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LAY SUMMARY

- This is a descriptive study examining habitat use of red deer hinds farmed within an extensive high-country system in South Canterbury. It expands previous work conducted at Haycocks Station in Southland (Netzer et al. 2009) to another site more representative of east coast South Island high-country.

- Over the last decade the number of breeding hinds being farmed in South Island high-country has markedly increased and this trend is expected to continue into the foreseeable future. However, at present relatively little is known about how these deer use and affect the expansive tussock rangelands used in high-country deer farming systems.

- Attaining basic quantative information on the type of habitat used by hinds is important for developing farm management strategies that aim to maximise animal production, while at the same time minimising negative impacts on the environment.

- Both the expansive and diverse nature of theses rangelands, along with the vigilant nature of red deer, hinders obtaining this information through visual observational studies. As an alternative, the daily behavioural patterns of red deer hinds were tracked by using Global Positioning System (GPS) collar units and each of the logged locations of the hinds was then related to detailed vegetation and topographic maps of the study site using Geographical Information System (GIS) software.

- The study was conducted in a large 180 ha modified tussock grassland paddock at White Rock Station, located in the Rangitata Gorge, South Canterbury, during the hind calving and lactation seasons of 2008/09 and 2009/10. In each year, the GPS units were fitted to a small subsample of eight hinds, which were set-stocked in this paddock at 1.1-1.3 hinds/ha as part of a much larger herd.

- The study paddock was located on a north-east facing hillside, ranged in altitude from 400-860m above sea level, and contained a complex vegetation mosaic of naturalised pasture, short and tall tussocks, bracken, and woody shrubs.

- The home ranges of the hinds varied between 35 and 97 ha in size and most (all but one) extended from the bottom to hilltop boundary fence lines of the paddock, thus encompassing a very wide range of elevations (400m-860m).

- The average size of a home range at White Rock Station was similar to that at Haycocks Station. Initially it was expected that the home ranges at Haycocks Station would be smaller, given the more favourable growing conditions and more productive pasture species present at this site. However, the higher stocking rate at Haycocks Station may have countered the inherent advantage by causing greater competition between the hinds for available resources.

- All of the GPS tracked hinds avoided a large region of the paddock representing 13% of the total paddock area. This highlights a farm management issue that in such diverse and extensive rangelands the effective grazing area may actually be much smaller than the total area of the paddock.

- Hinds tracked over both years showed strong fidelity in their range use, occupying similar regions in the paddock each year. This was particularly evident for hinds which showed signs of being dominant females. This behaviour raises the question whether their progeny will also use a similar home range and by doing so, to at least some extent, pre-determine their progeny’s future performance.

- The 50% core occupancy area within each hind's home range varied between 4 and 25 ha in size, indicating that over calving and lactation each hind only heavily used a relatively small proportion (9-32%) of their total home range. However, at the stocking rates used the hinds would not be able to graze in isolation, with the need for considerable overlap between their core use areas.

- Averaged over the entire period of GPS tracking, pasture and tussock species dominated the main vegetation occupied by the hinds and these two classes of vegetation were used more than would normally be expected given their overall availability in the paddock. In contrast, none of the tracked hinds used shrub dominant vegetation more than in proportion to its availability, with over half avoiding this vegetation class.

- However, there was considerable diurnal variation in the classes of vegetation that the hinds occupied, which also changed seasonally. The latter was likely strongly related to the reproductive state of the hind.

- The four states of hind behaviour around calving, defined and modelled by Asher et al. (2009) for Haycocks Station, were also identified from sequential GPS fixes recorded in the present study in 2008/09. On the day of parturition either tussock or shrubland vegetation was used significantly more than normal, given its availability in the paddock.

- All of the hinds showed marked diurnal patterns of movement indicative of morning and evening feeding bouts. Similarly, the hinds also showed a strong diurnal altitudinal movement pattern, with them in the morning moving uphill into tussock and shrubland vegetation and then returning back down the hillside again in the evening onto gentler more pasture dominant areas. The need for adequate cover for resting and sheltering especially during daylight hours was postulated to be a major driver for this behaviour. However, limited drinking water sources located near the top of the hill may have also influenced the diurnal movement patterns.

- Overall, the general behavioural patterns described in this study for Hind 374, indicated that this hind was a heavier dominant female, who was able maintained a very similar home range each year, had access to lower slope pasture areas and also showed signs of less stress at calving.

ABSTRACT

Global Positioning System (GPS) receivers were fitted as neck collars on red deer hinds to determine their daily movement patterns and habitat use over calving and lactation on an extensively managed high-country Station in South Canterbury. This expands research conducted at Haycocks Station in Southland by Netzer et al. (2009) to another site more representative of South Island East Coast high-country, especially in terms of the climate, vegetation, and breeding hind stocking rates farmed.

The study site was an 180 ha paddock on White Rock Station, in the Rangitata Gorge, and ranged in altitude from 400-860m. It was located on a steep north-easterly facing hillside and its indigenous tussock and woody shrub vegetation has been modified by over-sowing with exotic pasture species and grazing with livestock.

Eight mixed-aged hinds out of 230 hind and 195 hind herds were tracked in 2008/09 and 2009/10, respectively. A different breeding herd was set-stocked in the study paddock each year. Nevertheless, four of the eight original hinds tracked in the first year were able to be mixed into the herd used in the following year, allowing a small subset of hinds to be tracked over two successive years. The GPS receivers took positional readings at 15 minute intervals and in 2008/09 and 2009/10 recorded on average 92% and 84% of all possible fixes, respectively.

Detailed vegetation and topographical maps of the study paddock were made to relate the recorded spatial positions of the hinds to the different habitats present within the paddock. The vegetation map was made from a recent high resolution satellite image of the study site and was validated through extensive ground surveying. ArcGIS 9.3, which is a Geographical Information System (GIS) software program, was used to display and analyse all of the spatial data.

The individual home ranges of the hinds varied from 35 to 97 ha in size, and all, except for one hind, bordered both the bottom and top boundary fence lines of the hill paddock. In contrast, the more intensively used 50% core occupancy areas within these ranges were a lot smaller, equating to between 9% and 32% of the total home range area, and each core area also covered a much more restricted altitudinal range. Pasture and tussock dominated the main vegetation used in the 50% core occupancy areas. However, there was considerable diurnal variation in the classes of vegetation that the hinds occupied, which also changed seasonally. The latter was likely strongly related to the hind's reproductive state. All of the hinds avoided two large areas of steep terrain, covered with a high proportion of shrub and tussock vegetation, which represented 13% of the entire paddock. Each year the hinds returned to a similar home range, and this was particularly strong for dominant females.

The four states of hind behaviour around calving defined and modelled by Asher et al. (2009) for Haycocks Station were also identified from sequential GPS fixes recorded in the present study in 2008/09. On the day of parturition either tussock or shrubland vegetation was used significantly more than normal, given its availability in the paddock.

All of the hinds showed marked diurnal patterns of movement indicative of morning and evening feeding bouts. Similarly, the hinds also showed a strong diurnal altitudinal movement pattern, with them in the morning moving uphill into tussock and shrubland vegetation and then returning back down the hillside again in the evening onto gentler more pasture dominant areas. The need for adequate cover for resting and sheltering during daylight hours was likely a major driver for this behavioural pattern, along with perhaps the limited availability of drinking water sources.

Key words: Red deer, GPS, GIS, home range, habitat use, grazing behaviour

1. INTRODUCTION

Over the last decade there has been a marked change in the type of land class where many of New Zealand's South Island red deer (*Cervus elaphus*) breeding herds are being farmed (Asher et al. 2009). In general, breeding hind numbers have increased in the high country, while they have decreased in the downs and lowlands. Several factors have likely contributed to this change. Breeding herds and finishing units have been lost from the downs and lowlands through conversion of this land to alternative land-uses such as dairy farming. In contrast, high country farmers have added deer breeding enterprises to their farms or expanded the size of existing enterprises because of their high economic returns, relative to traditionally run sheep and cattle, and also their perceived suitability to the type of management, resources, and more extreme environmental constraints typical of high country farming systems (Peoples and Asher 2009).

Deer farm management in the high country ranges from low input extensive systems through to higher input semi-intensive systems (Peoples and Asher 2009). Many high-country farmers strategically graze their breeding hinds in modified (semi-improved) tussock grasslands for at least part of the year, often set-stocking them in large paddocks, at low stocking densities (1-4 hinds/ha), over the late-spring through to early-autumn calving and lactation period. These paddocks usually contain a very diverse range of elevations, aspects, slope classes, and indigenous and exotic plant species (Netzer et al. 2009).

Previous research has shown that similar grazing management practices used in large heterogeneous paddocks or rangelands enables animals to selectively graze for highly nutritious forages, resulting in high individual animal performance (Purvis 1986). However, over time, this same strategy can also cause localised degradation in the vegetation patches or landscape units preferred by the grazing animals (Stafford Smith 1996). More intensive use of an area, or the transferral of soil nutrients without replenishment away from the same area increases the level of disturbance and environmental stress experienced by the resident vegetation. This can cause a shift in the botanical species composition of the vegetation, by influencing the competitiveness of individual plant species, and eventually can reduce the overall productive capacity of the preferred patch or landscape unit (Briske 1996).

The diverse topography and vegetation cover usually contained in large tussock grassland paddocks, combined with a low hind stocking density, provides greater opportunity for farmed deer to exhibit their natural range of behaviour over calving in comparison to more intensively managed deer farming systems. In the wild, a pre-parturient hind will normally isolate itself away from the rest of the herd to give birth and for several weeks afterwards the newborn calf hides out of sight in a secluded position (Darling 1937; Clutton-Brock and Guinness 1975; Guinness et al. 1979). Similar hind and calf behaviour has been recorded in observational studies of intensive deer farming systems with stocking densities of up to 11 hinds/ha (Wass et al. 2003, 2004). However, the more limited space available between the hinds, along with normally less topographical or vegetative cover, restricts the ability of the hind and calf to sufficiently isolate themselves away from the rest of the herd. This leads to greater levels of disturbance and interference by other hinds than observed in the wild (Church and Hudson 1996; Wass et al. 2003, 2004). Such lack of isolation at parturition and while the hind and calf are initially bonding is considered to be a major contributory factor to increased perinatal calf mortalities in intensive deer farming systems (Asher and Pearse 2002; Pollard 2003; Pollard and Stevens 2003).

