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The impact of red deer grazing on the vegetation of a modified subalpine red tussock grassland paddock in Te Anau, Southland.

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LAY SUMMARY

- This report investigates what impact farmed red deer hinds are having on the vegetation of South Island high country tussock grassland paddocks and the resulting implications for both deer production and the long term stability of these ecosystems. This information combined with the findings from two previous hind grazing behaviour studies will help in the development of farm management strategies that aim to improve breeding hind and calf productivity, while at the same ensuring these extensive grazing systems remain sustainable.

- The study was based on a large 250 ha red tussock grassland paddock at Haycocks Station, near Te Anua. Prior to being deer fenced in 2003, the main plant communities (vegetation types) in the tussock grassland paddock had already been highly modified by being oversown with exotic pasture species and grazed with sheep and cattle. The study paddock also contained very diverse topography, including a wide range of elevations, hill slopes, and aspects.

- Each year, approximately 620 mixed aged (MA) breeding hinds graze the paddock from late October through until late May, while 600 MA beef cows graze it in June. During these two periods, the hinds and cows are set-stocked at 5 and 14 stock units per hectare (SU/ha), respectively. The hind stocking rate used on this farm is at the high end of the scale for South Island extensive deer farming systems, but is still much lower than those typically used on lowland intensive farms (e.g. often up to 16 SU/ha at calving).

- Repeated vegetation surveys of the study paddock, taken in 2005/06 and 2010, were compared to determine if the abundance and distribution of the resident plant species have changed over time under the current deer and cattle grazing management practices. Two survey methods were used to measure any potential changes at both the individual plant species level and also the broader plant community level. Detail field surveys were conducted for the former, whereas high resolution satellite image analysis was used for the later.

- Four main vegetation types were identified in the paddock and given the following names describing their most prominent characteristics: medium legume content (ML) pasture, high legume content (HL) pasture, shrubland, and tussock vegetation. A fifth category ‘bare ground’ was also identified in the satellite imagery.

- In 2006, ML pasture covered the greatest total area of the study paddock (36.3%), followed in order by shrubland (28.6%), HL pasture (25.4%), tussock (9.2%) and bare ground (0.4%). HL pasture only approached a similar level of abundance to ML pasture on rolling to strongly-rolling (8-20^{o}) terrain, at mid-to-high elevations (550-599m above sea level), and on westerly aspects (NW, W, SW). Shrubland and tussock were mainly located on steep southerly hill slopes, increasing in abundance on lower and higher elevations, respectively.

- One of the greatest changes in vegetation coverage that occurred between 2006 and 2010 was a 20% increase in HL pasture, at the expense of mainly ML pasture (17.9% substitution) and to a much lesser extent tussock vegetation (1.6% substitution). The increase in legume content was attributed to lower spring and early-summer pasture growth rates in 2010, compared to in 2006, enabling the hinds to control excessive pasture covers and encouraging the proliferation of legume growing points in the base of the pasture sward. The availability of high quality forage in inter-tussock areas, along with high soil fertility, can increase the palatability of tall tussocks to grazing livestock. This, along with possibility that some sub-dominant hinds in the herd were being forced by other more dominant hinds to graze these areas, may have caused the loss of tussock paddock coverage to HL pasture.

- In 2010, the average legume content in the pasture was 30%, whereas it was 10% in 2006. Developing grazing management practices that attain the former high legume content every year over summer and autumn (i.e. the calving and lactation seasons) would be highly profitable, benefiting both the overall body condition of the breeding hinds and also the growth rates of their calves at foot.

- The total paddock area covered in shrubland increased by 9% between 2006 and 2010. Encroachment was mainly into ML pasture (5.8% substitution) and to a lesser extent tussock vegetation (3.0% substitution). This natural succession from grassland to shrubland would have occurred in the absence of livestock grazing. High grazing pressure can suppress the establishment of woody plant seedlings, which may have been the reason why there was no ingression of shrubland vegetation into HL pasture vegetation. The increase in shrubland vegetation, especially large dense patches of matagouri, will reduce the paddock's effective grazing area and increase hind competition for alternative more accessible pasture and tussock vegetation areas.

- Less tussock vegetation in the paddock may reduce the breeding herd's reproductive productivity via higher perinatal calf mortality. This vegetation is valued by hinds for enabling them to give birth in isolation away from the rest of the herd. Loss of this vegetation could lead to greater levels of stress in parturient hinds as they seek a suitable birth site for calving and may also lead to greater disturbance and interference when the hind and newborn calf are initially bonding. In addition, the loss of tussock vegetation especially on steep upper hill slopes may increase these areas susceptibility to soil erosion.

- There was no significant loss in total plant species richness in the paddock. However, remnant tussocks in pasture dominant vegetation have decreased in abundance and there has also been an increase in the total number of weed and rush species present in tussock dominant vegetation.

- Overall, the results show that the presently used grazing management regime is causing a change in the abundance and distribution of the current vegetation in the paddock. It also highlights many of the difficulties faced when trying to manage large grassland paddocks with highly diverse topography. More even control of excess spring pasture growth across the whole paddock looks to be a major factor for encouraging greater legume contents in the pasture. Increasing the grazing pressure on ML pasture areas may also help to stem the encroachment of shrubland vegetation into this vegetation type, but would need to be carefully managed so not to place any extra grazing pressure on the tussock vegetation.

ABSTRACT

Repeated vegetation surveys were conducted in a large modified red tussock grassland paddock in Southland to determine the effect farmed red deer are having on the resident vegetation over time. The vegetation surveys were based on detailed field-plot measurements of individual plant species and also much broader satellite image analysis of the main identified plant communities (vegetation types) in the paddock. The topography of the paddock was highly variable and was covered in a complex mosaic of mainly pasture, tussock, and shrubland vegetation. The resulting survey comparisons showed that both the distribution and overall abundance of the main identified vegetation types in the paddock have been changing under the current deer grazing management practices. Two of the most marked changes in the paddock have been an increase in shrubland coverage and conversely a decrease in tussock coverage. Different grazing pressures applied to each main vegetation type look to be a major driver of these changes, which in turn is being affected by the variable topography of the paddock and the current set-stocking densities being used. There was no significant loss in total plant species richness in the paddock. However, remnant tussocks in pasture dominant vegetation have decreased in abundance and there has also been an increase in the total number of weed and rush species present in tussock dominant vegetation.

Key words: Red deer, red tussock, vegetation mapping, plant species diversity

1. INTRODUCTION

Increasingly more and more of New Zealand’s national red deer breeding herd is being farmed in the South Island high-country (Asher et al. 2009). The expansion of this type of livestock enterprise has arisen from its favourable economic returns, relative to traditionally run sheep and cattle, and also its high compatibility with the available resources and farm management practices typically used in South Island high-country farming systems (Peoples and Asher 2009). On these farms, parturient hinds are normally set-stocked at a low density of 1-4 hinds per hectare (ha) in large (e.g. 100-250 ha) semi-improved tussock grassland paddocks over calving and lactation, with the overall aim of maximising the calving and weaning performance of the herd. Owing to the sheer size of the paddocks and the class of land where they are situated, these paddocks usually contain a very diverse range of elevations, aspects, slope classes, and indigenous and exotic plant species (Netzer et al. 2009; Wall et al. 2011).

The set-stocking of these large paddocks at low stocking rates allows the hinds to selectively graze for highly nutritious forages, which when abundant normally leads to achieving high individual animal performance. However, previous research in other hill country and rangeland farming systems has shown that allowing for highly selective grazing, and also the effects of diverse topography on animal grazing behaviour, can alter the disturbance and environmental stress inflicted on resident plants, causing a shift in the botanical species composition of a paddock’s vegetation over time (Harris 1990; Briske 1996). From an animal production point of view, changes towards more agronomically productive plant species could be highly beneficial. However, less desirable would be the loss of vegetation valued by the hinds for shelter and cover for parturition, the ingression of plant species with little agronomic or soil/water conservation value, and the development of plant communities with little resilience to coping with major environmental perturbations.

Until recently, little quantitative information was available on how farmed red deer even use the different habitats available within semi-improved tussock grassland paddocks. However, two recent studies conducted at Haycocks Station in Southland (Netzer 2008; Netzer et al. 2009) and at White Rock Station in South Canterbury (Wall et al. 2011), using remote sensing GPS and GIS technologies, have revealed red deer hinds mainly use pasture and tussock vegetation, rather than shrubland vegetation, during the calving and lactation seasons. Also, the majority of hinds throughout the course of a day did not evenly use these vegetation types, indicating that they may be applying uneven grazing pressure to some plant communities and potentially transferring soil fertility to others. Overall, these results indicate that the presently used grazing management regimes could over time cause changes in the abundance and distribution of the current vegetation within these paddocks.

For the original Haycocks Station study a detailed botanical species composition field survey was conducted and also a detailed vegetation map created from an aerial photograph of the site (Netzer 2008; Netzer et al. 2009; Clarke 2012). The objective of this study was to re-survey the vegetation several years later to determine how the abundance and distribution of the main previously identified plant communities have changed over time under the current grazing management practices. This information, together with the deer grazing behaviour results obtained from previous work, will provide baseline information useful for developing management strategies that aim to increase or at least maintain desirable plant species considered important for both deer production and the long term stability of these high-country ecosystems.

2. MATERIALS AND METHODS

2.1 Site description

The study site at Haycocks Station was a large 250 ha tussock grassland paddock ('Rough Gully'), located near the junction of State Highway 94 and Mavora Lakes Road, approximately 30 km east of the township of Te Anau (Long. 45^{o} 30'40''S Lat. 168^{o}01'20''E). This paddock was deer fenced in 2003, but prior to this its indigenous tussock and shrubland vegetation had already been highly modified by being oversown with exotic pasture species and grazed with sheep and cattle. As a result, by 2006 when the first detailed vegetation map of the paddock was created by Netzer (2008), the majority of its area was pasture (77%), followed in order by shrubland (15%) and then tussocks (7%), with minor patches of bare ground also present (1%) (Figure 1a). The main naturalised exotic grass and legume species in the pasture areas were crested dogstail (*Cynosurus cristatus*), cocksfoot (*Dactylis glomerata*), browntop (*Agrostis capillaris*), and white clover (*Trifolium repens*). Red tussock (*Chionochloa rubra*) was the dominant tussock species, with silver tussock (*Poa cita*) and blue tussock (*Poa colensoi*) equally the next most prominent. Matagouri (*Discaria toumatou*) was the main woody shrub species (Clarke 2012). In the study on Haycocks Station by Netzer (2008) and Netzer et al. (2009), hind daily behavioural patterns and resource use was tracked with Global Positioning System (GPS) receivers in two other neighbouring paddocks as well – Beehive Gully and Big Basin (Figure 1a). However, the present study was restricted to the Rough Gully paddock because it was the only paddock where Clarke (2012) first conducted a detailed plant botanical species composition field survey of the area in 2005/06.

Rough Gully consists of several sub-catchments, which are located between 420 m and 700 m above sea level (a.s.l.), has mainly hill (12-28^{o}) to steep land (>28^{o}) topography, and also contains multiple aspects (Figure 1b). The climate of the site is 'summer-moist'. Annual rainfall at Manapouri Airport, located 27km east of Haycocks Station at 209 m a.s.l., is 1076 mm and this rainfall is distributed evenly throughout the year, with February being the driest month (84 mm) and October the wettest (106 mm). The mean annual air temperature is 9.4^{o}C, ranging from 14.7^{o}C in January to 3.8^{o}C in July (NIWA, 2012).

Since the paddock's redevelopment for deer farming in 2003, it has been grazed with hinds set-stocked at a density of 2-3 hinds/ha over late spring (October) through to late autumn (early May) and is also grazed with cattle for just under a month in mid-winter (July) (Paul Ewing pers. comm. 2011). This hind stocking rate is relatively high for extensive deer farming systems, which normally stock hinds at 1-4 animals/ha, but is much less than the 8-12 hinds/ha often used in intensive lowland systems (Asher and Peoples 2009; Netzer et al. 2009; Wall et al. 2011). .

2.2 Vegetation field surveying

2.2.1 *Field survey plots*

The vegetation of the paddock was first field-surveyed over two separate months in November 2005 and January 2006 by Clarke (2012). For this original survey 59 randomly selected plots located across the paddock were sampled. Prior to conducting the fieldwork, Global Positioning System (GPS) co-ordinates of the survey plot locations were generated on a topographical map of the site in ArcGIS using the Hawth’s Tools open source extension computer program. Within the Hawth’s Tools toolset the ‘Generate Random Points’ function was used to generate the random sample points for the survey plots. These sample points were then related to ‘real world’ reference points based on the NZMS260 co-ordinate system in ArcGIS. In the field, all of the sample points were located using a Garmin 76™ GPS unit, which has a manufactures reported accuracy of 15m (Clarke 2012).

Each field-survey plot consisted of a 5 m X 5 m square quadrat, positioned on the magnetic north side of its GPS point. Inside the quadrat perimeter all vascular plant species were identified and their percent coverage visually estimated. Samples of any species unable to be clearly identified in the field were collected for later identification. The slope and aspect of the plots were measured with an abney level and magnetic compass, respectively; while, the altitude of a plot was estimated by superimposing its GPS location onto a 1:50 000 scale topographical map of the site in ArcGIS (Clarke 2012). Initially 100 points were generated in ArcGIS for sampling. However, only 59 were used, as this number was deemed sufficient to characterise the vegetation of the paddock based on the levelling off of a developed species richness-area curve (Clarke 2012).

Clarke (2012) categorised the 59 field-surveyed plots into four main plant communities (vegetation types), based on the relative abundance (measured as percent coverage) of each of the identified plant species within the plots, using multidimensional scaling (MDS) and Cluster Analysis statistical methods. These main vegetation types were given a descriptive name relating to the main plant species contributing to their differentiation, and included: matagouri shrubland, snow tussock, pasture, and clover fields. Out of the 59 plots sampled 11, 30, 8, and 7 were categorised as matagouri shrubland, snow tussock, pasture, and clover fields, respectively. Three of the field-surveyed plots were identified as outliers in the statistical analyses and as a result were removed from the study.

