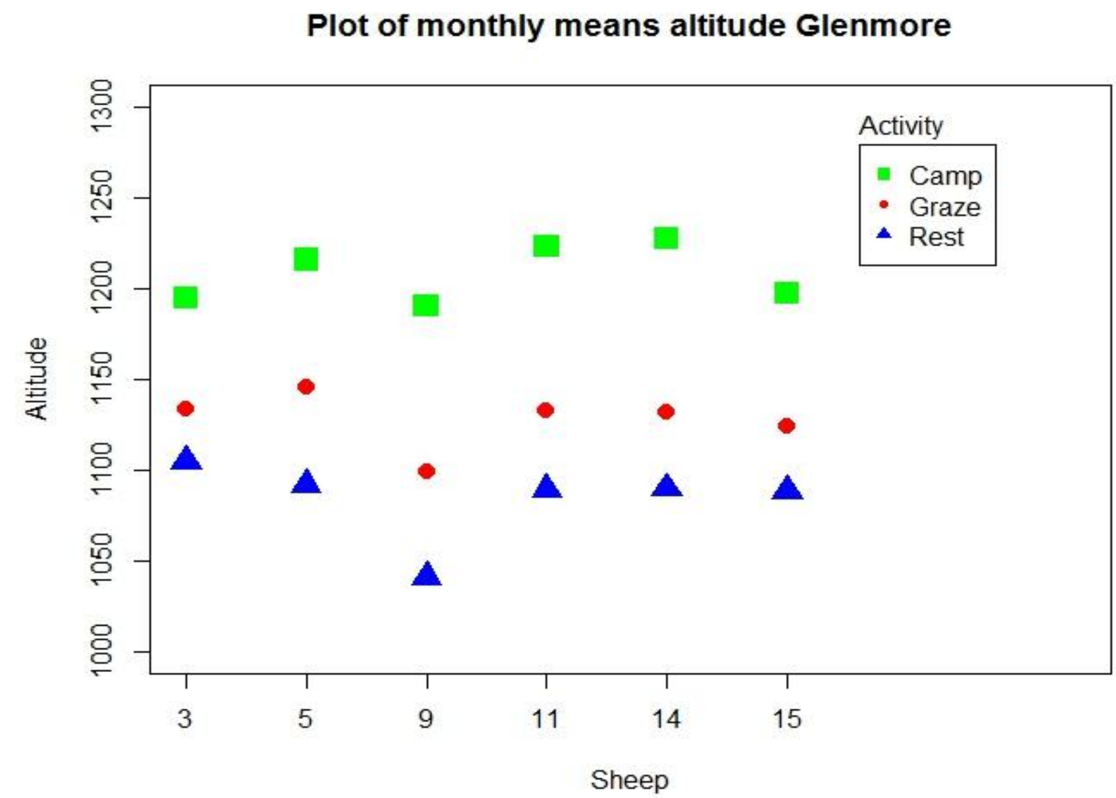
Percentage of vegetation type used and available on Glenmore, using weekly data from 13 sheep