While the large tussock grassland paddocks used in the South Island high-country should allow deer to selectively graze high quality forage and more fully express their natural behaviours, leading to high individual animal performance, there are potentially issues around what effect these animals are having on the ecology of the system and how this may impact on the long term productivity of these deer farms. Currently, there is little information available on the resource use of tussock grasslands by red deer set-stocked at densities typical of extensively managed deer farming systems (Netzer et al. 2009). Obtaining this information through direct observational studies would be problematic given the expansive and complex terrain of the large tussock grassland paddocks, combined with the vigilant nature of deer and their isolation-seeking behaviour around the time of parturition (Asher et al. 2009).

During the late-spring through to early-autumn seasons of 2006/07 and 2007/08, Netzer et al. (2009), using Global Positioning System (GPS) receivers on neck collars, successfully tracked the movement patterns of parturient red deer hinds grazing in large high-country paddocks in the Te Anau basin, Southland. Hind movement patterns were overlaid onto detailed vegetation and topographical maps of the study site to enable the habitat use of the tracked hinds to be determined. In addition, the influence of weather conditions encountered at the time on hind habitat selection was also investigated (Netzer at al. 2009).

The study site chosen by Netzer et al. (2009) had a summer-wet climate with an annual rainfall of >2000 mm. The hinds were set-stocked at 2.8 hinds/ha and red tussock (*Chionochloa rubra*) was the dominant tussock species at the site (Netzer et al. 2009). The present study extends the work of Netzer et al. (2009) to another site more representative of summer-dry tussock grasslands, which cover extensive areas of South Island high-country along the entire eastern flank of the Southern Alps (Mark 1969). In these grasslands, *Poa* and *Festuca* short tussocks and *Chionochloa* tall snow tussocks are the dominant indigenous tussock species (Mark 1994). The main objectives were to identify the daily behavioural patterns and habitat use of parturient hinds over calving and lactation.

2. MATERIALS AND METHODS

2.1 Site description

The study was conducted in a large 180 ha tussock grassland paddock on 'White Rock Station', located in the Rangitata Gorge of South Canterbury, approximately 50 km north-west of the township of Geraldine (Figure 1). The paddock covered a large section of steep north-easterly facing hillside bordering the Rangitata River. Several gully systems were present, with the largest being located near the centre of the paddock. This main central gully system had in particular a very steep rock-face on its south-eastern edge (Figure 1). Overall, the paddock ranged in altitude from 400 m above sea level next to the river up to 860 m at the crest of the hill.

The indigenous tussock vegetation of the paddock had been modified by oversowing with exotic pasture species and grazing with sheep and cattle. Silver tussock (*Poa cita*) and fescue tussock (*Festuca novae-zelandiae*) were the dominant indigenous short-tussock species, with taller narrow-leaved snow tussock (*Chionochloa rigida*) located near the top of the hill. The inter-tussock areas consisted of mainly naturalised exotic pasture species, including browntop (*Agrostis capillaries*), sweet vernal (*Anthoxathum odoratum*), cocksfoot (*Dactylis glomerata*), and white clover (*Trifolium repens*). Woody plant species, such as matagouri (*Discaria toumatou*) shrubs and bracken (*Pteridium esculentum*), were also scattered in patches across the hillside (G.W. Asher, unpublished data).

The site has a summer-dry climate, with pasture growth largely restricted to late-spring/early-summer, and being mainly influenced by cold winters and often hot, dry summers (Ross Stevens pers. comm.). Annual rainfall measured at Peel Forest climate station, located near the base of the Rangitata Gorge, is 888 mm, with December (105 mm) and June (50 mm) the wettest and driest months of the year, respectively. The average air temperature is 9.9^{o}C, ranging from 15^{o}C in January to 4.3^{o}C in July (NZ Meteorological Service, 1981).

Sheep and cattle regularly grazed the paddock until 2008, when it was completely enclosed with 7 km of deer-proof fencing. Since then, it has been set-stocked solely with red deer at 1-4 hinds/ha over spring and summer (September-February) and also in winter (June-August) (Ross Stevens pers. comm.).

2.2 GPS tracking of red deer hinds

Eight adult (>3 years old) red deer hinds, which had been mated in March, were tracked with GPS collars over the spring (October) through to early-autumn (March) period of 2008/09 and 2009/10. The GPS tracked hinds were set-stocked for calving in the study paddock as part of a 230 hind (1.3 hinds/ha) and 195 hind (1.1 hinds/ha) mixed-aged hind herd in 2008/09 and 2009/10, respectively, and in both years had expected mid-late November calving dates. Totally different herds were set-stocked in the study paddock each year. However, four of the eight hinds tracked in 2008/09 were able to be mixed into the alternative herd used in 2009/10, just prior to them being set-stock in spring, allowing a subset of the GPS tracked hinds to be monitored over two consecutive years. The spring of 2008 was the very first season that deer were grazed in the newly fenced paddock, presenting a unique opportunity to monitor the behaviour of farmed hinds when introduced into an unfamiliar tussock grassland environment and also to monitor their environmental impact over time.

The live weights of the eight hinds randomly selected for GPS tracking in 2008/09 were not measured. In contrast, in 2009/10 a stratified random selection process was used to ensure monitoring of hinds with a wide range of live weights. The mean live weight of the GPS tracked hinds was 110 kg ± 4 kg (mean ± SEM), ranging between 95 kg and 124 kg. At weaning the udders of the GPS tracked hinds were examined for signs of lactation. Only one of the collared hinds (Hind 459) in 2009/10 did not exhibit any signs of successfully rearing a calf.

The GPS collars (Blue Sky Telemetry Inc., Edinburgh, Scotland) carried by the hinds weighed 590g, equivalent to approximately 0.5% of the hind's body weight. The GPS units started recording global positional fixes at 08:00h on a pre-determined date and thereafter at 15 minute intervals for as long as their reserve battery power allowed. Each GPS unit contained twelve AA-sized lithium batteries providing enough power under optimal conditions to reliably record GPS fixes for up to 5 months. However, if a GPS unit failed to receive an adequate satellite signal it continued to search for an additional 5 minutes to increase the likelihood of achieving a GPS fix. Thus, the repetitive failure of a GPS unit to acquire an adequate satellite signal had the potential to rapidly exhaust the energy reserves of the AA batteries.

Fitting and removing the GPS collars coincided with routine mustering and yarding operations. In both 2008 and 2009, collar fitting occurred at the last health check of the hinds before being set-stocked for calving in the study paddock in October. Collar removal happened in February/March, when the hinds and calves were mustered for calf weaning. In 2008/09 and 2009/10, the GPS units started recording global positional fixes on 1 October and 21 October, respectively.

On retrieval of the collars the GPS data was downloaded into ArcGIS 9.3 (ESRI, Readlands, CA. USA) for spatial analysis. Due to the method that the collars use to receive satellite signals, differential correction was not possible on the GPS data. Instead, the accuracy of the GPS collars was assumed to be similar to estimates from the Netzer et al. (2009) study, where stationary testing of the same units indicated an accuracy ranging from 1-7 m. However, it is acknowledged, as Netzer et al. (2009) stated, "that this methodology is limited in truly assessing the overall spatial accuracy of the collars, as the accuracy could be negatively affected in different areas of the large study paddocks due to topographic interference or vegetation cover".

2.3 Vegetation and topographic mapping of the study site

The GPS fixes of each tracked hind were overlaid onto detailed vegetation and topographical maps of the study paddock to determine their movement patterns in the landscape and overall habitat use. ArcGIS 9.3 (ESRI, Readlands, CA. USA), which is a Geographic Information

System (GIS) computer software package, was used to display and analyse all of the spatial data related to the topography and vegetation of the site. Topographic map elevation contour lines of the paddock were obtained from the Land Information New Zealand (LINZ) UOSS database. Using ArcGIS Spatial Analyst extension software, the slope and aspect of the terrain at different locations within the paddock were also calculated from a 15 m spatial-resolution Digital Elevation Model (DEM) of New Zealand, obtained from Landcare Research. The vegetation cover of the study paddock was digitally mapped from a very high resolution 'Quickbird' satellite image taken on the 26 February 2006.

2.3.1 *Satellite image analysis of the study paddock's vegetation cover*

2.3.1.1 Satellite image characteristics and pre-processing

The satellite digital imagery included blue (0.45-0.52 µm), green (0.52-0.60 µm), red (0.63-0.69 µm), near infrared (0.76-0.90 µm), and panchromatic (black and white, 0.45-0.90 µm) spectral wavebands and had a spatial resolution of 0.6 m. Geometrical distortions in the imagery, caused by variable topography of the site, were corrected (orthorectified) using 18 GPS ground control points that were clearly visible in the panchromatic image. Based on 28 additional GPS check points, the study paddock orthorectified satellite imagery had a geolocation Root Mean Square Error (RMSE) of 0.65 m. The RMSE for the worst 10% of GPS check points was 1.8 m. Post-processing differential correction was conducted for all GPS fixes.

2.3.1.2 Segmentation of satellite image into discrete land cover objects

Using Definiens Professional 5 (eCognition) computer software, the study paddock was subdivided into discrete land cover objects based primarily on their spectral identities shown in the digital satellite imagery. Each object was an adjoining group or cluster of pixels that shared spectral characteristics markedly different from the pixels contained within neighbouring objects (Mathieu et al. 2007). The blue, green, red, NIR, and panchromatic image layers, along with a Normalized Difference Vegetation Index (NDVI = NIR-green/NIR+green), were used to differentiate these objects. Each spectral layer was given an equal weighting, since no single one proved to be totally suitable for this process. The NDVI aided in separating shrub and tree vegetation (Mallinis et al. 2008).

A scale factor and a heterogeneity criterion were used in eCognition to control the extent that small image objects were merged into larger ones. The scale factor specifies the maximum allowable increase in object heterogeneity after a pair-wise merge, thus indirectly determining the size (i.e. number of pixels) of the objects. In contrast, the heterogeneity criterion controls the actual merging decision process, and includes two mutually exclusive properties: homogeneity of colour and geometrical shape (Mathieu et al. 2007). The values for each of these parameters were selected using a systematic trial and error approach, with the resulting objects visually compared to the original panchromatic image. A weight of 0.8 was given to colour respectively to shape, emphasising the importance of the former over the latter. The main land cover classes that could be remotely identified in the study paddock were characterised using a scale factor of 30. This produced 14,831 individual image objects in total, each with an average size of 132 m^2. At this scale the objects were easily identifiable in the field for subsequent detailed ground surveying.