In total, 23 out of the 59 original survey plots were re-sampled in February 2010, using exactly the same procedure used by Clarke (2012). Out of the re-sampled plots 5, 12, 4, and 2 were from matagouri shrubland, snow tussock, pasture, and clover fields, respectively. The plots were relocated with a Garmin 76™ GPS using the same GPS co-ordinates used by Clarke (2012). The plots were also grouped into the same vegetation types to which they were originally categorised into by Clarke (2012). However, unlike Clarke’s categories, both the pasture and clover field plots were combined into a single ‘pasture’ category, owing to the small number of plots (n=2) re-sampled for the latter in 2010.

2.2.2 *Livestock grazing of study paddock*

Over the 4 years between vegetation field-surveys the Rough Gully paddock was grazed each year with about 618 mixed aged (MA) breeding hinds in the spring-autumn (October to early May) and with 600 MA beef cows for a short period in the winter (June). During these two periods, the hinds and cows were set-stocked at 5 and 14 stock units per hectare (SU/ha), respectively, which on average was equivalent to 1327 SU grazing days/ha/yr (Table 1). Over the same 4 year interval between field surveys, 125 kg/ha of superphosphate fertiliser was aerially top-dressed onto the paddock in 2006 and 2008, while 1 t/ha of lime was applied in 2010 (Paul Ewing pers. comm. 2011).

2.2.3 *Plant diversity indices calculated from field-survey plots*

The plant species richness (S), and a Shannon diversity index (H) and Pielou evenness index (J) of each paired plot, surveyed in both 2005/06 and 2010, was calculated to investigate whether there had been any significant changes in plant species diversity over time. Plant species richness was calculated as the total number of different plant species visually identified in each plot and is a measure of the variety of species present (Spellerberg and Fedor 2003). However, it does not provide any quantitative information on the structure of the plant community in terms of the abundance of individual species relative to each other, which also contributes to the overall diversity of a plant community (Landsberg et al. 2003). In contrast, the Shannon diversity index (H) weights each of the identified species to its relative abundance in a plot based on the formula:

$$H = - \sum(pi*\ln(pi))$$

where, pi is the proportion of the plot area covered by species i (Magurran 1988).

Using the formula $N = e^H$, the Shannon diversity index values were converted to values representing the effective number (N) of equally-abundant species required to obtain the same mean proportional species abundance as that actually observed for each plot.

In response to livestock grazing, often the abundance of the different plant species relative to each other changes more rapidly than the species richness in a plant community (Chapin et al. 2000). Therefore, given the relatively short time frame of 4 years between field surveys, a Pielou evenness index (J) was also calculated to investigate whether the evenness in abundance of the different species (i.e. dominance structure) in the plant communities has changed. This index was calculated as:

$$J = H/H_{max}$$

where, H is the number derived from the Shannon diversity index and H_{max} is the maximum value of H, equal to:

$$H_{max} = - \sum(1/S*\ln(1/S)) = \ln(S)$$

where, S is the total number of species identified in the plot (species richness) (Magurran 1988).

This index quantifies how similar in abundance the different species are to each other and its value is constrained between 0 and 1. When the proportions of all of the species in a community are the same then the Pielou evenness index will equal 1, but when their abundances are very dissimilar (i.e. some species are rare, while others are very common) then the value decreases (i.e. the less variation in species abundance, the higher the index value).

2.3 Vegetation and topographic mapping of the study site

High resolution digital satellite images taken of the Rough Gully paddock in late January 2006 and early February 2010 were also compared to assess if the abundance and distribution of the four main vegetation types originally identified by Clarke (2012) had changed over time on a much broader whole paddock scale. Both satellite images were analysed using ENVI EX (ITT Manufacturing Enterprises, Inc.) image analysis computer software. This process involved three stages: 1. preparing the raw satellite imagery for analysis, 2. characterising and mapping the vegetation in the two satellite paddock images, and 3. identifying any change in the location of the four main vegetation types. The geospatial data generated from the image analyses in ENVI EX were then exported into ArcGIS 9.3 (ESRI, Readlands, CA. USA), which is a Geographic Information System (GIS) computer software package, to identify the type of topography where the changes were detected.

The ‘Quickbird’ satellite (DigitalGlobe, Inc.) took the 2006 imagery on 31 January, whereas the ‘Worldview2’ satellite (DigitalGlobe, Inc.) took the 2010 imagery on 10 February. These satellites both carry multispectral and panchromatic (black and white) waveband sensors, which have spatial resolutions of ≤ 2.4m and ≤ 0.6m, respectively. The high spatial resolution of the panchromatic images enabled the identification of individual shrubs in the paddock. The spectral wavebands used for the image analyses included: blue (450-520 nm), green (520-600 nm), red (630-690 nm), near infra-red (760-900 nm), and panchromatic (black and white; 450-900 nm). Even though the newer ‘Worldview2’ satellite also measures several other multispectral wavebands, these were not used for this study to maintain consistency between years.

2.3.1 *Preparing the raw satellite images for analysis*

Several image pre-processing and enhancement procedures were used to correctly align and increase the overall accuracy of the raw satellite imagery. The location of a series of permanently identifiable ground control points (GCPs), clearly visible in the panchromatic satellite images, were measured in the field with a highly accurate (<0.5m) Trimble ProXH GPS receiver (Trimble Navigation Ltd.). In ENVI EX, these GCPs were used to geo-reference all of the satellite geospatial data into one common geographical co-ordinate system, which in turn enabled the images to be correctly aligned. The locations of the GCPs were distributed evenly over the acquired satellite images, included a range of representative elevations, and some points were located well outside the study paddock’s boundary to ensure its entire area was covered for making the spatial adjustments.

The satellite images were supplied in a format already radiometrically calibrated and corrected for sensor and satellite platform-induced distortions. However, topographic (relief) image distortions had to be corrected using a 15 m spatial resolution digital elevation model (DEM) of the region, which was obtained from Landcare Research Ltd. Without this adjustment the highly variable topography of the study paddock altered the scale of objects displayed in the images by changing their angle of incidence with the satellite’s sensors. A comparison of the GCPs latitude and longitude co-ordinates in the adjusted (Orthorectified) images against those measured with the GPS receiver on the ground revealed the ‘Quickbird’ and ‘Worldview2’ imagery had a root mean square error of 0.91m and 8.5m, respectively. The much larger error of the latter was likely due to this image scene having a lot fewer available GCPs.

Both images were panchromatic-sharpened in ENVI EX, using the Gram-Schmidt method, to enhance their visual interpretation (Laben and Brower 2000). This process merges/fuses the geospatial data contained in the high resolution panchromatic and lower resolution multispectral imagery together to create a single high resolution colour image (Pohl and Van Genderen 1998). Merging all of the spectral wavebands, enabled the identification of finer object detail, compared to using the multispectral wavebands separately, and also increased the spectral ‘texture’ of the image.

Neither of the satellite images covered the entire area of the study paddock. Therefore, the image analyses were restricted to only where the two images overlapped, which represented 62% (155 ha) of the total 250 ha paddock (Figure 2).

2.3.2 *Characterising the spectral signatures of the main vegetation types and mapping their coverage in the study paddock*

Two digital vegetation maps of the study paddock were created from the adjusted 2006 and 2010 satellite images using the ‘supervised classification workflow’ in ENVI EX. For this method the blue, green, red, and infra-red spectral properties of each of the four main vegetation types were sampled from a series of ‘training sites’ identified in the satellite imagery. In ENVI EX, the perimeters of the ‘training sites’ were outlined and the multiple spectral properties of each pixel within their boundaries measured. Wherever possible, the training sites for each vegetation type were taken from a variety of regions across the paddock to incorporate their full range of spectral characteristics. Table 2 presents the hierarchical classification scheme used for the main vegetation types at Haycocks Station and also includes information on the total number of ‘training sites’ measured for characterising their spectral properties.

The sampled spectral properties were used to assign all of the pixels making up the paddock’s digital image into the main vegetation class to which they had the highest probability of belonging based on a maximum-likelihood algorithm. This parametric classification method assumes the multivariate (blue, green, red and infrared waveband) spectral data follows a normal probability distribution and determines the appropriate parameters (mean vector and covariance matrix) from the sampled training data. Each pixel in the digital image is then assigned to the vegetation class for which its spectral values are most likely, i.e. the class with the highest posterior probability (Keuchel et al. 2003).

Classifying digital image pixels based solely on their multiple spectral properties, without using additional information given by neighbouring pixels, often leads to noisy classification results that cause a ‘salt and pepper’ effect on the resulting vegetation maps (Keuchel et al. 2003). These effects were subjectively removed in both the 2006 and 2010 maps by using smoothing and aggregation ‘cleanup’ functions in ENVI EX.

2.3.3 *Identifying changes in vegetation cover that have occurred over time*

The 2006 and 2010 vegetation maps were compared using the ‘thematic change detection’ workflow in ENVI EX. This post-classification method takes the classified vegetation maps (thematic images) of the same scene at different times and identifies all of the pixels that have changed from one vegetation type (class) to another. To show the extent and distribution of these temporal changes new digital maps illustrating the vegetation class transitions were generated in ENVI EX and this spatial data was also exported into ArcGIS to determine where in the paddock the changes were occurring in terms of hill slope, aspect, and elevation. For this latter analysis a topographical map of the study paddock was created in ArcGIS from a 15 m resolution digital elevation model (DEM) of the region obtained from Landcare Research Ltd.

2.4 Statistical analysis

The range of elevations, slopes, and aspects present within the study paddock’s topographical map were split into discrete categories (classes) using ArcGIS Spatial Analyst Extension software. A definition of the hill slope categories is given in Appendix 1. The total area of the paddock included within each category was then calculated and the percentage of the paddock which this represented graphed to provide a basic description of the study paddock’s topography. For each of these categories the percentage area covered by the three main vegetation types, along with an additional bare ground land cover type, were also calculated from the 2006 vegetation map and then graphed to give a description of where each vegetation type initially resided.

The total plant species richness, diversity, and evenness of the main pasture, tussock and shrubland vegetation types identified in the paddock were compared between the two field-survey years using pairwise t-tests. For each of these three main vegetation types all of the plant species present within their respective quadrats were further subdivided into the following sub-categories (guilds): indigenous woody shrubs, indigenous ferns and bracken, indigenous herbs and climbers, indigenous tussocks, exotic grasses, exotic legumes, exotic pastoral weeds, and unidentified species. The average species richness and percentage coverage of each sub-category per quadrat was then analysed separately, again using pairwise t-tests, to determine if they also changed significantly over time.

The locations where the main vegetation classes had changed between survey years were related to the discrete slope, aspect, and elevation categories using ArcGIS Spatial Analyst Extension software.

3. RESULTS

3.1 *Topography and locations of the main vegetation types*

Figure 3 provides a general description of the topography present in the section of the Rough Gully paddock covered by both the 2006 and 2010 satellite imagery. Overall, the satellite imagery included a wide range of paddock elevations from 445m to 645m a.s.l. Both of these extremes were within 50m of the reported range surveyed for the entire paddock by Netzer (2008) and Netzer et al. (2009). The largest percentage of area covered in the imagery (44%) was in the low-to-mid (500-549m) elevation class, while the high (600-645m) elevation class contained the smallest percentage of area in the imagery (8%) (Figure 3a). The slope of the paddock also varied markedly from flat (0-3^{o}) to very steep (>35^{o}). Rolling to strongly rolling (8-20^{o}) terrain, accounted for 59% of the area covered in the imagery, whereas moderately steep to steep (21-35^{o}) terrain accounted for a further 34% of the area covered (Figure 3b). The paddock contained multiple aspects, but the hill slopes generally faced a north-westerly, westerly and southerly direction, with little area particularly situated on east and north-east facing aspects (Figure 3c).

In 2006, pasture was the dominant plant community (vegetation type) in the paddock, making up 62% of the total land cover (Figure 4a). Of the two identified sub-categories of pasture, medium legume content (ML) pasture made up a larger percentage of the vegetation within each elevation class in comparison to the high legume content (HL) pasture, particularly at the highest elevation (600-645m) and to a lesser extent at low (445-499m) and low-to-mid (500-549m) elevations (Figure 4b). The amount of tussock in each elevation class was more variable than for the pasture vegetation, ranging from 3% to 23%, and increasing exponentially when moving up the different elevation classes. In contrast, the greatest proportion of shrubland vegetation occurred at the lowest elevation class of 445-499 m a.s.l., making up 38% of the vegetation, and decreased exponentially when moving up the elevation classes.

ML pasture also made up the greatest percentage of vegetation in all of the defined hill slope classes, except for steep (26-35^{o}) terrain, and ranged between 30% and 53% of the total vegetation (Figure 4c). In contrast, each slope class contained a much lower percentage of HL pasture, with a maximum of 31% occurring in rolling (8-15^{o}) terrain. Tussock made up the lowest percentage of vegetation in all of the slope classes and was particularly low (<5%) on the flat to undulating land (0-7^{o}). The percentage of shrubland increased especially on moderately steep (21-25^{o}) to steep (26-35^{o}) terrain, accounting for 32% and 44% of the vegetation, respectively.

Figure 5 indicates that the North, North-East, East, and South-east facing hill slopes were dominated by ML pasture, which ranged from 49% to 82% of the vegetation on these aspects. In contrast, shrubland vegetation dominated the South and South-west aspects, while both subclasses of pasture and shrubland were equally the main vegetation types present on West and North-west hill slopes. Tussock was confined mainly to locations on Southerly and to a lesser extent Westerly aspects. Bare ground made up <1% of the land cover on all aspects, but was most prevalent on southeast facing hillsides (Figure 5e).

3.2 Changes in the distribution of the main vegetation types

Figure 6 shows the two vegetation maps developed from the 2006 and 2010 high resolution satellite imagery. A visual comparison of Figure 6a and 6b clearly indicates that between the two survey years there was a large reduction in ML pasture and to a lesser extent tussock vegetation, with a corresponding increase in HL pasture and again to a lesser extent shrubland vegetation. The ‘thematic change detection’ image analyses carried out in ENVI EX further confirmed these observations. Out of the main identified vegetation types in the paddock, the total area covered by ML pasture and tussock decreased by 24 and 5 percentage points, respectively (Figure 7). Conversely, HL pasture and shrubland vegetation increased by 20 and 9 percentage points, respectively (Figure 7). There was also a small increase in total paddock area covered by bare ground with it increasing by about 1 percentage point (Figure 7).

Of the 24% of total paddock area that had changed from ML pasture to another vegetation type, 18% changed to HL pasture and 6% changed to shrubland vegetation (Figure 8a). For the latter two vegetation types, additional but more minor gains in total paddock area also originated from tussock vegetation (Figure 8c). The small increase in Bare ground area came mainly from ML pasture (Figure 8e).