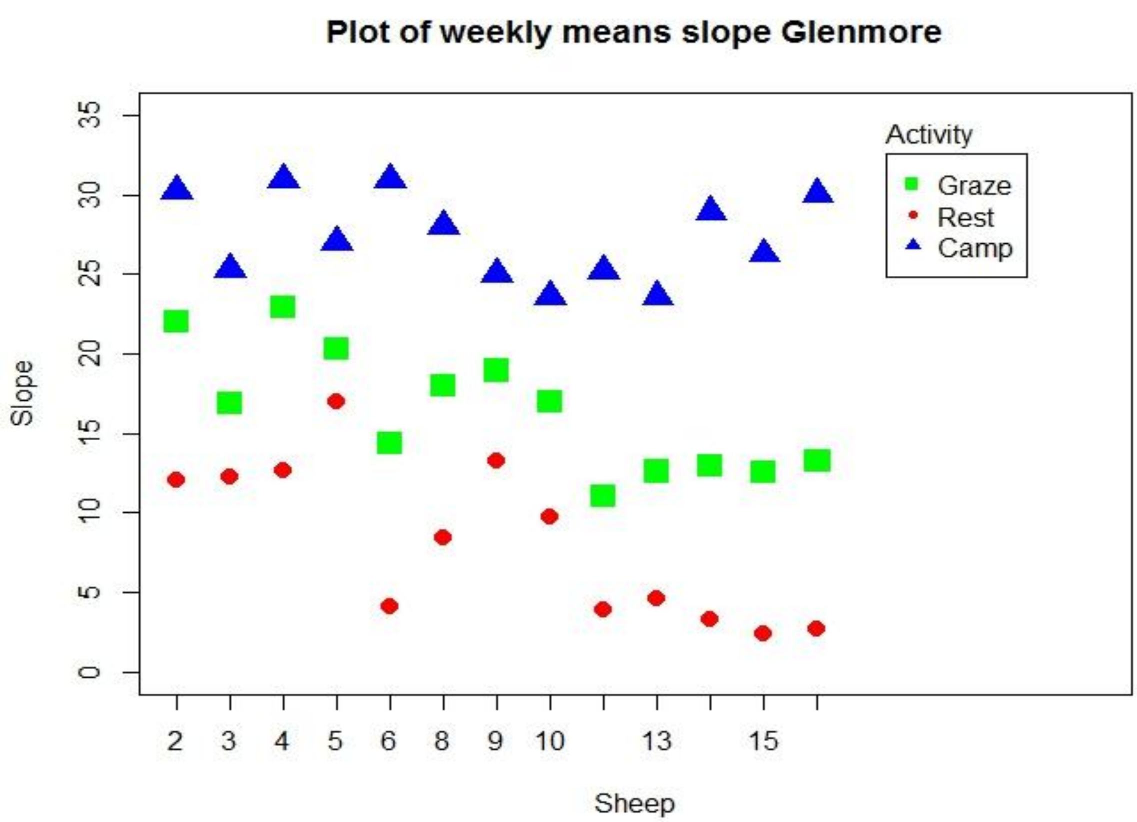
Vegetation type	Resting	Grazing	Night camping	Study area
Alpine Grass/Herbfield	0.0	0.0	0.0	1.8
Alpine Gravel and Rock	3.6	4.9	3.7	15.3
Grey scrub	0.0	0.1	0.0	1.3
Low producing grassland	0.0	0.1	0.0	2.0
Exotic grassland	0.0	0.0	0.0	0.2
Native mix	4.7	11.8	27.8	4.6
Riverbed	34.4	10.7	0.6	14.4
Short tussock grassland	46.3	50.0	22.7	20.7
Sub Alpine Shrubland	0.0	0.0	0.1	2.6
Tall tussock grassland	11.1	22.4	45.2	37.2