2.3.1.3 Unsupervised classification of land cover objects into preliminary vegetation classes

Using MATLAB® computer programming software, all of the objects identified in the previous image segmentation process were grouped into 25 preliminary vegetation classes based on a K-mean cluster analysis of their spectral characteristics (Figure 2). This multivariate analysis technique minimises spectral differences within classes while maximizing the differences between classes. These 25 classes formed strata from within which 291 randomly selected image objects were field-surveyed to gather more detailed information on their typical vegetation and other physical characteristics. Field-sampling was carried out in the last week of February 2009, with GPS coordinates, aspect, slope, percentage (%) cover of dominant and other relevant plant species, % cover of bare ground, and height of vegetation recorded, as well as photographs taken, for each sample-plot. The total number of image objects surveyed for each preliminary vegetation class was balanced in relation to the overall area of the paddock that they represented.

2.3.1.4 Supervised classification of objects into final vegetation classes

The field-surveyed image objects were used to identify the spectral and textural characteristic associated with certain types of land cover. This information was then used in eCognition to develop a class definition scheme for improving the classification of image objects into more biologically relevant vegetation classes. Several definition schemes with up to 30 different classes of both pure and mixed species vegetation were investigated, again, on the basis of a systematic trial and error approach. Only a few of the image objects sampled in the field were actually used for directly training the object classifiers. Instead, the majority of training objects were selected directly from the satellite image based on their spectral and textural signatures. This strategy allowed the remaining field-surveyed objects to be used later for assessing the accuracy of the final vegetation classifications.

The variable topography of the paddock affected its illumination in the satellite imagery, which in turn confounded the spectral signatures of some of the vegetation cover classes. In particular, the rugged terrain in the southern part of the paddock was less exposed to the sun than the main slope. Since it received less irradiance, this area reflected less energy and appeared much darker in the satellite imagery. In response, an atmospheric and topographic correction was attempted, but was unsuccessful due to the 15 m spatial-resolution of the Digital Elevation Model (DEM) being too coarse. As an alternative, the blue spectral waveband was used to mitigate the topographical effects on the green, red and NIR bands by the means of a rationing technique. This involved, firstly, empirically correcting all of the spectral bands for atmospheric effects by using a dark object subtraction method (Chavez, 1996) and secondly, creating modified spectral image layers by dividing the green, red, and NIR wavebands by the corrected blue waveband.

The modified spectral layers, along with the NDVI, were used to re-characterise the training objects. The standard deviation of pixel values belonging to each object in the panchromatic image layer was also used to define their texture. Table 1 summarises the final parameters and rules used for classifying the image objects. Membership to a vegetation class was estimated using a nearest neighbour algorithm, which assessed the similarity of an unknown object to the training samples of each defined class according to their spectral and textural patterns. The segmentation scale was reduced from 30 to 15, which decreased the average object area from 132 m^2 to 33 m^2 and increased the overall resolution of the digitally produced vegetation map.

2.4 Statistical analysis

2.4.1 Vegetation map accuracy

The accuracy of the vegetation map was assessed by developing an error matrix, comparing the vegetation recorded in the field-surveyed image objects against their classifications in the final map (Congalton, 1991). All field-surveyed objects used to produce the final vegetation map were not used in this analysis, while some additional sample-plots were created when they could be reliably identified and interpreted from field-survey information and photographs. In total, the error matrix included 358 sample-plots representing >1% of the entire paddock area. ‘Producer’s’, ‘User’s’, and ‘Overall’ accuracy statistics, as well as kappa statistics (*k*), were calculated (Congalton and Green 1999).

2.4.2 Home ranges and core areas of the GPS tracked hinds

The home ranges of the collared hinds, and core areas used within these ranges, were estimated from the GPS fixes using the fixed kernel method in the software package 'Home Range Tools for ArcGIS' Version 1.1 (Rodgers et al. 2007). Each home range represented the area of the paddock that the hinds occupied while performing their 'normal' daily activities (e.g. grazing, resting, nurturing their calves, etc.). By creating an utilisation distribution (UD) of the paddock as part of this method, a subset of more intensively used core areas were identified. These areas were superimposed as contour lines (isopleths) onto the vegetation and topographic maps of the site in ArcGIS 9.3. Their outer perimeters were restricted to within the paddock's boundary fence line, using the ArcTools 'Clip' function, to remove extraneous information not related to the study. The smallest area of the paddock including 95% of the GPS fixes defined the 'total' home range and the smallest area including 80%, 50% and 20% of the GPS fixes defined core areas of increasing intensity of use within the home range (Edwards et al. 2001).

Home range and core area analysis was limited to a single temporal scale covering calving and peak lactation. In 2008/09, the collared hinds were set-stocked into the newly fenced study paddock, together with the rest of their herd, on 13 October 2008 and were not mustered out of this paddock again until 144 days later on 6 March 2009. In contrast, in 2009/10, the collared hinds did not enter the study paddock until 28 October 2009, which was seven days after the main herd had already been set-stocked in this area. Thereafter, the hinds remained in the study paddock for 129 days until 6 March 2010.

While some of the GPS collars successfully logged positional fixes over the entire duration that the hinds were in the study paddock, other collars functioned for a much shorter period. As a result, for 2008/09 and 2009/10, the GPS fixes used for determining the home ranges and core areas were restricted to: 1 November 2008 to 21 January 2009 (81 days), and 11 November 2009 to 21 January 2010 (71 days), respectively. The first two weeks of GPS fixes recorded once the hinds entered the study paddock were omitted from the analyses to give the hinds time to settle into their new environment and establish a home range. Whereas, the 21 January was used as a cut off date, as this was the latest date that the majority (>80%) of units functioned for over both years. In 2008/09, one of the collared hinds evaded mustering into the correct study paddock, resulting in it being removed from the study.

The topographical relief and vegetation within the home ranges and 50% core areas were calculated on an area basis using the 'Zonal – tabulate area' function in 'Spatial Analyst Tools' for ArcGIS. In addition, the proportion of time that each vegetation type was used by the hinds was determined from their GPS fixes on the vegetation map within the 50% core areas. Pairwise t-tests were used to compare the 50% core areas of the four hinds that were tracked in both years.

2.4.3 Vegetation selection indices

Vegetation selection indices were developed by dividing the proportion of time a hind occupied a particular vegetation class by the proportion of the entire paddock that the same vegetation class represented. Index values greater than 1 indicate positive selection, whereas values less than 1 indicate avoidance. A Chi-square analysis was used to test the hypothesis that a vegetation class was occupied in proportion to its availability. If this hypothesis was rejected, Bonferroni confidence intervals were used to separate which vegetation classes were used more or less than expected (Alldredge and Ratti 1986).

2.4.4 Hind diurnal behavioural patterns

The distance a hind travelled between successive GPS fixes was used as an indicator of when they were most or least active over the course a day. Daily patterns were calculated by breaking up a day into 15 minute intervals and averaging the distance each collared hind travelled over the entire study period for each interval. These values were then smoothed using a 'LOESS smoother' (locally weighted scatterplot smoothing) to produce graphical displays showing each hind's diurnal activity patterns (Cleveland and Devlin 1988). To examine any potential monthly changes in these diurnal patterns, the distances travelled for all of the hinds and days within a particular month were averaged together for each 15 minute interval and again smoothed to show the average diurnal pattern for each month. Several parameters describing the spatial movement patterns of the hinds within the paddock and the characteristics of the habitat occupied for each 15 minute interval were also investigated. These parameters included: altitude (m a.s.l.), slope of terrain (degrees), position on NE and NW primary axes of the paddock (m), indicating movement along and across the hillslope, respectively; and the proportion of dominant vegetation classes (%).

2.4.5 Estimating hind parturient behaviour and birthing location

For the 2008/09 dataset, variation in the distance each collared hind travelled between sequential GPS fixes over the course of the study was used identify the time, and therefore the site, of calving. Based on this measure of hind activity, four pre-defined behavioural states around estimated parturition were indentified using a simple Markov modulated regression model (Asher et al. 2009). These states included: (1) late pregnancy, when the hind moves normally within its social group; (2) pre-parturient birth site searching, characterised by a large increase in the magnitude of spatial movement; (3) birth/nurturing, indicated by a marked decrease in spatial movement; and (4) the mobile state, when the hind/calf pair reunites with the hind's social group and a more normal pattern of movement resumes (Asher et al. 2009). Basic graphical displays of each hind's movement patterns were used to investigate whether these four behavioural states could be recognised in the data and were also used to attain initial estimates of transition times between the behavioural states. The regression analyses were carried out using the HiddenMarkov package in R (Harte, 2008). For further explanation of the simple Markov modulated regression model used in the analyses refer to Asher et al. (2009).

3. RESULTS

3.1 *Vegetation and elevation map*

The vegetation of the study paddock was categorised into two main hierarchical levels, which included 12 specific vegetation classes nested within three general classes (Table 2). Classification of the two broadest vegetation categories, 'Grassland' and 'Shrubland', was very accurate at 98.5% ± 1.3% (Table 3b). However, this decreased to 80% ± 3.7% for the 12 more specific vegetation classes. The highest rates of misclassification errors were noted in the case of the 'tussock' class, where objects belonging to 'tussock/pasture' and 'short pasture/tussock' were incorrectly assigned, thus decreasing both the user's accuracy for this class (53.8% ± 5.2%) and the overall accuracy for all classifications (Table 3a,b). The spectral signatures of these three specific vegetation classes would likely have been very similar, given their main plant species. Nevertheless, the Kappa value of 77.2% ± 4.7% indicated there was good agreement between the classified and field-surveyed objects (Landis and Koch 1977) and the overall classification accuracy was similar to other previous studies based on very high resolution satellite imagery (Mathieu et al. 2007).

Overall, pasture dominated vegetation classes covered 94 ha (52%) of the paddock and were especially prevalent in the north-western half of the paddock (Table 4; Figure 3a). In contrast, tussock dominated vegetation covered 53 ha (29%) of the paddock and was located mainly above the paddock's mid-elevation. Shrubland dominated vegetation covered 32 ha (18%) and was generally restricted to within the various gully systems across the paddock's hill-face. A large area of Coprosma, Matagouri, Bracken, and Muelenbekia was located on the eastern side of the large central gully system of the paddock (Figure 3a).