All of the above changes in land cover generally occurred in proportion to each vegetation type’s original 2006 hill slope and elevation class distribution across the study paddock, so that the greatest levels of change occurred where the vegetation was already most abundant (Figure 9 and 10). The only exception was for bare ground in the mid-to-high (550-599 m) and high (600-649 m) elevation classes. In the former elevation class the increase in Bare ground area was less than in proportion to its original area; whereas, for the latter elevation class the increase was greater than in proportion to this vegetation type’s original area ($P<0.05$; Figure 10e). This indicates even though the increase in bare ground was very small on a paddock scale, it was more atypically occurring in the highest elevation class. Nevertheless, overall the greatest area of bare ground remained in low-to-mid (500-549 m) and low (445-499 m) paddock elevations (Figure 10e).

The extent of the changes in a particular vegetation type’s land cover also generally occurred in proportion to its original 2006 distribution across the paddock’s different aspects (Figure 11). However, for HL pasture, shrubland, and Bare ground their gains in paddock area on north-west, south and south-west, and south-east aspects, respectively, were less than expected given their original distribution ($P<0.05$; Figure 11b, d, e). These aspects represented areas where each vegetation type was already highly abundant (refer to Section 3.1). In contrast, for shrubland vegetation the increase in land cover on the north-west aspects of the paddock was greater than in proportion to its original distribution in 2006, indicating that this could particularly be an area of encroachment ($P<0.05$; Figure 11d).

3.3 Plant species richness

In 2006, a total of 82 different vascular plant species were identified in the detailed paddock field survey. Of these species, 50% were indigenous to the area, while the other 50% were exotic (Appendix 2). This number increased slightly to 86 species in the second field survey carried out in 2010, while the relative percentages of indigenous and exotic species remained similar. In 2010, 22 of the plant species previously found in 2006 were absent, resulting in there being 60 species commonly found in both years. The missing species included 7 indigenous graminoids and forbs, 1 indigenous shrub, 8 exotic graminoids and forbs, and 4 species whose genus was able to be indentified but not their exact species or origin (Table 3). However, compensating for this loss was the identification of 27 previously unfound or non-identified species, which included 9 indigenous graminoids and forbs, 2 indigenous shrubs, 12 exotic graminoids and forbs, and 4 species whose genus was again able to be indentified but not their exact species or origin (Table 4).

Overall, the average number of plant species identified per quadrat, when pooled across all three main vegetation types, did not change significantly between 2006 and 2010 (P=0.4793), averaging 21.7 ± 0.9 (mean ± s.e) and 22.3 ± 0.7 species, respectively; and ranging between 13 and 31 species per quadrat. Similarly, out of the three main vegetation types present in the paddock, the number of species identified in the pasture and shrubland plant communities also did not vary significantly between the two survey years (Table 5). However, the average number of plant species found in the tussock vegetation increased slightly between the two surveys by 13% (Table 5). Based on the plant species sub-categories (Guilds) within this main vegetation type, the major contributor to this increase was in the number of exotic weed and rush species found in each quadrat (Table 6).

At the same plant species sub-category level, the average number of indigenous tussock species found in the pasture vegetation decreased by 61% between 2006 and 2010 (Table 6). However, countering this decrease were several small, statistically non-significant, increases in other plant species sub-categories, such as indigenous shrubs, exotic grasses, and exotic weeds and rushes (Table 6).

In general, the ground area covered by each of the plant species sub-categories did not change significantly between 2006 and 2010 (Table 7). The only exception was a 3-fold increase in the percentage of area covered by exotic legume species for the pasture vegetation (Table 7). At an individual species level, the increase in ground area coverage was mainly by sucking clover (*Trifolium dubium*) and white clover (*Trifolium repens*) (data not shown).

3.4 Plant species diversity

The Shannon diversity index for shrubland vegetation decreased by 9% between 2006 and 2010, which indicated that there had been a slight decrease in either the average number of plant species present or in their evenness of abundance (Table 5). For this plant community, the values for both of these latter diversity indices decreased slightly between the two survey years, but were not statistically significant at the 0.05 level (Table 5). Neither the Shannon diversity index or the Pielou evenness index change significantly between the two surveys for pasture and tussock vegetation (Table 5).

4. DISCUSSION

4.1 General distribution of the main vegetation types in 2006

Overall the study paddock contained a very diverse range of elevations, aspects, slope classes, and indigenous and exotic plant species, which is typical of many semi-improved tussock grassland paddocks used for grazing farmed red deer hinds in the South Island High-country (Netzer et al. 2009; Wall et al. 2011). At the time of the first detailed vegetation survey in 2006, the general distribution of the main plant communities (vegetation types) within the paddock likely strongly reflected the paddock's highly variable topography, past pastoral development history, and original grazing management with sheep and cattle. Pasture was the most abundant vegetation type throughout the paddock, accounting for 62% of the total area included in the over-lapping satellite imagery (Figure 4a). Of the two pasture subclasses, ML pasture was more abundant compared to the HL pasture in all elevation and hill slope classes (Figure 4b,c) and particularly dominated the sunny north and east facing aspects that would also have been less exposed to the main rain-bearing westerly and southerly winds of the region (Figure 5c). In contrast, the HL pasture approached a similar level of abundance to the ML pasture only at a mid-to-high elevation on rolling and, to a slightly less extent, strongly rolling terrain (Figure 4b,c), located on more shaded and probably more wetter south and west facing aspects of the paddock (Figure 5a,b).

White clover was the dominant exotic legume present in both subclasses of pasture (Appendix 2). This perennial species does not have a strong drought tolerance, requiring adequate soil moisture levels and warm temperatures (8-25^{o}C) to flourish (Kemp et al. 1999; Scott 2003). Thus, the soil moisture and temperature gradient caused by the topography of the paddock was probably a major determinant of the distribution of ML and HL pasture throughout the paddock. Another significant factor determining their general distribution would be the effect of the paddock's topography on livestock grazing behaviour. Livestock such as sheep and cattle more readily graze and camp on easier and sunnier hill slopes (Suckling 1964, 1975; Gillingham 1980). Close grazing on the gentler hill slopes by the hinds and calves at foot, especially over late-summer/autumn months, would reduced white clover's abundance by reducing its leaf area and stolon density; whereas, continual lax grazing pressure and higher pasture covers on the steeper slopes would enable more drought tolerant plant species such as crested dogstail and browntop to outcompete and smother the white clover plants (Suckling 1964; Smetham 1990; Dodd and Sheath 2003). The spring flush in pasture growth normally starts earlier on the sunny (warmer) north facing aspects compared to shaded (colder) south facing aspects (Suckling 1959, 1975). Inadequate control of this early pasture growth leading to high spring pasture covers is detrimental to white clover stolon and growing point development (Smetham 1990; Brock 2006). Fertility transfer from steeper slopes to flatter areas, especially high levels of phosphorus (P) and sulfur (S) in the dung of livestock, would also benefit white clover growth on the latter slope classes (White 1990; Kemp et al. 1999).

Shrubland was the next most abundant vegetation type in the paddock, accounting for 29% of the area covered in the overlapping satellite imagery (Figure 4a). Its distribution was largely on the wetter south and west facing aspects (Figure 5d), increasing in abundance particularly at lower elevations on strongly rolling to steep terrain (Figure 4b,c). Tussock, which covered 9% of the paddock, was located on similar facing aspects to shrubland vegetation and also tended to increase in abundance on the steeper hill slopes (Figure 5c and Figure 4b). However, unlike shrubland, the abundance of tussock increased at higher elevations (Figure 4b). During the paddock's original development for pastoral use the wetter south and west aspects where these two vegetation types now mainly reside would have reduced the effectiveness of clearing this indigenous vegetation by burning. Also, if the sheep and cattle numbers originally grazed in the study paddock were not high enough during its pastoral development phase, the greater preference of livestock for grazing warmer (sunny) and gentler hill slopes would also have allowed remnants of these vegetation types on the colder (shaded) and steeper slopes to regenerate (Levy 1970).

4.2 Changes in the distribution of the main vegetation types

4.2.1 *Large decrease in ML pasture to mainly HL pasture*

The greatest change in paddock vegetation coverage between the two survey years was the reduction in ML pasture from 36% of the overlapping satellite imagery in 2006 to 12% in 2010 (Figure 6 and 7). The vast majority (17.9 percentage points) of the ML pasture coverage that was lost went to HL pasture, with a smaller area (5.8 percentage points) also changing to shrubland vegetation (Figure 6 and 8). The decrease in ML pasture between the survey years occurred in proportion to this vegetation type's original distribution across the landscape in 2006, resulting in the greatest loss in ML pasture occurring where it was initially most abundant and vice versa (Figures 9, 10, & 11). Weather measurements taken from the closest weather stations to the study site, indicate the spring and early-summer of 2010 were drier than in 2006 (Figure 12b). This would have reduced the pasture growth over this period in 2010 enabling the hinds to maintain a lower pasture cover and reduce the degree of pasture senescence (dead matter) and seed head formation in the sward. Maintaining a lower pasture cover especially in spring-early summer reduces the competitiveness of other non-legume plant species in the pasture and increases the penetration of light to its base, which at that particular time of the year stimulates legume stolon development (Smetham 1990; Brock 2006). This may also explain why the reduction in ML pasture in 2010 occurred in proportion to its original 2006 distribution, as the above effect would be less where the hinds were already controlling excessive pasture growth and maintaining lower pasture covers. The same reason would also apply to the HL pasture and why its increase in paddock coverage between 2006 and 2010 was less than expected on the north-west facing aspects where it was already abundant (Figure 11b). In addition, the application of 125 kg/ha of superphosphate in 2006 and 2008 (Section 2.2.2) would have promoted the growth of the exotic pasture legume species (Edmeades et al. 1984; Boswell et al. 2003).

The greater abundance of exotic legumes in the pasture in 2010 compared to 2006 was also found in the detailed ground survey of the paddock, with coverage of mainly white clover and suckling clover in the survey plots increasing from 9.5% to 33% (Table 7). Achieving the latter level of abundance over summer provides breeding hinds and calves at foot with a much higher quality diet in comparison to the former level, benefiting both hind reproductive performance and calf live weight gain (Asher et al. 2003; Nicol and Barry 2003). Thus, developing grazing management strategies that enable a high exotic legume content to be consistently achieved in these semi-improved tussock grasslands each year could generate considerable farm productivity gains.

Especially in summer-wet environments, greater control of the early flush in spring pasture production by grazing another more flexible class of livestock (e.g. trading cattle) in the same paddock prior to calving could help to reduce excessive spring pasture covers and improve feed quality. However, pasture covers in the paddock would need to be monitored to ensure optimum levels are achieved at hind parturition.

4.2.2 *Large decrease in tussock to mainly shrubland and HL pasture*

Along with ML pasture, tussock vegetation was the only other main vegetation type to lose paddock coverage between 2006 and 2010. Between the two survey years tussock coverage decreased from 9.2% to 4.3% of the total area in the overlapping satellite imagery (Figure 6 and 7). Of the total paddock area that was lost, 3 percentage points changed to shrubland and 1.6 percentage points changed to HL pasture vegetation (Figure 8c). Matagouri and to a much lesser extent the indigenous shrub daisy *Olearia bullata* and mingimingi (*Coprosma propinqua*) were the dominant woody-plant species in the paddock (Appendix 2). The increase in shrubland vegetation area mainly occurred along its patch boundaries (Figure 6), which is highly feasible as new matagouri seedling recruitment is by mature plants shedding seeds adjacent to their canopies or by sending up new sprouts from underground stems (Bellingham 1998).

This natural succession would be aided by matagouri not being preferentially browsed by livestock, especially once the young plants develop spines and become lignified (woody) (Bellingham 1998; Forsyth et al. 2010). All three main woody shrubland species also have very small leaves and a divaricating (tangled) canopy structure, reducing their palatability to browsing ruminant animals (Bee et al. 2011). GPS tracking studies conducted by Netzer (2008) at Haycocks Station and by Wall et al. (2011) at White Rock Station showed pasture and tussock are the main vegetation types occupied by red deer hinds over summer and autumn. None occupied shrubland vegetation more than expected given its availability, suggesting for the majority of time this vegetation is not preferentially used. The only exceptions were often a small increase in occupation around midday, postulated to be used by the hinds for resting and ruminating in under the security of cover, and also for calving in by some hinds (Netzer et al. 2009; Wall et al. 2011). None of these activities suggest the shrubland vegetation was under any significant grazing/browsing pressure to help control its spread into other vegetation types. Matagouri biomass production can be rapid, with the effective grazing area of a burnt patch reduced by 50% within 5 years (Daly 1969). Growth is also normally more vigorous on soils with a good supply of plant available phosphate and sulphur (Daly 1969).

Mixed aged cows are mob-stocked in the paddock at a high stocking rate of 14 stock units per ha for a month in winter (Table 1), which should aid in the control of woody shrubland species, especially if there is high utilisation of the available pasture forcing the cows to forage widely (Suckling 1964; Daly 1969). However, based on the vegetation survey results, this measure has not been sufficient enough to stem the ingression of woody shrubland species into other areas of the paddock. Over winter the cattle would likely have preferred to graze the warmer and easier north facing hill slopes of the paddock. Thus, more expensive control measures, such as burning/ herbicide spraying and over-sowing with pasture species (Field and Daly 1990), may be required in the future.

Matagouri shrubs do provide multiple benefits for extensive deer farming systems such as fixing atmospheric nitrogen in the soil and providing shade, shelter, and a secluded calving habitat for the hinds (Daly 1969; Netzer 2008; Netzer et al. 2009; Wall et al. 2011). However, such benefits may be negated if the matagouri patches become too dense to use and reduce the overall effective grazing area of the paddock.