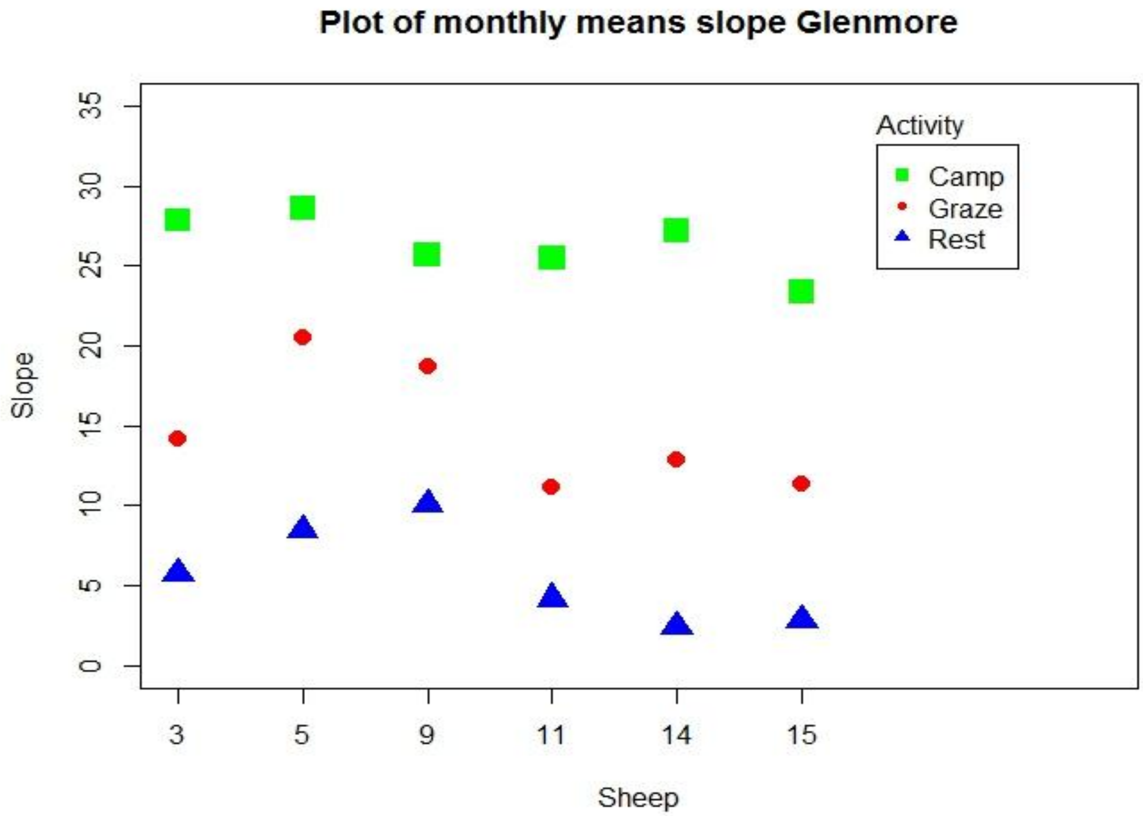
Percentage of vegetation type used and available on Glenmore, using monthly data from 6 sheep

Vegetation Type	Resting	Grazing	Night Camping	Study area
Alpine Grass/Herbfield	0.0	0.0	0.0	1.8
Alpine Gravel and Rock	3.3	4.1	4.0	15.3
Grey Scrub	0.0	0.0	0.0	1.3
Low producing grassland	0.0	0.4	0.0	2.0
Exotic grassland	0.0	0.0	0.0	0.2
Native mix	2.8	9.1	30.7	4.6
Riverbed	42.1	13.6	0.9	14.4
Short tussock grassland	47.3	56.2	25.2	20.7
Sub Alpine Shrubland	0.0	0.1	0.2	2.6
Tall tussock grassland	4.6	16.6	39.1	37.2




Plot of monthly means altitude Glenmore
Activity
Camp
Graze
Rest
Altitude
1000
1050
1100
1150
1200
1250
1300
3
5
9
11
14
15
Sheep


Plot of weekly means slope Glenmore
Activity
Graze
Rest
Camp
Slope
0
5
10
15
20
25
30
35
2
3
4
5
6
8
9
10
13
15
Sheep