3.2 Effectiveness of GPS units in recording hind locations

In 2008/09, the GPS units started recording the locations of the collared hinds on the pre-determined date of 1 October 2008 and thereafter reliably took positional recordings for between 102 and 158 days over the calving and lactation period. Over this time the GPS units logged between 83% to 98% of all possible 15 minute interval positional fixes, with only one unit recording <89% (Table 5).

Similarly, in 2009/10 all of the GPS units successfully started recording the locations of the collared hinds on the pre-determined date of 21 October 2009. However, they generally functioned for fewer days, compared to in 2008/09, and three GPS units logged <80% of the possible global position fixes (Table 5). Close inspection of the GPS collars at the end of the trial revealed the circuit boards of the less reliable units had suffered various degrees of moisture damage, which may have interfered with the electronics of the system receiving the satellite signals. The GPS units were programmed to search for a signal continually for up to 5 minutes if they failed to initially receive a strong enough signal. This would have contributed to the units rapidly using up their reserve battery power as they tried to resample after not initially attaining an adequate positional fix.

3.3 Home range and core occupancy area

The 2008/09 home ranges of the GPS tracked hinds are presented in Figure 4. Total home range size (shown as 95% contour lines) varied between 50 ha and 97 ha, corresponding to 28% and 54% of the total paddock area, respectively. All extended from the valley floor to the hilltop boundary fences, thus encompassing a very wide range of elevations (400m-880m a.s.l.). However, across the hill-face the home ranges were generally restricted to within the north-western half of the paddock. Hind 606 was the only exception, with its home range covering a very disjointed area, including much of the south-eastern half of the paddock (Figure 4). All of the collared hinds avoided an area of steep topography bordering the south-eastern side of the main central gully system of the paddock. Dense tussock, Bracken, and Coprosma, Matagouri, and Muelenbeckia woody-shrubs made up a considerable proportion of the vegetation within this area.

The 50% core areas within the home ranges varied in size from 12.0 ha to 25.1 ha, corresponding to 6.7% and 13.9% of the total paddock area, respectively (Table 6; Figure 4). Thus, the hinds concentrated 50% of their space use in 14% to 32% of their total home range, indicating marked heterogeneity in space use. Only Hind 567 and 606 had their 50% core area centred above the paddock's mid-elevation of 630m. All were located on a north-east (NE) aspect that was in line with the predominant, and generally very consistent, aspect of the paddock. The 50% core area of each hind contained between 65% and 94% grassland vegetation (i.e. pasture and tussock species) at the broadest scale (Table 6). However, at a more detailed level, the proportions of pasture, tussock and shrub dominant vegetation within each 50% core area varied considerably (Table 6; Figure 5). Based on the vegetation at each recorded GPS location, pasture dominant classes made up the majority of vegetation within the 50% core area of Hind 374, 567, 595, 600 and 2365; ranging in occurrence from 57% to 77% (Table 6; Figure 5). In contrast, the 50% core area of Hind 606 mainly consisted of tussock dominant classes, while Hind 459 had similar proportions of pasture, tussock and shrubs (Table 6; Figure 5). All of the hinds with appreciable levels of tussock in their 50% core area (i.e. Hind

606, 567 and 459) were generally located at higher altitudes on steeper terrain, compared to the other collared hinds (Table 6). Hind 2365 also had an appreciable level of shrub dominant vegetation within its 50% core area (Table 6; Figure 5). Overall, undefined (shadow) areas made up a very small proportion of each hind's 50% core area (<1% based on the vegetation at each GPS fix).

Table 10 shows that within Hind 374, 595, 600, and 2365 home ranges they all used pasture dominant vegetation to a greater extent than would be expected, given its availability in the paddock, indicating they were actively selecting for this vegetation class. Hind 567 also had a selection index >1 for pasture dominant vegetation, but the proportion of use was not statistically different from the proportion available in the paddock. In contrast, Hind 459 and 606 used pasture dominant vegetation less than in proportion to its available area. Instead, Hind 459 occupied mainly tussock and shrubland in proportion to its availability, while Hind 606 actively selected tussock vegetation. None of the tracked hinds occupied the shrubland dominated vegetation to a greater extent than would be expected given its available area in the paddock, with Hind 567, 606, 595, and 600 actually using this vegetation class less than in proportion to its availability (Table 10).

The following year's 2009/10 home ranges of the collared hinds are presented in Figure 6. Total home range size varied between 35 ha and 83 ha, corresponding to 19% and 46% of the entire paddock area, respectively. On average, the total size of the home ranges did not differ between the two years (P=0.1075), despite the hinds being set-stocked at a slightly lower stocking rate in the second year (refer to Section 2.2). Similarly to 2008/09, the home ranges of all of the collared hinds, except for Hind 599, extended from the valley floor to the hilltop boundary fence lines. All of the home ranges, except for again Hind 606, were also generally located on the north-western flank of the main central gully system of the paddock (Figure 6). Out of the four hinds tracked in both years, Hind 374 in particular maintained a very similar home range over both years (Figures 4 and 6). This hind had the greatest live weight (122 kg) out of the four hinds tracked in both years (the live weight of hind 459, 606, and 567 was 99 kg, 111 kg, and 112 kg, respectively). The home ranges of Hind 567 and 606 were more centralised in 2009/10 compared to 2008/09 (Figures 4 and 6).

The 50% core areas within the home ranges varied in size from 4.3 ha to 19.4 ha, corresponding to 2.4% and 10.8% of the total paddock area, respectively (Table 7; Figure 6), and were on average 35% smaller than in the previous year (P=0.04). Hind 459 had the smallest 50% core area out of the GPS tracked hinds and, when yarded at calf weaning, was the only one that did not show any visual signs of raising a calf. By removing this hind from the analysis as an outlier, the average size of the 50% core areas did not differ between the two years (P>0.05). In contrast to 2008/09, the 50% core areas of all of the tracked hinds, except for Hind 374 and 674, were centred above the paddock's mid-elevation of 630m, but were still generally positioned on a north-east (NE) aspect.

In 2009/10, grassland vegetation (i.e. pasture and tussock species) remained the dominant vegetation that hinds occupied within their 50% core areas, ranging between 86% and 98% of occupancy (Table 7; Figure 7). However, in the second year of the trial, hind occupancy in tussock dominated vegetation increased (P=0.033), while occupancy in shrub dominated vegetation decreased (P=0.021), in comparison to the first year. As a result, based on the vegetation at each recorded GPS location, pasture dominant classes made up the majority (>70%) of vegetation within the 50% core area of only Hind 374 and 674, both of which had ranges centred on the more gentle lower slopes of the paddock (Table 7, Figure 6). In contrast, the 50% core area of Hind 459, 567, 606, and 95 mainly consisted of tussock dominated classes, ranging in occurrence between 61% and 69%, whereas, Hind 161 and 599 had similar proportions of both pasture and tussock dominant vegetation (Table 7; Figure 7). Out of the four hinds tracked in both years, Hind 374 exhibited the least variation in the vegetation it occupied between successive years (Figures 5 and 7). Similarly to 2008/09, all of the collared hinds avoided a large area, consisting of mainly shrub and tussock, on the south-eastern side of the main central gully system of the paddock (Figure 6). The total size of the area not used by the tracked hinds over both years was 24 hectares and included a high proportion of dense tussock (30%) and shrubland (29%) on steep topography (Figure 8a,b). Undefined (shadow) areas made up a very small proportion of each hind's 50% core area (<1% based on the vegetation at each GPS fix) (Table 7; Figure 7).

Table 11 shows that within Hind 374 and 674 home range they each used pasture dominant vegetation to a greater extent than would be normally expected, given its availability in the paddock, indicating they were actively selecting for this vegetation class. In contrast, Hind 459, 567, and 606 used pasture dominant vegetation less than in proportion to its available area. Instead, these hinds, along with Hind 95 and 599 selected tussock vegetation. Similarly to 2008/09, none of the tracked hinds occupied shrubland dominated vegetation to a greater extent than would have been expected, given its available area in the paddock, with the majority of hinds (Hind 459, 567, 606, 95, 599, and 161) using this vegetation class less than in proportion to its availability (Table 11). Only Hind 374 and 674 occupied shrubland vegetation in proportion to its availability in the paddock (Table 11). These two hinds had their core areas centred further downslope compared to the other GPS tracked hinds (Table 7; Figure 6).

Overall, the vegetation selection index values for the four hinds tracked in both years were very similar in 2008/09 and 2009/10 (Tables 10 and 11). The main differences were Hind 459 and 567 increased their selection of tussock dominated areas at the expense of shrubland and pasture dominated areas, respectively. Hind 374 and 606 in particular maintained very similar vegetation selection index values over both years.

3.4 Calving date and habitat of birthing site

The specific 2008/09 calving dates and duration times for hind behavioural states around calving estimated from the simple Markov modulated regression model are given in Table 8. Estimated individual calving dates occurred between 12 and 28 November 2008 (Table 8). The time spent searching for a birthing site by the hinds prior to calving ranged from 1 to 25.5 hrs (Table 8; Figure 9). The difference between late pregnancy (μ_1) and birth site searching (μ_2) regression parameters characterising the extent of movement by the hinds indicated that while the hinds were in the latter behavioural state there was a 2- to 4-fold increase in the average distance they travelled per GPS recording (Table 9). However, not all of the hinds exhibited this greater level of activity, with little change in the magnitude of movement occurring in particular for Hind 374 leading up to parturition (Table 9; Figure 9). The standard error (SE) of μ_1 was also smaller than the SE of μ_2, indicating hind spatial movement during late pregnancy was less variable compared to when they were searching for a birth site (Table 9).

The estimated time taken by the hinds to give birth and nurture their newborn calves mainly ranged from 5 to 13 hrs. Nevertheless, there were exceptions with Hind 600 and 2365 remaining in this behavioural state for 1 and 5 days, respectively (Table 8; Figure 9). The mean μ_3 regression parameter, characterising the extent of movement by the hinds during birth/nurturing, was -0.97, compared to 0.22 for μ_1 in late pregnancy. This indicated that while the hinds gave birth and nurtured their calves the average distances they travelled between successive GPS recordings decreased by approximately 70%, compared to in late pregnancy (Table 8; Figure 9). Similarly to birth site searching, the pattern of movement by the hinds while giving birth and nurturing their calves was more variable than during late pregnancy ($SE_{\mu3}$ vs. $SE_{\mu1}$; Table 9). Thereafter, the hinds, presumably with calves at foot, returned to a more mobile behavioural state (Figure 9), shown by the large increase in the value of the μ_4 relative to μ_3 regression parameters (Table 9). However, for most of the hinds, except Hind 567, the magnitude of spatial movement remained slightly lower than during late pregnancy (Table 9; Figure 9).