Both Netzer (2008) and Wall et al. (2011) reported that several of the red deer hinds tracked in their studies used tussock vegetation more than would be expected given its availability in the paddock, indicating that this vegetation was a highly valued habitat for some hinds. It was also hypothesised from both of these studies that for hinds with a significant proportion of tussock in their home range this vegetation was used particularly for resting and ruminating. Red deer are highly selective grazers/browsers that prefer to eat the highest quality feed available to them (Cosgrove and Hodgson 2003; Bee et al. 2010; Forsyth et al. 2010). Given that most tussock species have a much lower feed quality value compared to pasture grasses, legumes, and other associated forbs (Connor et al. 1970; Macrae and O'Connor 1970; Fenner et al. 1993) it is unlikely that the tussocks were being preferentially grazed. Nevertheless, the hierarchical structure of the deer breeding herd may have restricted sub-dominant female's access to the former more high quality forage, forcing them to increase their intake of tussock species. The results of Netzer et al. (2009) and Wall et al. (2011) indicate that heavier dominant hinds have greater access to pasture vegetation, whereas the home ranges of smaller less dominant hinds are restricted more to tussock and shrubland vegetation. Tussock vegetation is also a preferred vegetation type used for calving sites. Thus, the low overall availability of tussock vegetation in the paddock (9.2% in 2006) may mean that it is placed under excessive hind stocking pressure at calving.

While red tussock in low fertility grasslands is known to be one of the least attractive tall-tussock species to livestock, its palatability markedly increases in higher fertility soils and when more highly nutritious plants such as white clover are also present in the plant community (Connor et al. 1970; Macrae and O'Connor 1970). Under these conditions heavy stocking rates can reduce red tussock plants to only stumps (Connor et al. 1970; Macrae and O'Connor 1970). Regrowth is often slow (Lee et al. 2000) and even though tall-tussocks can tolerate the removal of a small number of tillers without seriously weakening the plants, persistent heavy grazing can severely weaken or even kill them (Mark 1969). The loss of red tussock vegetation in the study paddock could have several negative effects on its productive capacity. Tall-tussocks are highly valued for their soil conservation role, especially on steep and exposed hillsides (O'Connor and Powell 1963) and as a hind habitat for resting/ruminating and calving in seclusion (Netzer 2008; Netzer et al. 2009; Wall et al. 2011).

Overall, the loss of tall-tussock vegetation likely indicates that at least at certain times of the year currently used stocking rates are too high, forcing sub-dominate hinds to graze these areas. If it is desirable to maintain the tall-tussocks, management methods aimed at reducing their palatability may be a feasible option, but would also require a reduction in livestock densities, otherwise intakes would be compromised. Avoiding topdressing or over-sowing specific red tussock areas may reduce the nutrient content in the tussocks and availability of higher quality forage. From a grazing management point of view monitoring the general vigour of the tussocks could be a useful indicator for optimising livestock stocking rates in tussock grassland paddocks, as intensive defoliation likely signals at least some hinds have restricted access to higher quality forage.

4.2.3 *Decrease in ML pasture to shrubland vegetation*

As discussed previously in Section 4.2.1, the ML pasture also lost 5.8 percentage points of total paddock area to shrubland vegetation between the two survey years (Figure 8d). Similarly to tussock vegetation, the lower feed quality of the ML pasture likely reduced its grazing pressure compared to the HL pasture, which again could have aided in the natural succession of this vegetation to shrubland (Suckling 1964). In contrast, the shrubland vegetation did not encroach into the HL pasture, which would have been under greater grazing pressure (Figure 8d).

4.3 Changes in plant species diversity

In general the overall plant species diversity in the paddock remained relatively constant between the two survey years (Table 5). However, there were some marked changes especially at the plant guild (sub-category) level. The most significant were a 61% decrease in the total number of tussock species identified on average in each field-survey plot of the pasture vegetation and contrastingly, a 13% increase in the total number of exotic weeds and rushes identified in each field-survey plot of the tussock vegetation (Table 6). Silver tussock and blue tussock were the tussock species that decreased in abundance (data not shown), both of which are much more palatable to livestock in comparison to red tussock (Scott et al. 1996). Clarke (2012) analysed the plant cuticles in deer faecal pellets from the study paddock to get an estimation of hind forage selection. The results showed that both silver and blue tussock were actively selected for, while red tussock was consumed only in proportion to its availability in the paddock (Clarke 2012). It is uncertain why the red deer hinds or potentially the breeding cows would have preferentially consumed these short tussock species when much more higher quality alternative forage was readily available in the paddock. Both livestock species do require a certain level of structural fibre in their diet for maintaining effective rumen function (Cosgrove and Hodgson 2003) and similar factors discussed in Section 4.2.2 for the apparent loss in red tussock abundance could be important. The increase in exotic weed and rush species in the tussock vegetation may have also resulted from the grazing actions of the deer and cattle, opening up areas in the tussocks for seedling establishment and also transferring seed on their coats and in their dung (Rose and Frampton 1999).

4.4 *Benefits of further monitoring*

Most vegetation maps are very rarely, if at all, 100% accurate. Generally accuracy values range between 70-90% (Netzer 2008; Wall et al. 2011). Different vegetation types having very similar biophysical properties (e.g. spectral reflectance, shape and texture) often cause misclassification errors. These biophysical properties are affected by environmental conditions impacting on such characteristics as flowering, chlorophyll concentration, degree of leaf display for deciduous species, and dead matter accumulation. This variation could cause the abundance of some vegetation types to be over-estimated one year and under-estimated in another year, confounding interpretations from the satellite image change detection analyses. Re-surveying the study paddock in several years time would help to determine whether the changes measured in this study are 'real' or more an 'artefact' of the environmental conditions that occurred at the time of sampling. It would also give an indication of whether the rate of change in vegetation coverage is varying over time.

5. CONCLUSION

A comparison of vegetation surveys taken in 2006 and 2010 shows that the distribution and abundance of several of the main vegetation types identified in the paddock are changing under the current grazing management practices. At the paddock scale, the main more permanent changes that occurred under the current deer grazing management were the encroachment of shrubland vegetation into ML pasture and tussock vegetation. However, this natural succession did not occur in the HL pasture, indicating that greater grazing pressure in the later may be halting the expansion of the shrubland vegetation. Tussock dominant areas were also lost to HL pasture, which may have been caused by sub-dominant hinds being excluded from other more resource rich areas. Overall, there was no significant loss in total plant species richness in the paddock. However, remnant tussocks in pasture dominant vegetation have decreased in abundance, while there has been an increase in the total number of weed species present in tussock dominant vegetation. In 2010, the average legume content in the pasture was 30%, whereas it was 10% in 2006. Developing grazing management practices that attain the former high legume content every year over summer and autumn (i.e. the calving and lactation seasons) would be highly profitable, benefiting both the overall body condition of the breeding hinds and also the growth rates of their calves at foot.

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TABLES AND FIGURES

Table 1: Stock unit (SU) grazing days per ha per year in the 250ha Rough Gully paddock

Stock class	Stock numbers	SU equivalents	Grazing days	Years	SU grazing days/ha/yr
MA hinds	618	2.1	212 (Oct-May)	4	1100
MA cows	600	6.0	21 (June)	3	227
Total					1327

Table 2: Hierarchical classification scheme for the main vegetation classes at Haycocks Station

Level 1- Habitat	Level 2- Vegetation type	Level 3 -	Description[1]	Number of 'training sites'
Grassland	Pasture		Dominated by exotic pasture grasses and legumes.	
		Medium legume[2]		4
		High legume[2]		3
	Tussock		Dominated by Red tussock, with mainly pasture species in inter-tussock areas.	7
Shrubland	Woody shrubs		Dominated by matagouri	4
Marginal classes	Bare ground		Devoid of vegetation	3

[1] A complete botanical species list is given in Appendix 2. [2] Medium and high legume content level 3 categories were originally called 'Brown pasture' and 'Green pasture' by (Netzer et al. 2009) and 'Pasture' and 'Clover fields' by Clarke (2012).

Table 3: Plant species identified in 2006 that were not found in 2010

Species	Family	Origin	Form
Brachyglottis bellidioides	Asteraceae	Indigenous	Forb
Centella uniflora	Apiaceae	Indigenous	Forb
Corybas sp.	Orchidaceae	Indigenous	Forb
Gonocarpus aggregatus	Haloragaceae	Indigenous	Forb
Helichrysum filicaule	Asteraceae	Indigenous	Forb
Linum monogynum	Linaceae	Indigenous	Forb
Rytidosperma unarede	Poaceae	Indigenous	Graminoid
Olearia bullata	Asteraceae	Indigenous	Shrub
Cirsium sp.	Asteraceae	Exotic	Forb
Linum catharticum	Linaceae	Exotic	Forb
Myosotis arvensis	Boraginaceae	Exotic	Forb
Ranunculus acris	Ranunculaceae	Exotic	Forb
Rumex acetosella	Polygonaceae	Exotic	Forb
Lolium multiflorum	Poaceae	Exotic	Graminoid
Poa pusilla	Poaceae	Exotic	Graminoid
Vulpia myuros	Poaceae	Exotic	Graminoid
Cardamine sp.	Brassicaceae	Unknown	Forb
Epilobium sp.	Onagraceae	Unknown	Forb
Ranunculus sp.	Ranunculaceae	Unknown	Forb
Stellaria sp.	Caryophyllaceae	Unknown	Forb

Table 4: Plant species identified in 2010 that were not found in 2006

Species	Family	Origin	Form
Anisotome aromatica	Apiaceae	Indigenous	Forb
Brachyscome sinclairii	Asteraceae	Indigenous	Forb
Celmisia gracilenta	Asteraceae	Indigenous	Forb
Hypericum pusillum	Hypericaceae	Indigenous	Forb
Ranunculus glabrifolius	Ranunculaceae	Indigenous	Forb
Viola cunninghamii	Violaceae	Indigenous	Forb
Dichelachne micrantha	Poaceae	Indigenous	Graminoid
Hierochloe redolens	Poaceae	Indigenous	Graminoid
Rytidosperma nigricans	Poaceae	Indigenous	Graminoid
Coprosma colensoi	Rubiaceae	Indigenous	Shrub
Muehlenbeckia sp	Polygonaceae	Indigenous	Shrub
Achillea millefolium	Asteraceae	Exotic	Forb
Callitriche stagnalis	Plantaginaceae	Exotic	Forb
Hydrocotyle americana	Araliaceae	Exotic	Forb
Lotus pedunculatus	Fabaceae	Exotic	Forb
Mycelis muralis	Asteraceae	Exotic	Forb
Ranunculus repens	Ranunculaceae	Exotic	Forb
Rumex acetosa	Polygonaceae	Exotic	Forb
Sagina procumbens	Caryophyllaceae	Exotic	Forb
Stellaria alsine	Caryophyllaceae	Exotic	Forb
Agrostis stolonifera	Poaceae	Exotic	Graminoid
Juncus bufonius	Juncaceae	Exotic	Graminoid
Poa annua	Poaceae	Exotic	Graminoid
Geranium sp.	Geraniaceae	Unknown	Forb
Gunnera sp.	Gunneraceae	Unknown	Forb
Elymus sp.	Poaceae	Unknown	Graminoid
Glyceria sp.	Poaceae	Unknown	Graminoid

Table 5: Species richness (total number of plant species/quadrat), Shannon's diversity index, and evenness index for the three main (Level 2) vegetation types in the highly-modified tussock grassland paddock.

Vegetation type	Richness		Diversity index		Evenness index	
	2006	**2010**	**2006**	**2010**	**2006**	**2010**
Pasture (n=6)	22.5 ± 2.1[a]	21.8 ± 1.5[a]	2.09 ± 0.17[a] (8.61 ± 1.31)	2.01 ± 0.14[a] (7.83 ± 0.88)	0.671 ± 0.034[a]	0.653 ± 0.034[a]
Tussock (n=12)	**19.7 ± 1.0[a, **]**	**22.3 ± 0.9[b]**	1.95 ± 0.09[a] (7.31 ± 0.62)	2.12 ± 0.05[a] (8.41 ± 0.41)	0.655 ± 0.026[a]	0.684 ± 0.014[a]
Shrubland (n=5)	25.4 ± 1.6[a]	23.4 ± 2.0[a]	**2.30 ± 0.05[a, *]** (10.07 ± 0.46)	**2.10 ± 0.07[b]** (8.06 ± 0.57)	0.715 ± 0.019[a]	0.664 ± 0.029[a]

Abbreviations: n, number of paired quadrats sampled. Values in parentheses are effective number of species found. Within columns, highlighted means followed by differing letters are significantly different at: *, P<0.05; **, P<0.01; ***, P<0.001.

Table 6: Species richness (total number of plant species/quadrat) in each major plant species sub-category of the pasture, tussock and shrubland.

Sub-category	**Main vegetation type**					
	Pasture (n=6)		**Tussock** (n=12)		**Shrubland** (n=5)	
	2006	**2010**	**2006**	**2010**	**2006**	**2010**
Indigenous shrubs	0.3 ± 0.21[a]	1.0 ± 0.52[a]	0.8 ± 0.18[a]	0.4 ± 0.26[a]	1.4 ± 0.40[a]	1.0 ± 0.55[a]
Indigenous Ferns & bracken	0.7 ± 0.33[a]	0.5 ± 0.34[a]	0.3 ± 0.19[a]	0.3 ± 0.19[a]	1.0 ± 0.45[a]	0.8 ± 0.37[a]
Indigenous tussocks	**1.3 ± 0.21[a,**]**	**0.5 ± 0.34[b]**	0.8 ± 0.30[a]	0.7 ± 0.22[a]	1.4 ± 0.40[a]	1.4 ± 0.24[a]
Indigenous herbs/grasses	4.0 ± 1.95[a]	2.8 ± 1.17[a]	3.1 ± 0.80[a]	3.8 ± 0.87[a]	5.2 ± 1.96[a]	5.4 ± 2.04[a]
Exotic grasses	6.2 ± 0.65[a]	7.3 ± 0.61[a]	5.9 ± 0.34[a]	6.4 ± 0.51[a]	6.2 ± 0.49[a]	5.6 ± 0.68[a]
Exotic legumes	2.7 ± 0.21[a]	2.2 ± 0.31[a]	1.9 ± 0.34[a]	2.4 ± 0.19[a]	2.8 ± 0.20[a]	2.2 ± 0.20[a]
Exotic weeds/rushes	5.8 ± 0.48[a]	6.8 ± 0.54[a]	**4.9 ± 0.66[a, **]**	**7.5 ± 0.66[b]**	5.8 ± 1.16[a]	6.2 ± 0.73[a]
Unidentified species	1.5 ± 0.34[a]	0.7 ± 0.33[a]	**2.0 ± 0.12[a, **]**	**0.8 ± 0.28[b]**	1.6 ± 0.40[a]	0.8 ± 0.49[a]

Abbreviations: n, number of paired quadrats sampled. Within columns, highlighted means followed by differing letters are significantly different at: *, P<0.05; **, P<0.01; ***, P<0.001.