Plot of monthly means slope Glenmore
Activity
Camp
Graze
Rest
Slope
0
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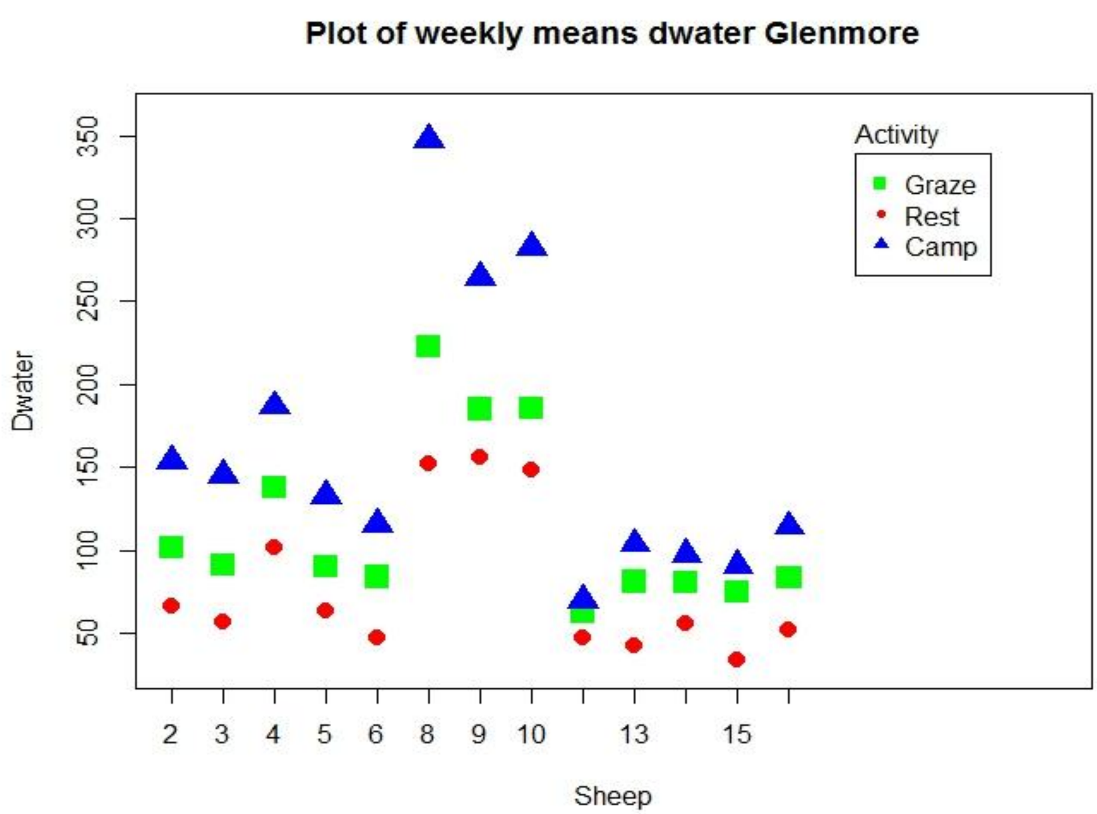
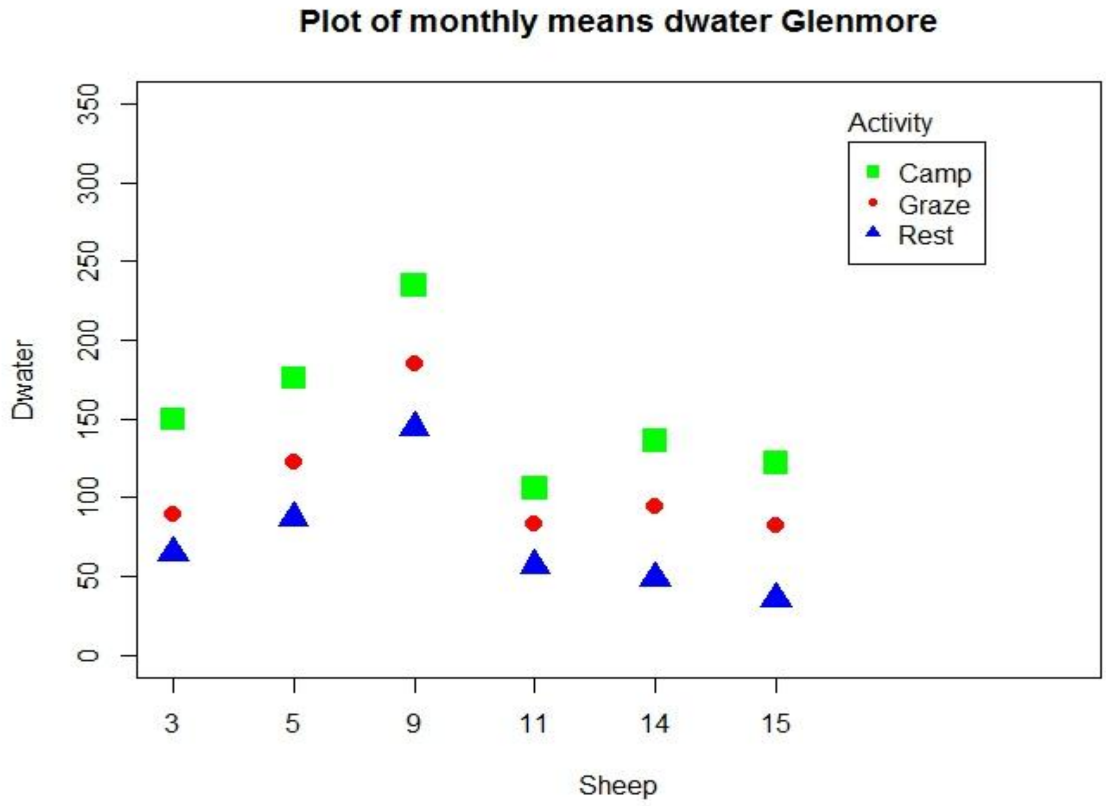
Sheep