Figure 10 shows the GPS positional recordings of the collared hinds for 24 hours (a) prior to and (b) after their estimated time of calving. The spatial movement of the hinds is clearly much greater within 24 hours prior to calving in comparison to within 24 hours post calving (Figure 10a vs. 10b). During the 24 hours leading up to calving, all of the GPS tracked hinds showed signs of moving along at least one paddock boundary fence line (Figure 10a). The estimated calving sites of Hind 459, 374, and 2365 were at a mid-to-lower elevation (500-600m) well within the paddock interior. In contrast, hinds 595, 567, 606, and 600 calved close to the hilltop boundary fence line (780-800m; Figure 10b).

The vegetation occupied by the hinds on their respective estimated calving dates is shown in Figure 11. Hind 459 almost exclusively used shrub dominated vegetation (93%) on its calving date. Similarly, the habitat occupied by Hinds 374 and 2365 also had a large component of shrubs (36 and 39%, respectively). However, pasture dominant vegetation still made up over half of the vegetation used (61% and 51%, respectively) by these hinds (Figure 11). Hinds 567, 606, 595 and 600 all selected mainly tussock dominated vegetation over calving, with pasture and shrubs making up less than 30% and 5% of the dominant vegetation, respectively (Figure 11). Overall, Hind 459, 374, and 2365 used shrubland, while Hind 567, 606, 595, and 600 used tussock at least twice as much as would have been normally expected, given its availability in the paddock, indicating the hinds were strongly selecting for these vegetation classes at parturition (Table 12).

3.5 Hind diurnal movement patterns

In 2008/09, all of the collared hinds expressed very clear and similar daily (24 hr) patterns of behaviour, especially in terms of the distance travelled between successive GPS fixes, movement in elevation and steepness of terrain, and vegetation occupation (Figure 12). The greatest distances travelled by the hinds between successive GPS fixes occurred from just before dawn (04:00) through until early morning (09:00) and then again from mid-afternoon (15:00) into late evening (23:00). Short increases in activity also occurred around midday and to a lesser extent around midnight (Figure 12a). The afternoon/evening peak in distance travelled was at least 1/3 greater than in the morning and, for all of the GPS tracked hinds, was very uniform in duration (Figure 12a).

From just before dawn (04:00) through until just after midday (13:00) all of the collared hinds moved upwards in elevation (Figure 12b). Thereafter, they descended at a very similar rate to their original ascent, reaching a minimum elevation by around midnight (24:00). The rate of change in elevation was particularly marked during the morning and afternoon/evening periods of increased activity (Figures 12a, b). Maximum and minimum elevations ranged between 640-760m and 490-640m, respectively (Figure 12b). Hinds 567 and 2365 showed greater amplitude in altitudinal movement compared to the other collared hinds (Figure 12b).

All of the collared hinds were located on $<23^{o}$ hill slopes from late evening (22:00) through until just before dawn (04:00) (Figure 12c). The hinds then moved into steeper terrain during the ensuing morning period of increased activity, only moving back onto slightly less steeper terrain around midday. Almost the exact opposite pattern of change in hind hill slope location occurred over the afternoon and evening. Figures 12d and 12e indicated the collared hinds exhibited far greater movement up and down the paddock's predominant north-east by south-west axis, compared to lateral movement across its hill face (i.e. north-west by south-east axis).

From just before dawn (04:00) though until just after midday (13:00) the proportion of pasture dominant vegetation occupied by the hinds decreased (Figure 13a), while at the same time, the proportion of tussock dominant vegetation occupied increased (Figure 13b). These trends were reversed over the ensuing afternoon and evening, with the hinds attaining a maximum and minimum level of pasture and tussock occupancy in the late evening (22:00), respectively (Figure 13a,b). Both Hind 459 and 374 also increasingly used shrub dominant vegetation as the morning progressed, peaking in use just before midday (Figure 13c).

In 2009/10, the collared hinds showed similar daily patterns of behaviour to in 2008/09 (Figure 12 vs. 14). However, overall the patterns were generally less uniform compared to the previous year. Two factors that may have contributed to this lower uniformity include: more of collared hinds had their home ranges centred above the mid-elevation of the paddock compared to in the previous year; and also the GPS units were less reliable in attaining GPS fixes in the second year, causing some of the units to represent a much shorter season (Table 5). The GPS unit of Hind 95 functioned only for the first 24 days of the study period, which was markedly fewer days than for the rest of the GPS units (data not shown). Overall, this hind also had the least conforming diurnal patterns (Figures 14 and 15).

Nevertheless, the peak distances travelled between successive GPS fixes were again generally around dawn and dusk, with smaller peaks also occurring at midday and midnight (Figure 14a). Coinciding with the increased activity around dawn, all of the collared hinds moved upwards in elevation, with the rate of change in altitude being greater for the hinds initially located at lower elevations (e.g. Hind 374 and 674) (Figure 14b). Similarly to 2008/09, the hinds continued to move uphill until just after midday (13:00), where thereafter they descended down the hillside at a rate closely mirroring their original rate of ascent (Figures 14b).

The majority of collared hinds moved into steeper terrain during peak activity times around dawn and dusk, and again, similarly to in 2008/09, generally moved into gentler terrain around midday and during the evening and early morning (Figure 14c). Unlike the majority of collared hinds, Hind 374 and 674 did not move into gentler terrain around midday (Figure 14c). Both of these hinds resided at a lower altitude compared to the other collared hinds (Figure 14b).

The clear 2008/09 diurnal movement patterns of the collared hinds moving up and down the paddocks hill face, along the paddocks predominant north-east by south-west axis, was less uniform in 2009/10 (Figure 12d vs. 14d). However, the majority of hinds still generally showed greater movement along this axis compared to the perpendicular north-west by south-east axis, indicating greater movement up and down the paddocks hill face, compared to movement laterally along its face (Figure 14d vs. 14e). The main exceptions were Hind 599 and 459, which exhibited little movement along both axes. Both of these hinds had home ranges located near the top of the paddock (Figure 6).

The majority of collared hinds tracked in 2009/10 (Hind 374, 567, 606, 161, and 674) had a similar diurnal pattern in vegetation occupation to that found in 2008/09 (Figure 15). The main exceptions were Hind 459, 599, and 95, especially for pasture and tussock occupancy (Figure 15a,b). In contrast to the other tracked hinds, the use of pasture and tussock by Hind 459 increased and decreased marginally over the course of a day, respectively. Whereas, Hind 599 and 95 showed less marked changes in vegetation occupancy during daylight hours compared to the other collared hinds (Figure 15a,b). All three of these hinds had home ranges located at high elevations near the top of the paddock (Figures 6 and 14b). The diurnal patterns of Hind 95 could have been influenced by its markedly shorter sampling period of 24 days. Hind 374 and 674 also increasingly used shrub dominant vegetation during daylight hours (Figure 15c). Both hinds had home ranges at a similar paddock elevation, which was lower than the other tracked hinds (Figure 14b), and their 50% core areas had the least amount of tussock dominant vegetation (Table 7).

3.4.2 Seasonal changes in diurnal patterns of hind movement

In 2008/09, the general diurnal patterns of hind movement described in the previous section for distance travelled between successive GPS fixes and hind movement in altitude did not change over the entire calving and lactation period. However, the overall extent of movement varied markedly over the course of the study (Figure 16a,b). The maximum distance travelled between GPS fixes, during times of increased activity around dawn and dusk, were at least 60% greater in the month (Day 1-30) prior to estimated calving (Figure 16a). Similarly, in this month, the absolute change in elevation, and the rate of change in elevation during times of increased activity, was much greater than over the following calving and lactation months (Figure 16b). During the estimated month of calving (Day 31-60), the collared hinds remained on average at a higher elevation from late evening through until early morning compared to in the month prior to calving, and thereafter (Day 61 onwards) their total range in altitudinal movement was more restricted (Figure 16b).

In the month prior to calving (Day 1-30), the collared hinds moved from steeper terrain onto gentler slopes around midday and from late evening to early morning (Figure 16c). However, this pattern of behaviour changed in the month of calving (Day 31-60), with the hinds thereafter moving onto steeper terrain early in the morning and remaining there until evening. Figure 16d indicated that in the month prior to calving (Day 1-30) the hinds at dawn and dusk moved up hill in a south-west direction both further and at a greater rate compared to in the other months (Day 31 onwards). Similarly, prior to calving (Day 1-30) they also showed greater lateral movement along the hill face, on average moving in a south-east direction in the morning and then in the opposite north-west direction in the afternoon (Figure 16e). After calving (Day 31 onwards) the lateral movement of the hinds along the hill face was much more restricted. Over time their ranges drifted slightly in a north-west direction (Figure 16e).

The general diurnal patterns of pasture and tussock usage by the hinds did not change over the entire course of the study, with pasture occupancy peaking just before dawn and also at dusk, while tussock occupancy peaked at around midday (Figure 17a,b). However, the overall proportion of time spent in each vegetation class varied as the season progressed. In both the month prior to (Day 1-30) and after (Day 61-90) estimated calving, the collared hinds spent a greater proportion of their total time in pasture dominated vegetation, compared especially to the month of estimated calving (Day 31-60) and, to a lesser extent, late in the season (Day 91-120). Contrastingly, in the month of estimated calving (Day 31-60), the time spent in tussock dominated vegetation increased especially from mid-afternoon through until at least mid-morning (Figure 17b). Shrubland occupancy increased, particularly during daylight hours, as the season progressed (Day 61 onwards; Figure 17c).

In 2009/10, there was less monthly variation in the daily movement patterns of the hinds, especially for distance travelled between GPS fixes, altitude, slope, and movement along the paddock’s north-east by south-west axis, compared to in 2008/09 (Figure 18). In particular, the extent of movement by the collared hinds in the first month (Day 1-30) of tracking in 2009/10 was less marked than in 2008/09 (Figure 16 vs. 18). Two potential contributing factors for the lower movement patterns over this first month in the second year were: some of the hinds likely calved in the first month of tracking in 2009/10, because the hinds were set-stocked two weeks later than in the previous year (refer to Section 2.5.2); and also the collared hinds in the second year were generally located at a higher altitude throughout the study, reducing the possible extent of movement up the hill face (Figure 18b vs. 16b). In both years, the average altitude that the collared hinds resided at during daylight hours decreased as the season progressed (Figure 18b and 16b).