Table 7: Percentage (%) of quadrat area covered by each major plant species sub-category of the pasture, tussock and shrubland.

Sub-category	**Main vegetation type**					
	Pasture (n=6)		**Tussock** (n=12)		**Shrubland** (n=5)	
	2006	**2010**	**2006**	**2010**	**2006**	**2010**
Indigenous shrubs	2.9 ± 2.2[a]	4.8 ± 4.3[a]	5.1 ± 2.2[a]	4.6 ± 4.4[a]	6.2 ± 3.6[a]	2.5 ± 1.7[a]
Indigenous Ferns & bracken	0.2 ± 0.1[a]	0.4 ± 0.3[a]	0.4 ± 0.3[a]	0.3 ± 0.2[a]	1.4 ± 1.2[a]	1.0 ± 0.5[a]
Indigenous tussocks	6.0 ± 3.1[a]	2.1 ± 1.4[a]	9.3 ± 5.0[a]	8.8 ± 4.3[a]	13.0 ± 5.4[a]	13.7 ± 11.3[a]
Indigenous herbs/grasses	9.8 ± 5.0[a]	2.8 ± 1.3[a]	4.4 ± 1.5[a]	9.5 ± 3.0[a]	10.3 ± 3.9[a]	8.1 ± 3.4[a]
Exotic grasses	64.0 ± 7.9[a]	38.9 ± 5.8[a]	57.2 ± 5.8[a]	44.4 ± 6.2[a]	46.9 ± 8.2[a]	48.3 ± 11.3[a]
Exotic legumes	**9.5 ± 2.4[a, ***]**	**33.2 ± 4.6[b]**	14.5 ± 4.1[a]	21.7 ± 2.7[a]	9.5 ± 4.0[a]	11.9 ± 4.1[a]
Exotic weeds/rushes	7.3 ± 1.9[a]	17.1 ± 9.2[a]	6.7 ± 1.7[a]	8.4 ± 1.1[a]	9.8 ± 4.9[a]	13.8 ± 6.9[a]
Unidentified species	0.4 ± 0.2[a]	0.6 ± 0.3[a]	2.4 ± 0.8[a]	2.3 ± 1.8[a]	2.8 ± 1.2[a]	0.7 ± 0.4[a]

Abbreviations: n, number of paired quadrats sampled. Within columns, highlighted means followed by differing letters are significantly different at: *, P<0.05; **, P<0.01; ***, P<0.001.

Figure 1: Vegetation (a) and altitude (b) maps of the study paddocks on Haycocks Station (Netzer et al. 2009).

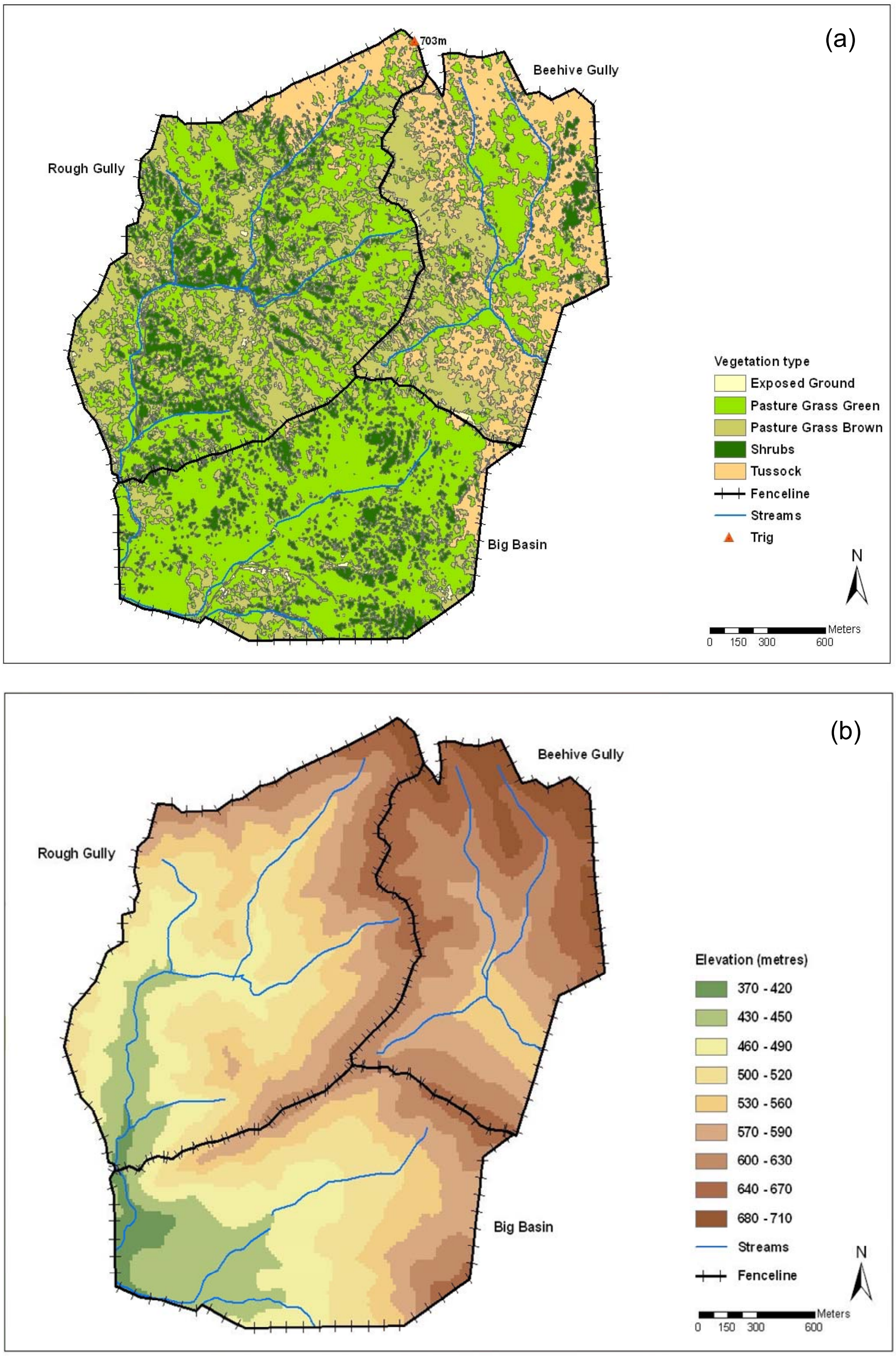


Figure 2: A three dimensional image of the Rough Gully study paddock. The red line indicates the perimeter of overlapping area covered by both the 2006 and 2010 satellite images.

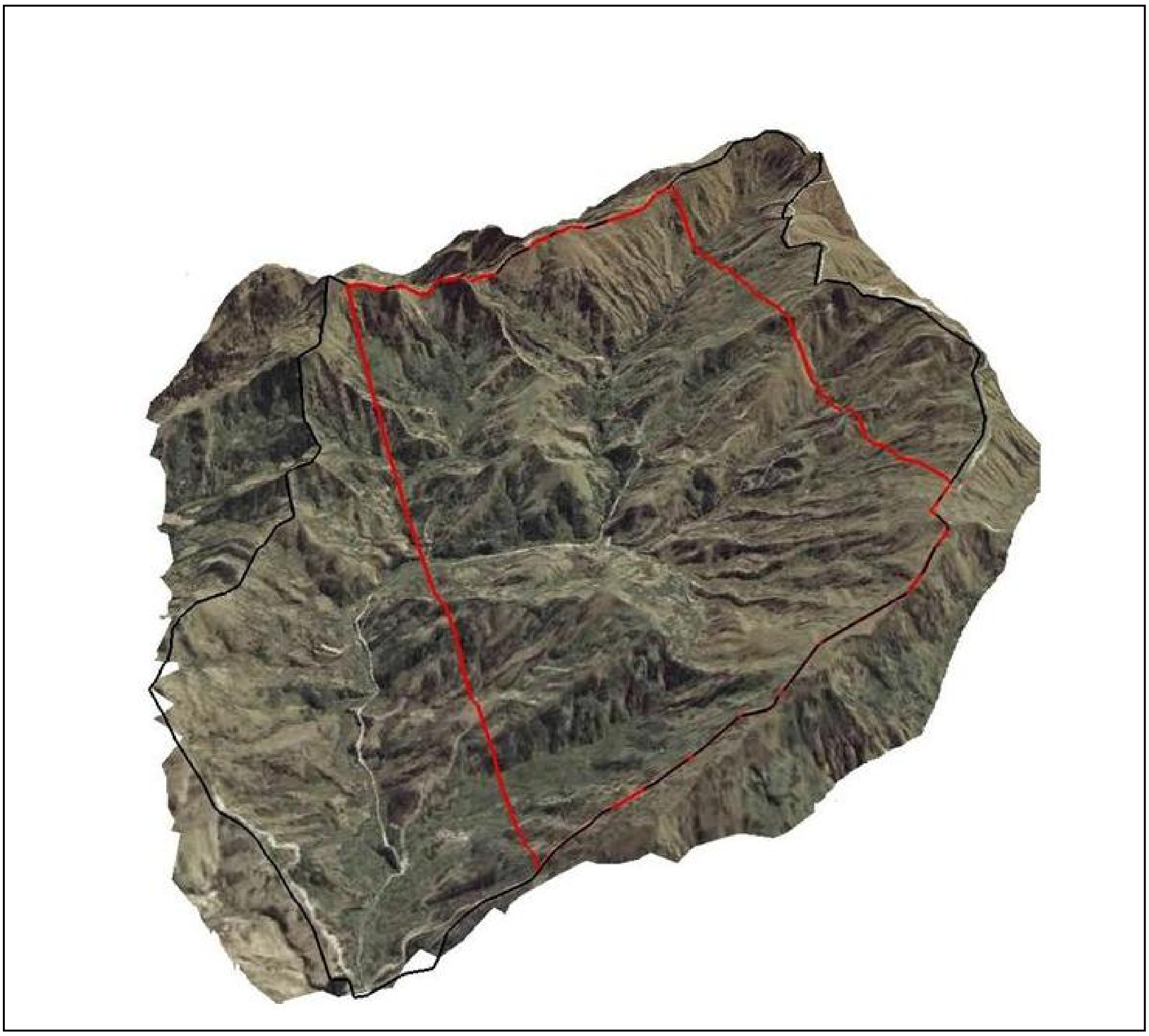


Figure 3: Topography of the 'Rough Gully' study paddock as a percentage of the total area remotely surveyed using high resolution satellite imagery.

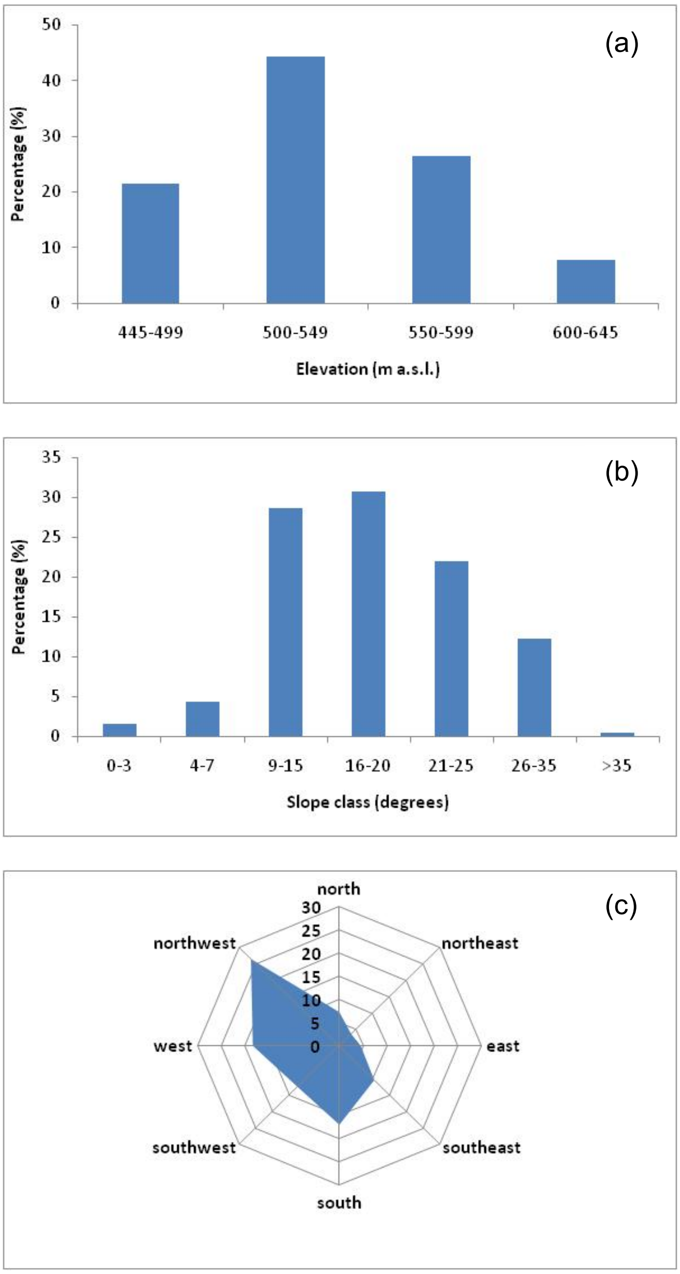


Figure 4: Percentage of vegetation within (a) the entire paddock and for each (a) elevation and (b) slope class in 2006. Vegetation types: medium legume content (ML) pasture, high legume content (HL) pasture, red tussock, shrubland (scrub), and bare ground.