Plot of weekly means dwater Glenmore
Activity
Graze
Rest
Camp
Dwater
50
100
150
200
250
300
350
2
3
4
5
6
8
9
10
13
15
Sheep



Otematata tables

Summary of landcover types and their brief description on Block A, Otematata. (Data from Landcover Database 2009, available from www.koordinates.com)

Abb.	Habitat	Plant communities	Area (ha)	Area (%)
TT	Tall tussock grassland	*C. rigida*, *Poa colensoi*, *Raoulia*, *Epilobium*	1304	57
AGR	Alpine gravel and rock	Low growing herbs	710	31
AGH	Alpine grassland and herbfield	Low growing herbs and grasses	205	9
DT	Depleted tussock grassland	*C. rigida*, *Festuca nz* and exotics	28	1
SHR	Subalpine shrubland	*Hebes*, *Dracophyllums*	16	1
HFV	Herbaceous freshwater vegetation	*Carex*, *Juncus*, *Schoenus*	10	0.5
Other	Ponds and lakes		5	<1
	Grey scrub		3	<1
	Landslide		1	<1

Summary of attributes on Block A, Otematata.

Altitude	%	Slope	%	Aspect	%
1300	4	5	12	Flat	11
1400	12	10	26	N	13
1500	15	15	21	NE	24
1600	18	20	15	E	26
1700	23	25	13	SE	12
1800	17	30	8	S	7
1800+	12	30+	6	SW	2
				W	0.5
				NW	5

Percentage of landcover types used by month and by time period for the pooled data from sheep 1,3 and 4 in Block A and the Chi-square statistic (df = 5, * p=0.05, ** p<0.01, *** p<0.001

	Dec	Jan	Feb	Mar	Morn	Day	Eve	Night	Ave	Avl
AGH	6.8	14.7	3.9	2.1	6.6	6.1	4.0	7.9	6.8	8.9
AGR	36.9	42.5	39.1	17.3	34.8	30.1	27.3	39.1	34.0	31.0
DT	3.4	0.5	0.5	0.0	0.6	1.9	1.6	0.0	0.8	1.2
HFV	0.8	0.2	1.1	1.0	0.4	1.7	1.0	0.1	0.8	0.7
SHR	0.4	1.7	0.5	0.3	0.6	1.1	1.3	0.0	0.9	0.7
TT	51.7	40.6	55.3	79.4	56.9	57.4	64.9	52.9	56.6	57.0
$\chi 2$	315 ***	990 ***	555 ***	1411 ***	54 ***	107 ***	337 ***	441 ***	53 ***	