In 2009/10, there was also less monthly variation in the daily pattern of vegetation usage by the hinds, especially between Day 1-90, in comparison to in 2008/09 (Figure 19). Peak occupancy in tussock dominant vegetation again occurred around midday; while conversely this time was the lowest point that pasture dominant areas were used (Figure 19a,b). Similar potential factors reducing the monthly variation in hind diurnal movement patterns may also have contributed to the reduced seasonal variation in vegetation occupancy in 2009/10.

4. DISCUSSION

4.1 Home ranges

The home ranges of the GPS tracked hinds at White Rock Station in 2008/09 and 2009/10 ranged between 35 ha and 97 ha in size, equating to 19% and 54% of the 180 ha paddock, respectively (Figures 4 and 6). Both the variation in home range size and also the average size of the home ranges did not differ significantly between these two years, with the average size of the home ranges equalling 66 ± 4.6 ha (mean ± standard error, n=15). In contrast, at Haycocks Station, in Southland, the average size of a hind's home range was 79 ± 9.5 ha (n=12). While a *post hoc* analysis indicated the differences in hind home range size at these two high-country stations was not significant (t-test, P=0.2527), there was greater variability at Haycocks station (F-test, P=0.032), with the home ranges varying between 28 ha and 130 ha, equating to 11% and 52% of the 250 ha main study paddock, respectively. Many previous wildlife studies on the habitat use of cervids have also reported large variation in home range size within a single population (Kie et al. 2002; Van Beest et al. 2011). However, the average size of the home ranges at the two high-country stations were considerably smaller than for wild red deer, which are typically found at much lower population densities (Georgii 1980, Carranza et al. 1991).

There are many factors that can influence an animal's home range size, including: its body mass, age, reproductive status, and social needs; and also the forage density and quality, availability of water, cover, shelter, topography and microclimate of the site within which it inhabits (Anderson et al. 2005; Rivrud et al. 2010; Van Beest et al. 2011). The importance of each of these factors can vary seasonally and, thus, the time frame that GPS analyses are based on will influence the estimation of home range size. Previous research has also shown that factors affecting the size of an animal's total home range may differ from those affecting the size of their core areas (Börger et al. 2006; Rivrud et al. 2010).

An animal's total home range is normally smaller where important resources are plentiful (Kie et al. 2002; Anderson et al. 2005). Given the greater abundance of high quality pasture species and the higher summer rainfall at Haycocks Station compared to White Rock Station, it was initially hypothesised that the average home range size of the GPS tracked hinds would be smaller at the former site, because they would be able to more readily satisfy their nutritional needs within a more confined area. However, this was likely offset by the 2-fold greater stocking rate at Haycocks Station compared to White Rock Station (2.8 versus 1.1-1.3 hinds/ha, respectively) restricting the availability of high quality forage via more intensive competition between the hinds. Greater competition for birthing sites may also have been a contributing factor causing the hinds to range more widely at Haycocks Station. Netzer et al. (2009) considered this to be a potential reason why some hinds even exited the main study paddock at Haycocks Station. In contrast, none of the GPS tracked hinds at White Rock Station migrated out of the study paddock.

Hind size differences could have contributed to the variation in home range size at each site through its effect on their feed requirements (Anderson et al. 2005). However, countering this relationship to some extent may have been the hierarchical social structure of the herd, with heavier or older hinds dominating the more resource rich areas of the paddock. At Haycocks Station, heavier hinds were found to select lower, flatter zones of pasture, while smaller hinds tended to select higher altitudinal zones dominated by tussock (Netzer et al. 2009). Tufto et al. (1996) also found heavier roe deer tended to have smaller home ranges than expected, indicating that some social mechanism may influence home range size in addition to metabolic requirements.

The reproductive stages that the GPS tracking covers for each hind can influence the total size of their home range, as this affects their nutritional needs and social behavioural patterns (Clutton-Brock et al. 1982; Mulley 2002; Asher et al. 2009). The feed intake requirement of a hind increases markedly particularly over the last trimester of pregnancy and during lactation, usually causing their total home range to expand (Tufto et al. 1996). In contrast, immediately after parturition the spatial movement of a hind can be severely constrained by the limited mobility of their offspring (Asher et al 2009; Long et al. 2009). Clearly, the identification of calving dates for each GPS tracked hind and the restriction of analyses to similar time frames around these dates is required for more detailed comparisons made between the two high-country station studies in relation to hind home range size, resource use and behavioural patterns. This will be able to be conducted once the ‘Hidden Markov’ calving behaviour model developed by Asher et al. (2009) has been verified through direct animal observations, which is due for completion in 2011. However, as discussed, there are likely to be multiple interacting factors involved.

In both 2008/09 and 2009/10, the home ranges of the GPS tracked hinds at White Rock Station extended from the valley floor to hilltop boundary fence lines and were generally restricted to the north-western side of the main central gully system dissecting the paddock (Figure 4 and 6). The large 24 ha area not used by any of the GPS tracked hinds, located on the north-eastern side of the main gully system, contained a high proportion of shrub dominated vegetation (29%) and dense tussock (30%) on mainly very steep (>26^{o}) terrain (Figure 8a,b). Ease of access issues, especially in relation to the likely lower forage quality of the vegetation present, may have precluded the use of this area. This area represents 13% of the total paddock area and highlights the farm management issue that in such diverse and extensive terrain the effective grazing area may actually be considerably smaller than the total area of a paddock.

Out of the four hinds tracked in both 2008/09 and 2009/10, Hind 374 in particular maintained a very similar home range over both years (Figures 4 and 6). This, despite being mixed into an unfamiliar herd just before calving in the second year (refer to Section 2.2). Hind 374 was the heaviest of these four hinds, which may indicate that it was able to exert a degree of dominance over other hinds in re-establishing its home range. The other three hinds also broadly used similar ranges over both years. However, in the second year the overall dispersion of their home range across the paddock decreased, while still covering a similar overall total area (Figure 4 and 6).

Wild populations of North American elk and white-tailed deer have been shown to consistently return to certain seasonal home ranges year after year (Tierson et al. 1985; Van Dyke et al. 1998). The strong fidelity in range use by the four hinds tracked over both years at White Rock Station indicates that in large tussock grassland paddocks farmed red deer also exhibit a similar behaviour. The generally more centralised nature of Hind 459, 567, and 606 home ranges in 2009/10 could at least partially be an artefact of the GPS tracking covering a more restricted period around calving, when hind movement patterns were likely limited by the lack of newborn calf mobility (refer to Section 3.4). Alternatively, the greater familiarity of the paddock through extensive exploration in the first year of GPS tracking may have enabled them in the following year to concentrate their movement patterns in a less dispersed range. Säid et al. (2005) found older female roe deer had smaller home ranges than younger ones, which they attributed to the older females greater experience and/or better knowledge of the environment. Again, older hind dominance over more resource rich areas could also have been a factor.

The strong fidelity in range use by the hinds at White Rock Station raises the question whether their progeny will also use a similar home range and by doing so, to at least some extent, pre-determine their progeny’s future performance. Wild red deer hinds usually return to their birthplace to breed (Clutton-Brock et al. 1982) and several recent deer wildlife studies have shown that the maternal use of available resources can influence patterns of resource use later observed in the offspring, and therefore the fitness-habitat association in offspring (McLoughlin et al. 2007, 2008).

4.2 Core area used within the home range

The 50% core occupancy area within each hind’s home range varied between 4 ha and 25 ha in size, indicating that over calving and lactation each hind only heavily used a relatively small proportion (9-32%) of their total home range (Figure 4 and 6). Pasture and tussock species dominated the main vegetation occupied by the hinds within these areas. However, there was considerable variation in the proportion of their use between the two years of GPS tracking. In 2008/09, 5 out of 7 hinds mainly occupied pasture dominant vegetation, with 1 of the remaining hinds occupying predominantly tussock, while the other used similar proportions of pasture, tussock, and shrubs (Table 6). In contrast, in 2009/10, 4 out of 8 hinds occupied mainly tussock dominated vegetation, with 2 of the remaining hinds occupying a similar proportion of both tussock and pasture dominant areas and only 2 hinds occupied mainly pasture dominant vegetation (Table 7). These changes coincided with the majority of the GPS tracked hinds in the second year centring their 50% core occupancy areas further upslope in higher altitude tussock-dominant zones of the paddock compared to in the first year of GPS tracking (Table 6 and 7).

The vegetation selection indices also showed that hinds occupied pasture and tussock dominated vegetation to a greater extent than would normally be expected given their overall availability in the paddock (Table 10 and 11). In contrast, none of the hinds used shrub dominant vegetation more than in proportion to its availability, with more than half of them actually avoiding this vegetation class in both 2008/09 (4 out of 7 hinds) and 2009/10 (6 out of 8 hinds). At Haycocks Station, Netzer et al. (2009) found that while there was some variation in hind vegetation occupancy, pasture and tussock were also the dominant vegetation classes utilised.

Similarly to Haycocks Station, the location of the 50% core occupancy areas varied widely across the full altitudinal gradient within the paddock (Table 6 and 7). However, the location of these intensively used areas was generally restricted to a north-east aspect by the fence layout of the paddock (Figure 3). In contrast, at Haycocks Station the diverse topography of the main study paddock created multiple aspects of which the hinds had no single preference (Netzer et al. 2009).

Several factors may have contributed to the 35% reduction in the average size of the 50% core areas between 2008/09 and 2009/10 (Table 6 and 7). As previously discussed, a hind's reproductive state affects its feed intake requirements and thus area needed for foraging. In 2009/10, Hind 459 was the only hind that did not show any visual signs of raising a calf and it also had the smallest 50% core area out of the GPS tracked hinds. By removing this hind from the analysis as an outlier, the average size of the 50% core areas did not differ significantly between the two years (P>0.05). Again, experience gained from the previous year may have allowed the hinds to use more concentrated areas or alternatively there may have been greater forage abundance, especially given that the hinds were set-stocked in the paddock two weeks later and at a slightly lower stocking rate (1.1 vs. 1.3 hinds/ha) in comparison to the year before. Another possibility is that by being positioned further upslope within the tussock zone, the hinds did not have to travel so far to find adequate cover and shelter. At Haycocks Station, hinds occupying higher altitudinal locations showed more restricted movement compared to others further down the hillsides (Netzer et al. 2009). Weather conditions can also impact on the behaviour and habitat use of an animal (Rivrud et al. 2010). However, this normally has a greater impact on their total home range rather than core occupancy areas (Börger et al. 2006; Van Beest et al. 2011) and the average size of the former did not vary significantly between the two years.