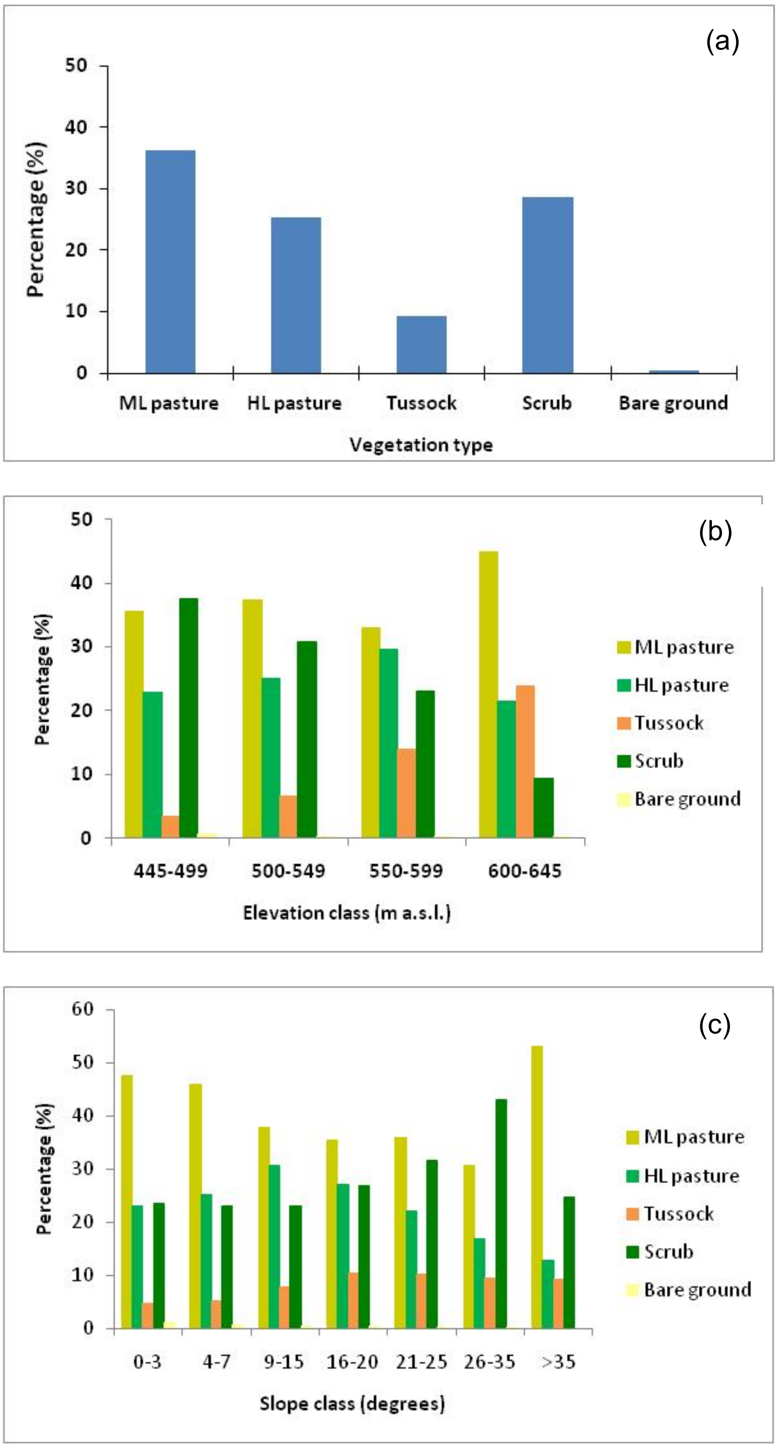


Figure 5: Percentage of vegetation class in each aspect in 2006: (a) Medium legume content naturalised pasture, (b) high legume content naturalised pasture, (c) tussock grassland, (d) shrubland, and (e) bare ground. Note the scale varies in each 'radar' plot.

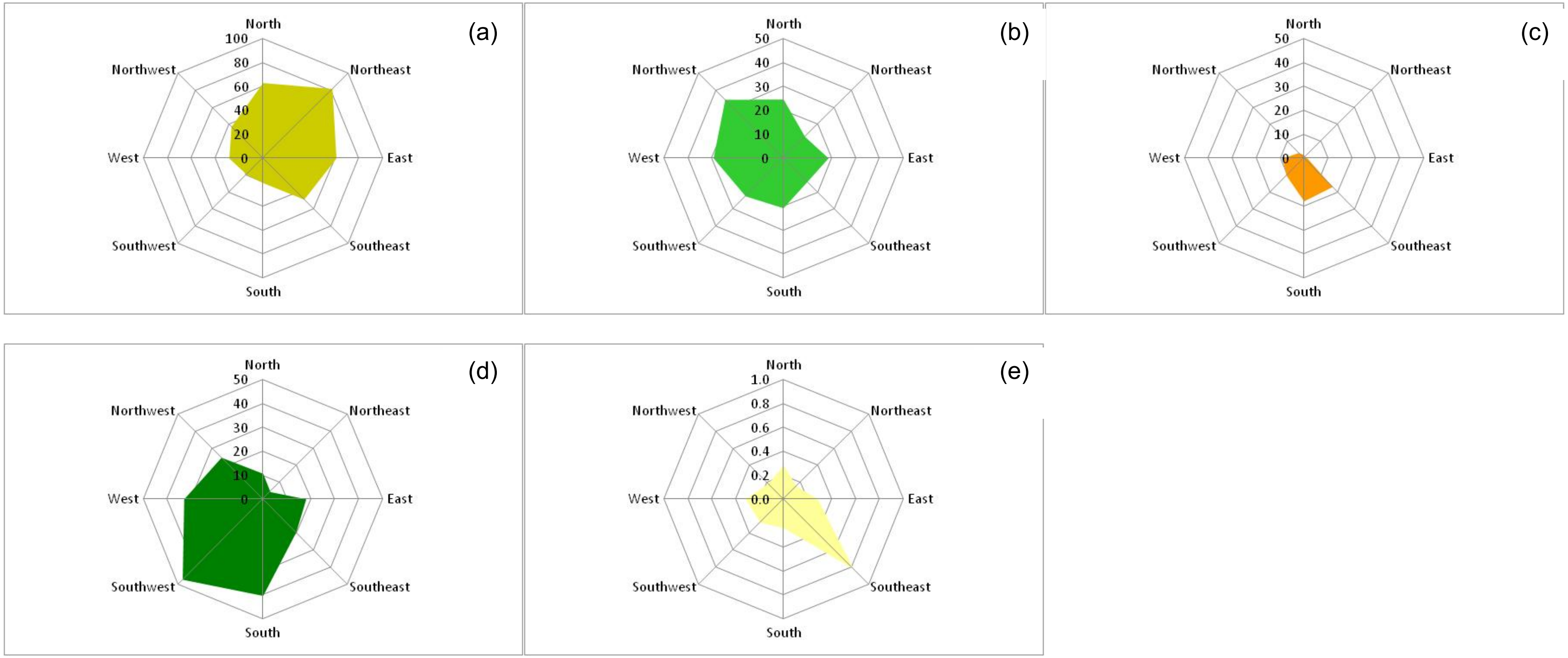
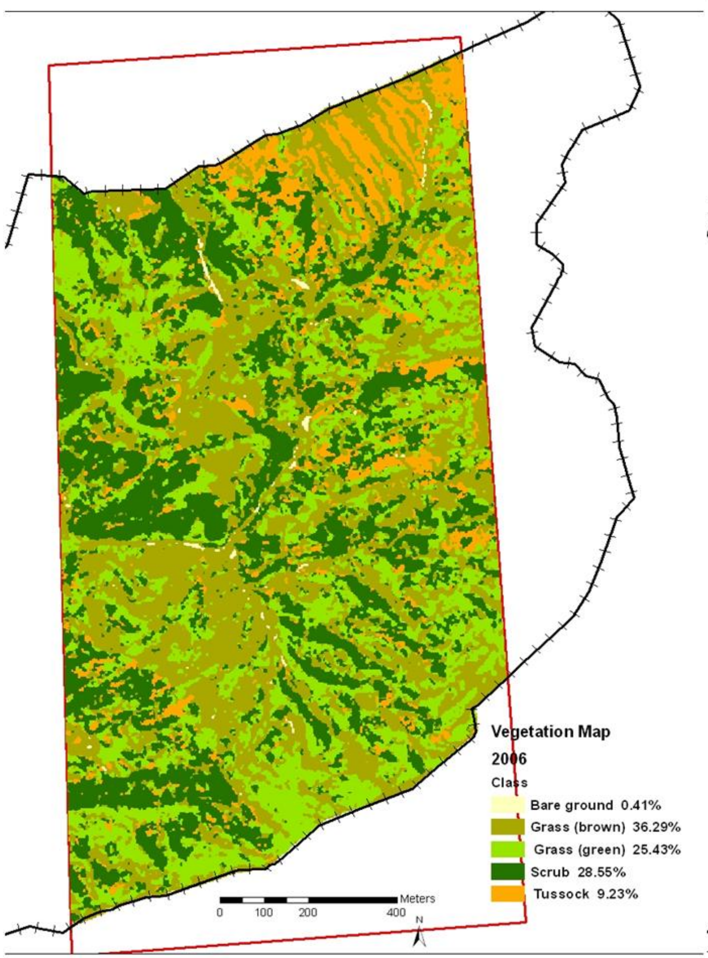
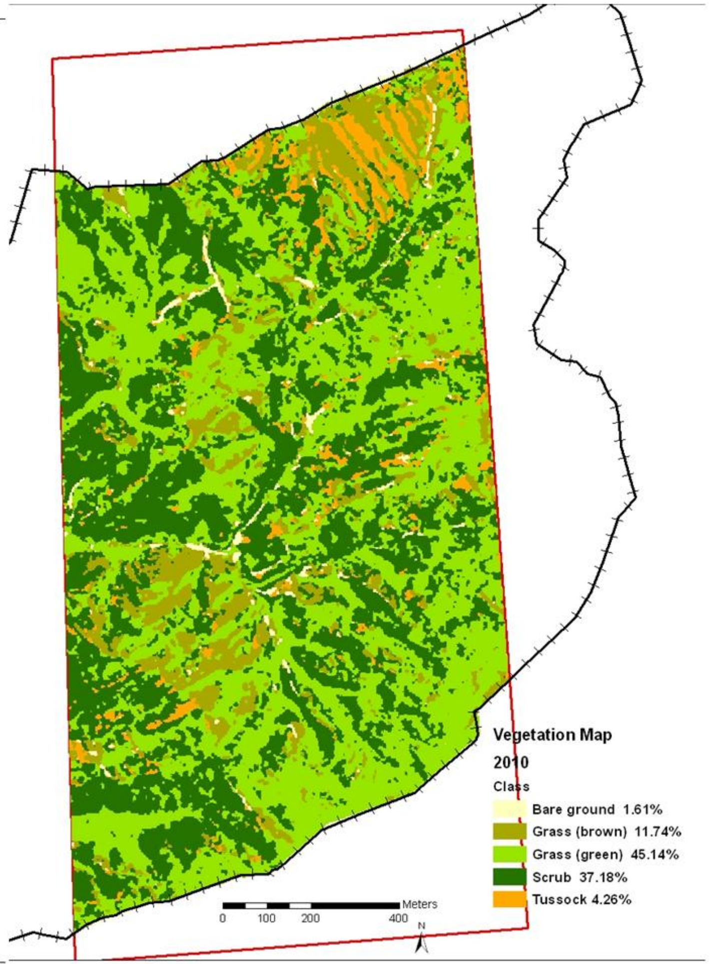


Figure 6: Vegetation map of the Rough Gully study paddock on Haycocks Station in (a) 2006 and (b) 2010.



(a)



(b)

Figure 7: Overall gains and losses in vegetation type paddock area between 2006 and 2010. Vegetation types: medium legume content (ML) pasture, high legume content (HL) pasture, red tussock, shrubland (Scrub), and bare ground.

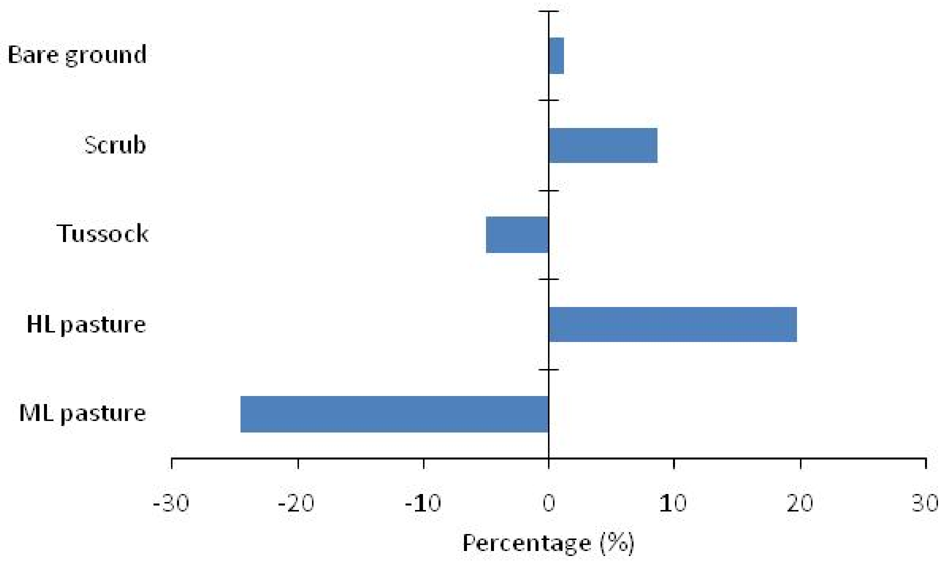


Figure 8: Percentage change in vegetation type area for (a) Medium legume content (ML) pasture, (b) high legume content (HL) pasture, (c) tussock, (d) shrubland, and (e) bare ground. Note: percentage scale varies for each main vegetation type.