A *post hoc* analysis indicated the average size of the 50% core occupancy areas at White Rock Station was not significantly different from at Haycocks Station (t-test, P=0.294). Nevertheless, the much lower stocking rate at White Rock Station meant there was likely far less overlap in these areas compared to at Haycocks Station. At a stocking rate of 1.1 hinds/ha, each hind at White Rock Station was effectively allocated 0.79 ha of the 156 ha useable area within the paddock, whereas they actually occupied 13.5 ± 1.5 ha (n=15) on average for their 50% core area. Thus, based on the gross simplification that the hinds were distributed evenly across the entire paddock, the 50% core occupancy area of each hind would overlap with at least 16 other hinds to make up the shortfall in area allocated. In comparison, at Haycock Station the hinds were set-stocked at a much higher rate of 2.8 hinds/ha within a 250 ha paddock and on average each had a 50% core occupancy area of 16.0 ± 1.8 ha (n=12). By effectively being allocated only 0.36 ha/hind, the core areas of each hind would overlap with at least 44 others. Clearly, using the average size of the 50% core areas and assuming the hinds are evenly spread out across the paddocks are gross oversimplifications of the real situation. However, it does illustrate the large differences in hind competition for space and resource use between the two sites. It also reiterates the observation made by Netzer et al. (2009) that even though each hind establishes an individually distinct home range within the larger paddock, they do not live in isolation, as clearly the hind population density relative to average 50% core area size precluded the opportunity for each animal to occupy an exclusive area.

4.3 Hind calving behaviour and habitat use

The four states of hind behaviour around calving defined and modelled by Asher et al. (2009) for Haycocks Station were also identified from sequential GPS fixes recorded in the present study in 2008/09. In both studies, the average distance travelled by the hinds between GPS fixes within 1.5 days of calving increased 2- to 4-fold in comparison to late pregnancy (Table 9; Figure 9). Asher et al. (2009) hypothesised that this increased level of spatial movement was associated with birth-site searching, where pre-parturient hinds attempt to isolate themselves from the rest of the herd and find a concealed birthing site. This behaviour has been reported in several observational studies of wild deer populations and is likely a strategy used by hinds to allow them to successfully bond with their new-born calves undisturbed and also to protect their calves from hostile hinds or predators (Darling 1937; Clutton-Brock and Guinness 1975). Hinds typically seek isolation between 2 to 12 hrs before parturition in the wild. However, there are instances where such behaviour occurs up to several days before parturition (Clutton-Brock and Guinness 1975).

On intensively stocked lowland deer farms, typically carrying 8-12 hinds/ha, the increase in the extent of hind spatial movement just before parturition usually takes the form of high-frequency fence pacing (Asher et al. 2009). This is due to the pre-parturient hinds not being able to find a secluded birth site from the rest of the herd when confined to a small area at a high stocking rate. Isolation seeking behaviour and increased fence pacing typically occurs 2-4 days before parturition and peaks the day before or on the day of parturition (Cowie et al. 1985; Pollard et al. 1998; Wass et al. 2003). A high incidence of disruptive interactions among non-pair hinds and new-born calves forced to remain in close proximity to each other is considered to be a significant contributory factor of calf mortalities on intensive deer farms (Wass et al. 2003).

The range in estimated time spent searching for a birth site at White Rock Station varied widely from 1-25.5 hours (Table 8; Figure 9). This suggests that, despite being at a low population density of <2 hinds/ha, some pre-parturient hinds still may of found it much more difficult than others to locate a suitable birth-site. Several factors could have contributed to this variation, including the hind's social-ranking within the herd, the density and hierarchical structure of hinds within the searched region of the paddock, and also the general suitability of the terrain and vegetation for calving. In particular, sub-dominant hinds could have taken longer to find a birth site owing to intense competition for suitable areas from more dominant hinds. A similar range of birth-site searching intervals (4.5-30 hours) were estimated at Haycocks Station at a higher stocking rate of 2.8 hinds/ha (Asher et al. 2009), indicating the hinds in both studies were likely facing similar levels of competition for suitable birth sites despite the markedly different hind stocking rates at each farm.

At White Rock Station, the change in the extent of spatial movement between the late pregnancy (μ_1) and birth site searching (μ_2) behavioural states was markedly smaller for Hind 374 compared to all of the other GPS tracked hinds (Table 9) and the Hidden Markov model also estimated that this hind was in the latter state for a considerably longer period (19 days) than is normally found for both wild and intensively farmed red deer (Brock and Guinness 1975; Wass et al. 2003). The only small increase in spatial movement by this hind could indicate it was a dominant female and thus was not under as much stress when finding a suitable birthing site. As discussed previously, the high fidelity in yearly home range use by Hind 374 also provided evidence that it was a dominant female.

The estimated length of time taken by the hinds at White Rock Station to give birth and nurture their calves closely mirrored Haycocks Station estimates (Asher et al. 2009), normally taking between 5-13 hrs, with some exceptions of up to 5 days (Table 8, Figure 9). These estimates seem plausible given that previous observational studies of calving hinds have reported parturition takes 0.25-12 hrs, with a further 0.5-4.5 hrs required for the new-born calves to stand and suckle (Church and Hudson 1996; Wass et al. 2003). Once a calf has successfully suckled, its dam often remains within close proximity to it for 4-5 hours (Cowie et al. 1985).

All of the collared hinds at White Rock Station calved within their home ranges (Figures 4 and 10). This contrasts with observational studies of much lower density wild elk and red deer populations, where pre-parturient hinds tend to move away from their usual home ranges just before calving (Clutton-Brock and Guinness 1975; Geist 1982 cited Church and Hudson 1996). All of the collared hinds at Haycocks Station also selected calving sites within their respective core areas (Asher et al. 2009). Hind movement outside of their home ranges on the high-country stations could have been restricted by the much smaller area available relative to the hind stocking rate in comparison to wild deer populations. Within the confines of the high-country paddocks there may have been few suitable birth sites outside each deer's normal range that were not already occupied by hinds from other matriarchal groups of the herd. As a result, the pre-parturient hinds would be forced to remain within their own matriarchal group and normal home range. At White Rock Station, all of the GPS tracked hinds, except for Hind 2365, moved extensively along the paddock's boundary fence lines during the 24 hours prior to their estimated times of parturition (Figure 10a). It is possible they were attempting to remove themselves from both their own and other matriarchal group home ranges in an effort to find a secluded calving site.

The GPS tracked hinds occupied a range of vegetation classes on their respective calving dates, as shown in Figure 11. However, all used either tussock or shrubland vegetation significantly more than would normally be expected, given its availability in the paddock (Table 12). The majority, four out of seven hinds, used mainly tussock dominant vegetation during the first 24 hours after parturition (Figure 11), which furthers supports the observation made by Netzer et al. (2009) for Haycocks Station that hinds prefer calving sites which conceal the calf while still providing the hind enough visibility to survey the surrounding region for any signs of danger. All of the hinds that actively selected tussock dominant vegetation had a higher proportion of this vegetation class within their home range compared to shrub dominant vegetation (Table 6). Only Hind 374 selected pasture dominant vegetation more than in proportion to its availability, which again may provide evidence that it was a dominant hind and did not perceive any external threat to its newborn calf.

4.4 Hind daily activity patterns

Over the course of a day peak distances travelled by the collared hinds occurred mainly around dawn and dusk, with greater movement in the latter twilight period (Figure 12a and 14a). Overall, this bimodal (double peaked) daily activity pattern was very consistent among all of the collared hinds and also between the two years of GPS tracking. A very similar pattern was found at Haycocks Station (Netzer et al. 2009) and has previously been reported in many other studies of both wild and farmed red deer (Hester et al. 1996; Georgii 1981; Pépin et al. 2009). At White Rock Station there was also often another smaller peak in hind movement around midday (Figure 12a and 14a).

In red deer locomotor activity is closely associated with feeding (Georgii 1981), thus these peaks in distance travelled likely represented peak grazing times. This pattern also closely resembles the 24-hour grazing time budgets reported by Clark et al. (1995) for red deer inhabiting heather moorlands in Scotland, where the topography and vegetation superficially resemble modified New Zealand tussock grasslands. On the Scottish moorlands in summer, the time spent grazing was particularly high between 0400-0630h (dawn) compared to between 1000-1530h, but increased even further between 1600-2130hr (dusk).

From just before dawn through until about midday all of the collared hinds moved between 30m and 200m upwards in elevation from the location where they resided at over night. Thereafter, they descended back down the hillside again at rate closely mirroring their original ascent, reaching a minimum elevation around midnight (Figure 12b and 14b). This behavioural pattern was consistent among all of the hinds tracked in both years. However, the absolute changes in altitude in 2009/10 were generally smaller than in 2008/09, especially for hinds with their home ranges centred further upslope (Figure 12b and 14b).

A similar diurnal pattern of behaviour was found at Haycocks Station for hinds with home ranges generally centred below the mid elevation (550m) of the study paddock (Netzer et al. 2009). However, an almost exact opposite pattern occurred for hinds occupying locations further uphill, with them travelling approximately 40m downhill in the morning and then back uphill a similar distance in the evening. This downwards movement was closely aligned with the wind speed of the site, which regularly increased in strength throughout the day light hours, and thus the change in altitude could have simply been the hinds moving into more sheltered zones as a thermoregulatory response (Netzer et al. 2009). Previous studies have shown that deer are sensitive to wind chill, particularly in their choice of resting sites (Staines 1977).

As the collared hinds at White Rock Station moved uphill over the course of a morning they increasingly occupied tussock dominated vegetation, as opposed to pasture dominated vegetation (Figure 13a,b and 15a,b). This pattern was then reversed over the ensuing afternoon and evening, with the hinds attaining a maximum and minimum level of pasture and tussock occupancy in the late evening (Figure 13a,b and 15a,b). The movement into tussock dominant vegetation also coincided with periods during daylight hours when the hinds were generally least active (Figure 12a and 14a), indicating that they could also have been moving upwards into this vegetation to rest and ruminate under greater cover than in the pasture zones. Similarly, in Scotland, Hester et al. (1999) found that when given the choice of pasture or heather vegetation patches, red deer almost exclusively rested in the latter, which provided greater physical cover. At White Rock Station several hinds located further downslope, with less tussock in their home ranges (e.g. Hind 375 and 459 in 2008/09), similarly increased their occupancy of shrubland vegetation over the same period of the day (Figure 13c), indicating that this vegetation was likely used as an alternative cover for the same purpose. Overall, the driver(s) causing the hinds to move uphill at White Rock Station during the morning must have been substantial, especially given the much higher energy cost involved compared to moving perpendicularly across the hillslope (Parker et al. 1984). No climatic factors were investigated for this report, but local data from the nearest weather station to the study site have been attained for further investigation.