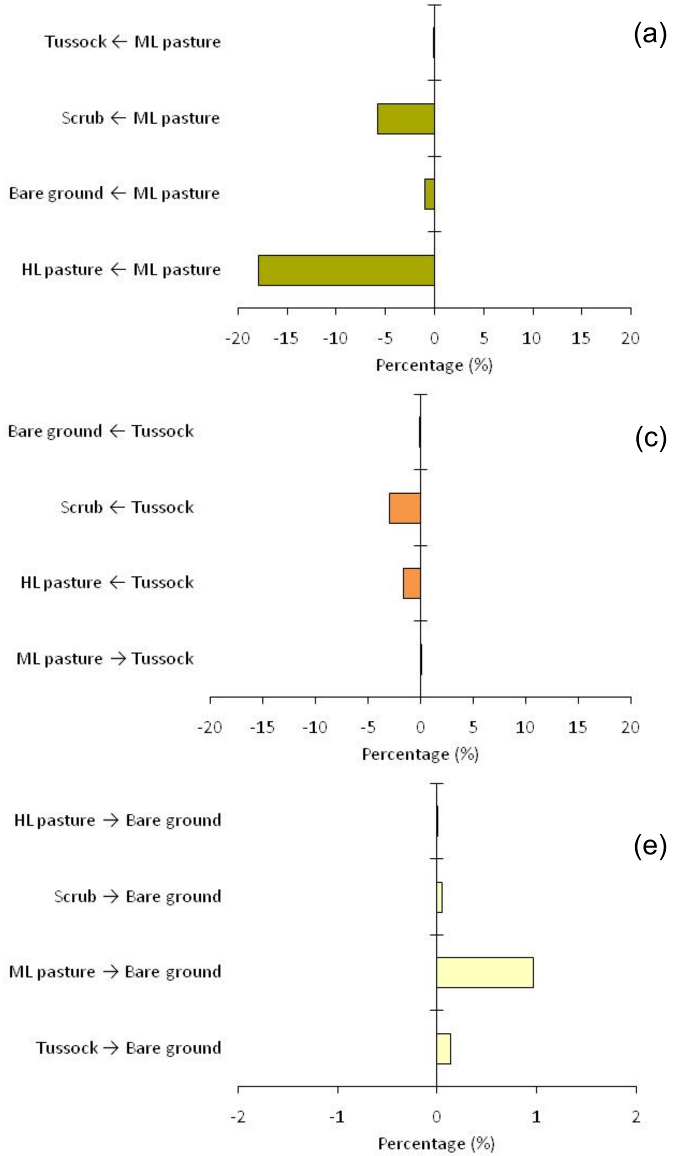


Figure 9: Vegetation distribution across slope classes in 2006 and 2010 for: (a) Medium legume content pasture, (b) high legume content pasture, (c) tussock, (d) shrubland, and (e) bare ground.

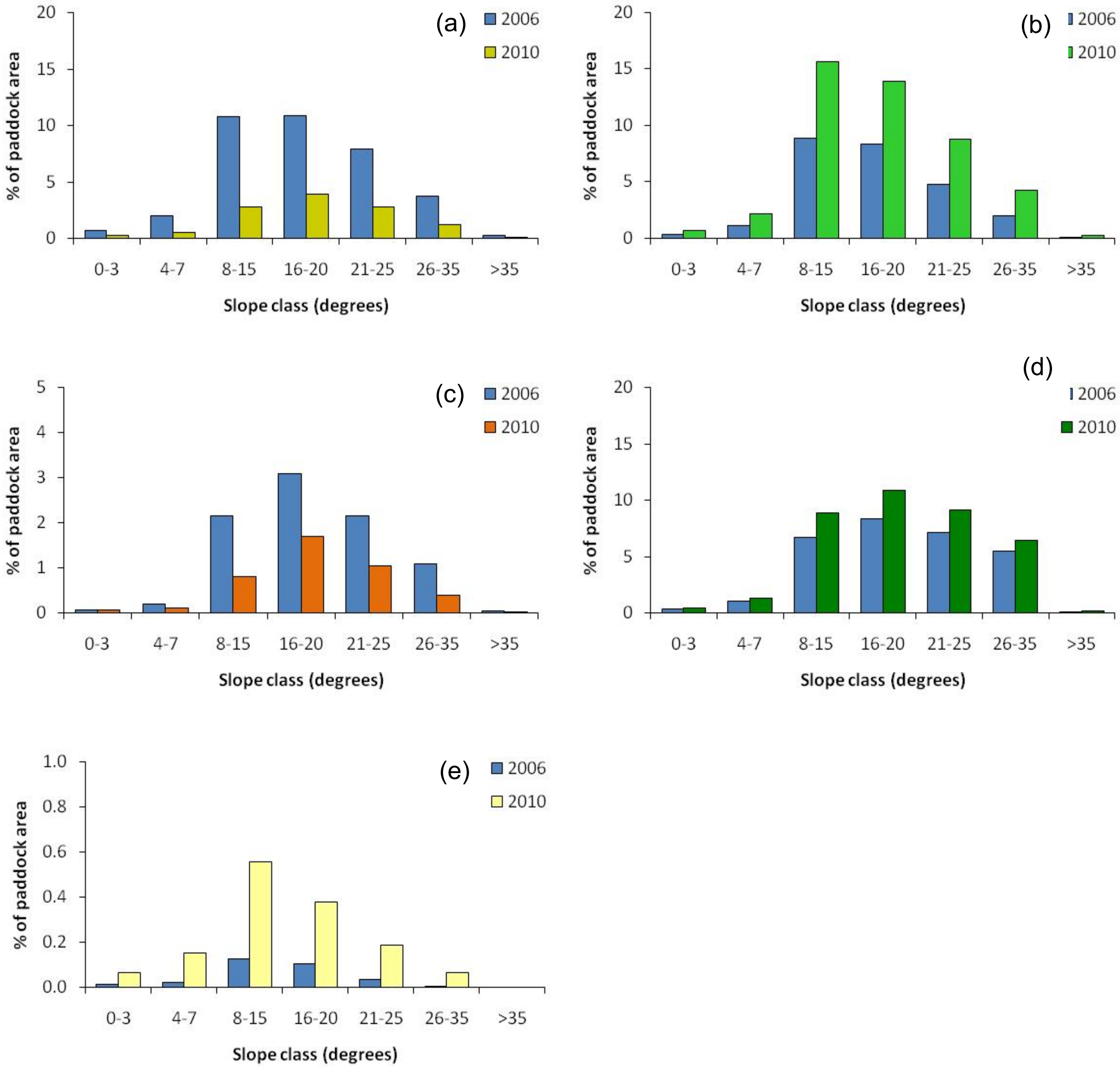


Figure 10: Vegetation distribution across elevation classes in 2006 and 2010 for: (a) Medium legume content (ML) pasture, (b) high legume content (HL) pasture, (c) tussock, (d) shrubland, and (e) bare ground.

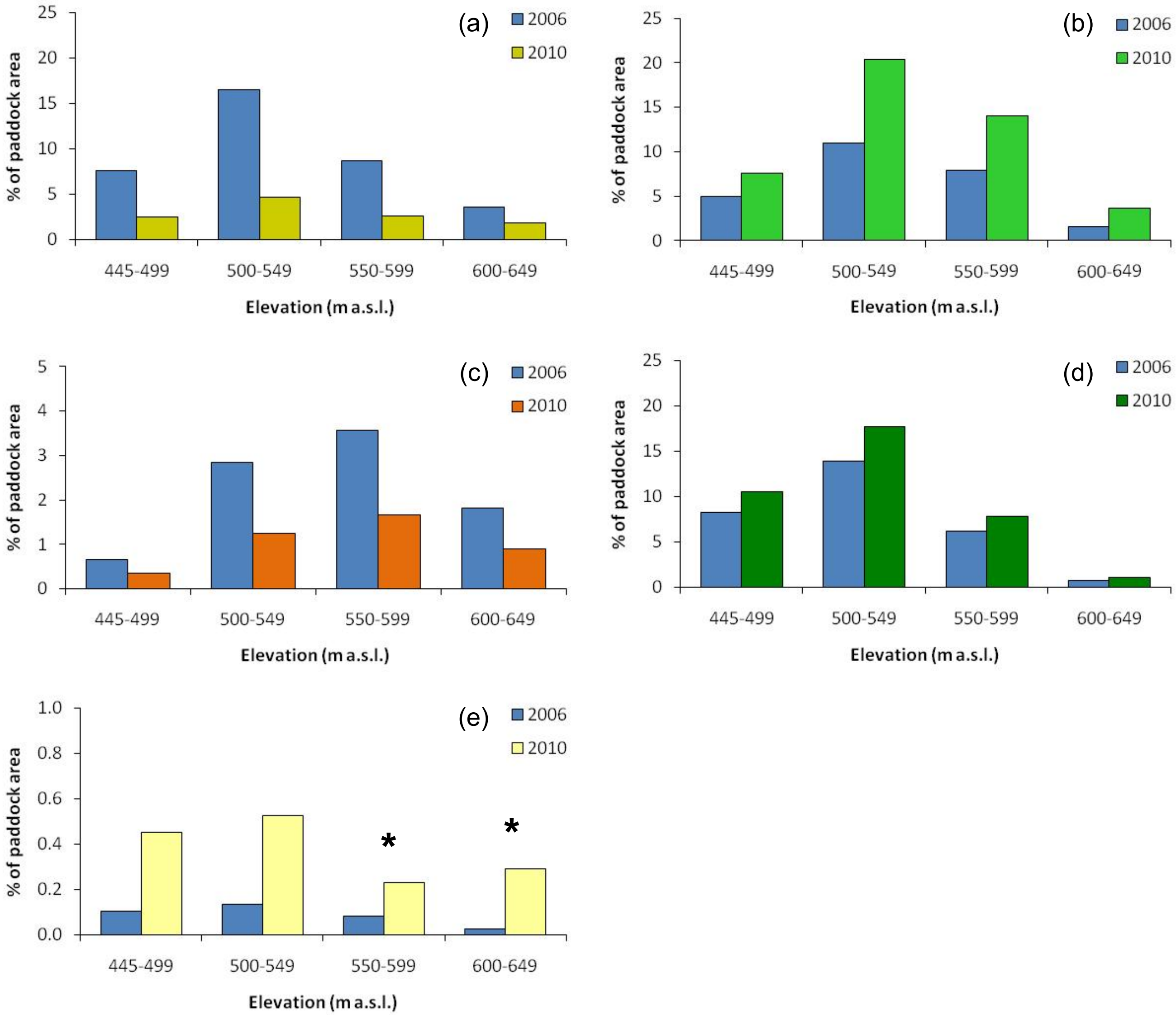


Figure 11: Vegetation distribution across aspects in 2006 and 2010 for: (a) Medium legume content (ML) pasture, (b) high legume content (HL) pasture, (c) tussock, (d) shrubland, and (e) bare ground.

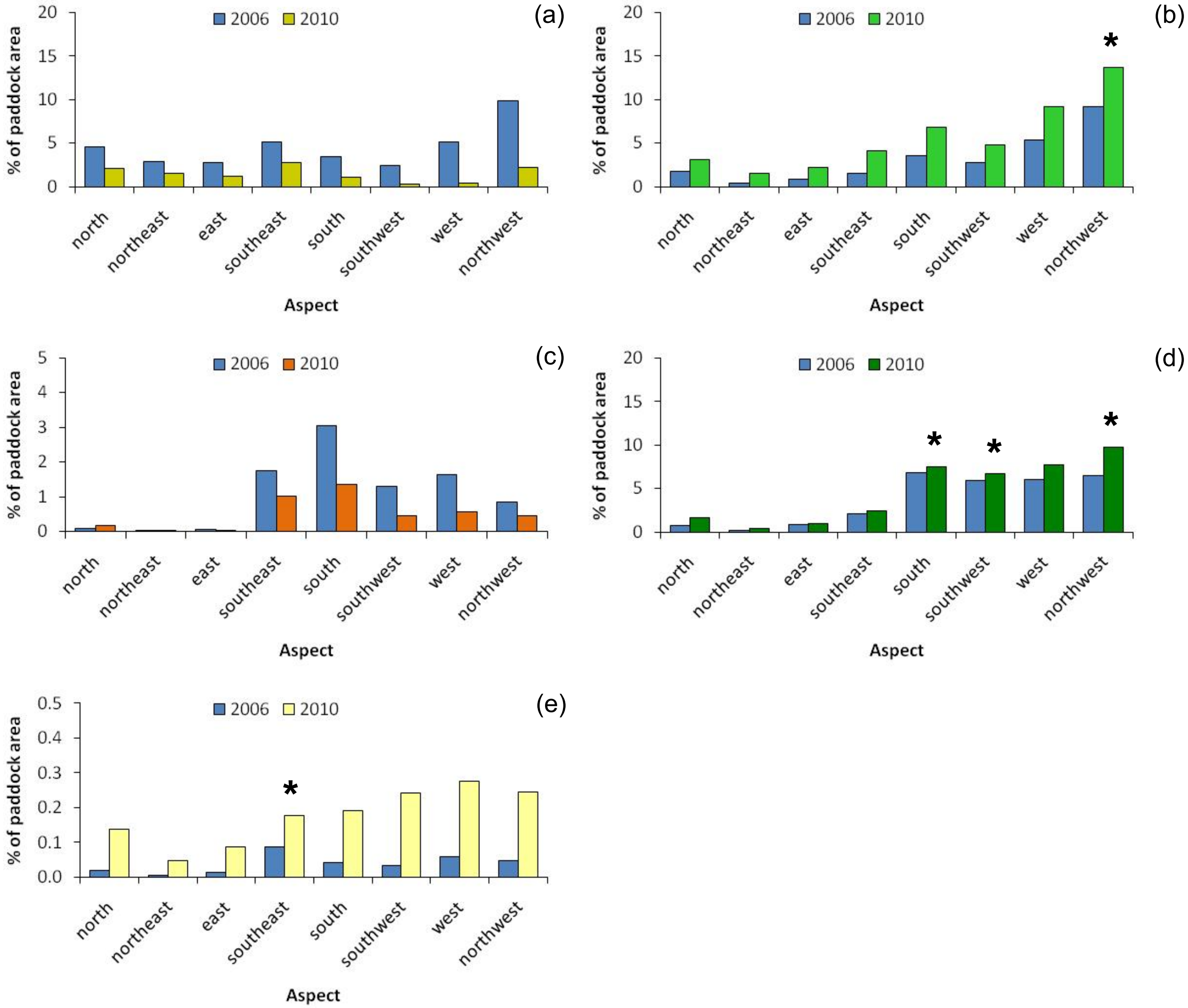
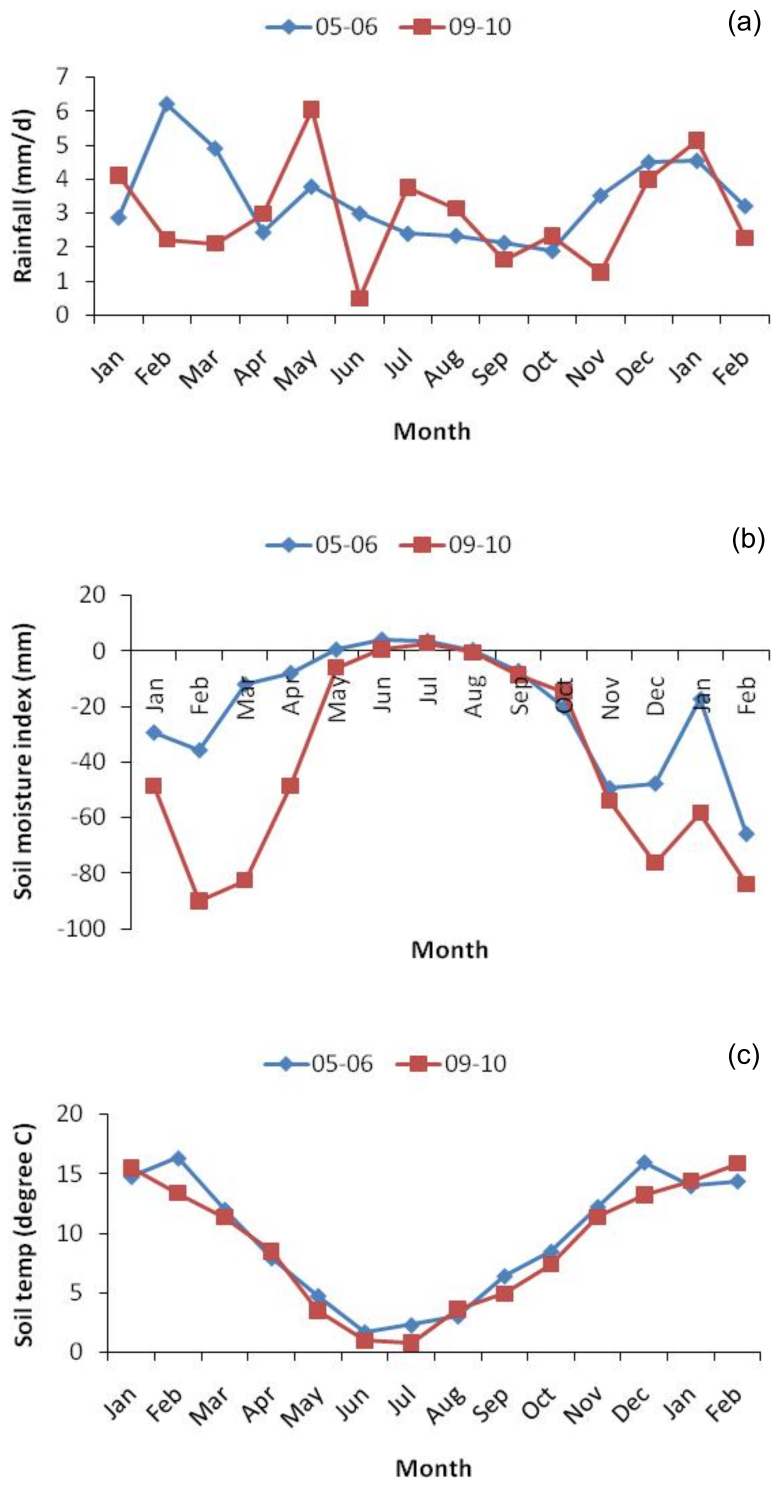


Figure 12: Monthly weather indices for the two survey years taken from the closest weather station to the study site (NIWA 2012): (a) rainfall, (b) soil moisture index, and (c) soil temperature.



APPENDICES

Appendix 1 LUC slope class categories

Slope class	**Degrees**
Flat	0-3
Undulating	4-7
Rolling	8-15
Strongly rolling	16-20
Moderately steep	21-25
Steep	26-35
Very steep	>35

Appendix 2 Plant species as a percentage of total survey-plot area

Vegetation	Pasture		Tussock		Shrubland	
	2006	2010	2006	2010	2006	2010
Exotic grasses						
Agrostis capillaris	13.94	8.97	8.28	15.62	4.53	21.82
Agrostis stolonifera	0.00	0.00	0.00	0.08	0.00	0.00
Anthoxanthum odoratum	7.97	6.71	8.09	2.98	11.08	2.14
Bromus diandrus	0.06	0.00	0.02	0.06	0.98	0.00
Bromus mollis	0.00	0.61	0.33	0.38	0.04	0.00
Cynosurus cristatus	19.84	4.86	9.02	10.54	5.92	8.89
Dactylis glomerata	10.56	6.37	13.39	5.09	16.73	4.21
Holcus lanatus	8.74	7.95	13.66	7.72	7.48	10.51
Lolium multiflorum	0.06	0.00	0.52	0.00	0.00	0.00
Lolium perenne	2.29	0.46	3.62	0.88	0.12	0.36
Phleum pratense	0.06	0.43	0.08	0.31	0.03	0.19
Poa annua	0.00	0.82	0.00	0.64	0.00	0.19
Poa pratensis	0.47	1.73	0.23	0.14	0.05	0.00
Poa pusilla	0.02	0.00	0.00	0.00	0.00	0.00
Exotic legumes						
Lotus pedunculatus	0.00	0.00	0.00	0.08	0.00	0.00
Trifolium dubium	0.13	13.73	1.01	1.09	0.45	0.78
Trifolium pratense	1.58	0.35	0.42	0.59	0.82	0.32
Trifolium repens	7.78	19.13	13.09	19.92	8.24	10.81
Exotic weeds/rushes						
Achillea millefolium	0.00	0.12	0.00	0.00	0.00	0.00
Callitriche stagnalis	0.00	0.00	0.00	0.07	0.00	0.00
Cerastium glomeratum	0.00	0.87	0.01	1.26	0.00	0.91
Cirsium arvense	3.48	0.35	1.76	1.54	0.56	0.36
Cirsium sp.	0.08	0.00	0.02	0.00	0.03	0.00
Cirsium vulgare	0.29	10.68	0.42	0.58	0.12	0.43
Crepis capillaris	0.48	0.76	0.17	0.84	0.11	0.91
Galium aparine	0.00	0.26	0.09	0.29	0.56	0.14
Hieracium pilosella	0.02	0.15	0.02	0.15	0.00	0.00
Hydrocotyle americana	0.00	0.00	0.00	0.15	0.00	0.14
Hypochaeris radicata	1.24	1.09	0.98	0.68	0.13	1.28
Juncus articulatus	0.00	0.00	0.00	0.00	0.00	0.00
Juncus bufonius	0.00	0.00	0.00	0.07	0.00	0.00
Juncus effusus	0.00	0.14	1.77	0.32	7.61	7.84
Lamiaceae	0.03	0.00	0.03	0.00	0.09	0.00

Appendix 2 continued

Vegetation	Pasture		Tussock		Shrubland	
	2006	2010	2006	2010	2006	2010
Lamiaceae sp.	0.06	0.00	0.00	0.00	0.00	0.00
Linum catharticum	0.19	0.00	0.02	0.00	0.04	0.00
Montia fontana	0.00	0.00	0.00	0.00	0.00	0.00
Mycelis muralis	0.00	0.14	0.00	0.00	0.00	0.00
Myosotis arvensis	0.00	0.00	0.02	0.00	0.00	0.00
Prunella vulgaris	0.00	0.00	0.00	0.16	0.04	0.00
Ranunculus acris	0.62	0.00	0.17	0.00	0.38	0.00
Ranunculus repens	0.00	0.80	0.00	0.30	0.00	0.00
Rumex acetosa	0.00	0.00	0.00	0.22	0.00	0.00
Rumex acetosella	0.00	0.00	0.37	0.00	0.00	0.00
Rumex crispus	0.00	0.00	0.00	0.00	0.04	0.17
Sagina procumbens	0.00	0.14	0.00	0.00	0.00	0.00
Sonchus oleraceus	0.00	0.14	0.02	0.00	0.00	0.00
Stellaria alsine	0.00	0.00	0.00	0.31	0.00	0.00
Stellaria media	0.00	0.37	0.01	0.59	0.00	0.54
Taraxacum officinale	0.03	0.00	0.15	0.22	0.06	0.14
Veronica arvensis	0.17	0.75	0.06	0.59	0.09	0.42
Veronica serpyllifolia	0.07	0.36	0.00	0.07	0.00	0.54
Vulpia myuros	0.51	0.00	0.57	0.00	0.00	0.00
Indigenous tussocks						
Chionochloa rubra	1.44	1.97	6.68	7.95	11.67	12.77
Festuca novae-zelandiae	0.00	0.00	0.02	0.00	0.00	0.31
Poa cita	1.89	0.15	2.47	0.78	1.36	0.60
Poa colensoi	2.63	0.00	0.13	0.08	0.00	0.00
Indigenous herbs/grasses						
Acaena caesiiglauca	0.05	0.26	0.04	0.15	0.69	0.38
Acaena novae-zelandiae	0.00	0.00	0.01	0.08	0.07	0.00
Anaphaloides bellidioides	0.88	0.48	0.00	0.23	0.00	0.56
Anisotome aromatica	0.00	0.12	0.00	0.23	0.00	0.00
Brachyglottis bellidioides	0.29	0.00	0.00	0.00	0.00	0.00
Brachyscome sinclairii	0.00	0.00	0.00	0.08	0.00	0.00
Bulbinella sp.	3.64	0.85	0.94	0.65	3.06	0.55
Cardamine corymbosa	0.00	0.00	0.00	0.00	0.00	0.00
Carex coriacea	3.41	0.00	1.36	4.83	2.41	3.79
Celmisia gracilenta	0.00	0.12	0.00	0.07	0.00	0.14
Celmisia graminifolia	0.03	0.00	0.00	0.08	0.02	0.00
Centella uniflora	0.00	0.00	0.03	0.00	0.00	0.00
Clematis marata	0.00	0.00	0.00	0.00	0.04	0.14
Connorochloa tenuis	0.00	0.00	0.02	0.08	0.00	0.00
Corybas sp.	0.00	0.00	0.00	0.00	0.02	0.00
Dichelachne micrantha	0.00	0.21	0.00	0.00	0.00	0.00
Epilobium nummulariifolium	0.00	0.00	0.00	0.00	0.00	0.00
Epilobium sp.	0.00	0.00	0.00	0.00	0.00	0.00
Geranium microphyllum	0.11	0.12	0.06	0.22	0.48	0.38
Geum leiospermum	0.00	0.00	0.00	0.00	0.00	0.00
Gonocarpus aggregatus	0.00	0.00	0.01	0.00	0.04	0.00
Gonocarpus micranthus	0.00	0.00	0.03	0.08	0.00	0.00
Gunnera prorepens	0.00	0.00	0.00	0.00	0.00	0.00
Gunnera sp.	0.00	0.14	0.00	0.00	0.00	0.00
Helichrysum filicaule	0.02	0.00	0.04	0.00	0.05	0.00
Hierochloe redolens	0.00	0.00	0.00	0.00	0.00	0.14
Hydrocotyle novae-zelandiae	0.29	0.00	0.17	0.16	0.06	0.55
Hypericum pusillum	0.00	0.00	0.00	0.09	0.00	0.00
Lagenifera strangulata	0.00	0.00	0.00	0.00	0.00	0.00
Linum monogynum	0.03	0.00	0.00	0.00	0.00	0.00

Appendix 2 continued

Vegetation	Pasture		Tussock		Shrubland	
	2006	2010	2006	2010	2006	2010
Luzula rufa	0.29	0.00	0.00	0.08	0.00	0.00
Muehlenbeckia complexa	0.00	0.00	0.58	0.07	3.07	0.14
Muehlenbeckia sp	0.00	0.12	0.00	0.72	0.00	0.24
Nertera sp	0.00	0.00	0.00	0.00	0.00	0.00
Oreomyrrhis ramosa	0.06	0.12	0.31	0.29	0.24	0.38
Ranunculus glabrifolius	0.00	0.00	0.00	0.47	0.00	0.00
Ranunculus hirtus	0.00	0.00	0.00	0.00	0.00	0.00
Ranunculus multiscapus	0.38	0.14	0.06	0.08	0.02	0.41
Ranunculus sp.	0.00	0.00	0.03	0.00	0.00	0.00
Rubus schmidelioides	0.00	0.00	0.74	0.36	0.00	0.00
Rytidosperma nigricans	0.00	0.00	0.00	0.13	0.00	0.19
Rytidosperma unarede	0.24	0.00	0.00	0.00	0.00	0.00
Sonchus kirkii	0.00	0.00	0.00	0.00	0.00	0.00
Uncinia rubra	0.00	0.00	0.00	0.17	0.02	0.00
Viola cunninghamii	0.00	0.00	0.00	0.08	0.00	0.00
Wahlenbergia albomarginata	0.03	0.15	0.00	0.00	0.00	0.14
Indigenous Ferns & bracken						
Blechnum penna-marina	0.10	0.26	0.08	0.14	0.41	0.14
Microsorum pustulatum	0.00	0.00	0.00	0.00	0.00	0.00
Polystichum vestitum	0.11	0.14	0.29	0.08	0.91	0.65
Pteridium esculentum	0.00	0.00	0.00	0.08	0.05	0.19
Indigenous shrubs						
Carmichaelia virgata	0.00	0.29	0.00	0.00	0.39	0.14
Coprosma colensoi	0.00	0.26	0.00	0.08	0.00	0.38
Coprosma propinqua	0.00	0.00	0.03	0.07	1.43	0.00
Coprosma rugosa	0.00	0.00	0.02	0.07	0.00	0.14
Discaria toumatou	2.92	4.29	4.22	4.39	1.85	1.85
Melicytus alpinus	0.00	0.00	0.00	0.00	0.00	0.00
Olearia bullata	0.00	0.00	0.80	0.00	2.56	0.00
Unknown						
Agrostis sp.	0.00	0.00	0.02	0.06	0.00	0.00
Cardamine sp.	0.00	0.00	0.03	0.00	0.04	0.00
Cardamine sp.	0.06	0.00	0.00	0.00	0.00	0.00
Cerastium sp.	0.22	0.00	0.41	0.06	1.75	0.00
Elymus sp.	0.00	0.29	0.00	0.00	0.00	0.36
Epilobium sp.	0.00	0.00	0.00	0.00	0.04	0.00
Geranium sp.	0.00	0.00	0.00	0.07	0.00	0.00
Glyceria sp.	0.00	0.00	0.00	1.74	0.00	0.00
Mysotis sp.	0.00	0.28	0.00	0.35	0.00	0.36
Poa sp.	0.00	0.00	0.00	0.00	0.00	0.00
Poa sp2.	0.00	0.00	0.00	0.00	0.00	0.00
Stellaria sp.	0.11	0.00	1.97	0.00	0.98	0.00