5. CONCLUSION

The daily behavioural patterns and habitat selection of the hinds at White Rock Station in South Canterbury were generally similar to findings reported in a previous study carried out at Haycocks Station in Southland, despite contrasting differences in the climate, vegetation, and hind stocking densities at the two high-country sites. Over calving and lactation the GPS tracked hinds mainly selected pasture and tussock dominated vegetation over shrubland. However, the use of these different vegetation classes varied over the course of a day and also seasonally. All of the hinds showed strong diurnal patterns in their level of activity and habitat use and reused similar home ranges each year. Tussock and to a lesser extent shrubland was used to a greater extent during daylight hours for cover and shelter. The four states of hind behaviour around calving defined and modelled by Asher et al. (2009) for Haycocks Station were also identified. On the day of parturition either tussock or shrubland vegetation was used significantly more than normal, given its availability in the paddock. Overall, the hind liveweight data recorded in 2009/10 indicated that heavier hinds tended to dominate the more resource rich areas of the paddock and they also showed signs of less stress at calving.

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TABLES AND FIGURES

Table 1: Classification parameters and rules for each land cover class

Land cover class	Parameters
Bare ground	Descending membership function applied on the mean NDVI value
Shadow	Nearest neighbour (NN) based on mean and standard deviation of all spectral layers
Vegetation	Not bare ground areas. NN based on mean green, green/blue, red/blue, NIR/blue, NDVI, and panchromatic standard deviation values

Table 2: Hierarchical classification scheme for vegetation classes

Level 1	Level 2	Level 3	Description
Grassland	Pasture dominated	Improved pasture	Mainly introduced grasses improved/modified under grazing management
		Naturalised pasture	Unimproved naturalised pasture species, predominantly browntop and sweet vernal
		Short pasture/bare ground	Pasture mixed with either soil or rock cover to a significant level
		Short pasture/tussock	Mix of pasture and tussocks with dominance of pastures over tusssock
		Pasture/low Matagouri	Mostly pasture with sparsely distributed small matagouri bushes
	Tussock dominated	Tussock/pasture	A mix of tussock and pasture with tussock the dominant species but pasture plants visible between tussocks
		Tussock	Tussock and pasture mix, with a dense cover of the former. There is also the likelihood of the presence of other species such as matagouri, braken, and at higher altitudes Spaniard grass.
Shrubland (Woody plants)		Matagouri	Matagouri bushes of varying size from 0.5 m (in which closed canopy) to >1 m.
		Bracken/Matagouri	Mix of bracken and matagouri, possibly mature dense bracken only
		Coprosma/Matagouri/ Bracken/Muelenbekia	A dense mix of any of these species
Marginal		Bare ground	Low NDVI areas, exposed rock or bare soil
		Shadow	Area with insufficient signal to enable a reliable classification

Table 3: Accuracy assessment of vegetation classifications from the satellite imagery
(a) Error matrix

Classified image (predicted)		**Ground references (observed)**												**Sum**	**Area**	**(%)**
		Grassland							**Shrubland**			**Marginal**				
		G1	G2	G3	G4	G5	G6	G7	S1	S2	S3	M1	M2			
G1	Improved pasture	**8**				1								9	2.6	1.3
G2	Pasture		**22**	2	3	2		2						31	31.2	15.9
G3	Tussock/pasture			**16**		6				1				23	12.1	6.2
G4	Short pasture/bare ground				**53**			2						55	25.8	13.2
G5	Short pasture/tussock			1		**40**	1				2			44	23.5	12.0
G6	Tussock			12	3	13	**35**	1			1			65	44.1	22.5
G7	Pasture/low Matagouri					1		**43**				1		45	21.5	11.0
S1	Matagouri								**29**					29	9.8	5.0
S2	Bracken/Matagouri									**9**				9	3.0	1.5
S3	Coprosma/Matagouri/Bracken/Muelenbekia								2	1	**34**			37	21.5	10.9
M3	Bare ground											**11**		11	0.6	0.3
M2	Shadow												**0**	0	0.5	0.3
Sum		8	22	31	59	63	36	48	31	11	37	12	0	**358**	196.2	100

(b) Accuracy assessment [a,b]

Level 1- Habitat type	Level 3 - Vegetation classes	Producer's (%) Level 1	Producer's (%) Level 3	User's (%) Level 1	User's (%) Level 3	Cond. Ḱ (%) Level 1	Cond. Ḱ (%) Level 3
Grassland		100 ± 0.0		98.2 ± 1.4		90.5 ± 6.1	
	Improved pasture		100 ± 0.0		88.9 ± 3.3		88.8 ± 20.9
	Pasture		100 ± 0.0		71.0 ± 4.7		67.3 ± 16.6
	Tussock/pasture		44.0 ± 12.1		69.6 ± 4.8		66.3 ± 20.2
	Short pasture/bare ground		83.1 ± 8.7		96.4 ± 1.9		95.7 ± 5.9
	Short pasture/tussock		59.1 ± 8.5		90.9 ± 3.0		88.9 ± 10.2
	Tussock		97.8 ± 4.2		53.8 ± 5.2		47.3 ± 12.3
	Pasture/low Matagouri		85.0 ± 9.5		95.6 ± 2.1		94.9 ± 6.9
Shrubland		93.5 ± 5.7		100.0 ± 0.0		100.0 ± 0.0	
	Matagouri		89.4 ± 12.4		100.0 ± 0.0		100.0 ± 0.0
	Bracken/Matagouri		72.7 ± 26.8		100.0 ± 0.0		100.0 ± 0.0
	Coprosma/Matagouri/Bracken/Muelenbekia		91.9 ± 8.1		91.9 ± 2.8		90.9 ± 9.7
Marginal		65.5 ± 47.0		100.0 ± 0.0		100.0 ± 0.0	
	Bare ground		56.3 ± 51.0		100.0 ± 0.0		100.0 ± 0.0
	Shadow		NA		NA		NA

	Nominal Level 1	Nominal Level 3	Corrected Level 1	Corrected Level 3
Overall accuracy (%)	98.6 ± 1.3	83.8 ± 3.7	98.5 ± 1.3	80.0 ± 3.7
Kappa Ḱ (%)	96.4 ± 3.1	81.7 ± 4.3	95.0 ± 4.1	77.2 ± 4.7

[a] Producer's, User's, and conditional ḱ accuracy measures have been corrected for bias by accounting for the marginal proportion of each class. [b] All confidence intervals correspond to the 95% confidence level (Congalton and Green 1999).

Table 4: Area of vegetation in study paddock

Level 1 – Habitat type	Level 2 – Dominant vegetation	Level 3 – Vegetation class	Hectares (% of paddock) Level 1		Level 2		Level 3	
Grassland			147.0	(81.5%)				
	Pasture				94.2	(52.2%)		
		Improved pasture					1.1	(0.6%)
		Naturalised pasture					29.6	(16.4%)
		Short pasture/bare ground					25.4	(14.1%)
		Short pasture/tussock					17.0	(9.4%)
		Pasture/low Matagouri					21.0	(11.6%)
	Tussock				52.8	(29.3%)		
		Tussock/pasture					10.0	(5.6)
		Tussock					42.8	(23.7%)
Shrubland			32.3	(17.9%)				
		Matagouri					9.3	(5.1%)
		Bracken/Matagouri					2.9	(1.6%)
		Coprosma/Matagouri/ Bracken/Muelenbekia					20.1	(11.1%)
Marginal			1.0	(0.6%)				
		Bare ground					0.6	(0.3%)
		Shadow					0.5	(0.3%)
Total			180.3					

Table 5: Summary of GPS fixes of adult red deer hinds monitored every 15 minutes over the entire calving and lactation study period.

Year	Hind No.	Collar No.	Start date	End date	Days	Possible fixes	Missed fixes	% of fixes
08/09	459	300	1/10/08	10/02/09	132	12669	1135	91
	374	301	1/10/08	8/03/09	158	15148	390	97
	567	304	1/10/08	26/02/09	148	13992	694	95
	606	305	1/10/08	7/03/09	157	10797	858	92
	595	303	1/10/08	8/03/09	158	15129	231	98
	600	306	1/10/08	28/01/09	119	11479	1141	90
	2365	302	1/10/08	11/01/09	102	9826	1688	83
Mean					139			92
(± SEM)					(± 8)			(± 2)
09/10	459	300	21/10/09	6/02/10	108	10377	255	98
	374	247	21/10/09	21/01/10	92	8783	1964	78
	567	301	21/10/09	25/03/10	155	14823	1317	91
	606	303	21/10/09	8/01/10	79	7633	802	89
	95	302	21/10/09	4/12/09	44	4259	1442	66
	161	304	21/10/09	6/03/10	136	13036	1287	90
	599	305	21/10/09	27/01/10	98	7068	2562	64
	674	306	21/10/09	20/03/10	150	14388	935	94
Mean					108			84
(± SEM)					(± 13)			(± 5)

Table 6: Summary of parameters recorded by each collared hind's GPS unit in 2008/09

Hind No.	**459**	**374**	**567**	**606**	**595**	**600**	**2365**	**Mean ± SEM**
Calving date[1]	13-Nov	17-Nov	19-Nov	18-Nov	22-Nov	28-Nov	12-Nov	
Hind mean values								
Distance travelled (m)[2]	27.8	30.5	38.5	34.3	31.3	37.0	39.8	34.2 ± 1.7
Temperature (°C)[3]	18.1	18.1	17.3	15.9	16.9	17.7	17.5	17.4 ± 0.3
Mean values for 50% COA's								
Area (ha)[4]	12.8 (7.1%)	12.0 (6.7%)	18.8 (10.4%)	14.0 (7.8%)	25.1 (13.9%)	20.2 (11.2%)	13.5 (7.5%)	16.6 ± 1.8
Perimeter (m)	2257	2045	3079	3529	4814	3509	2753	3141 ± 353
Altitude (m)	598	514	684	727	579	517	566	598 ± 31
Slope (°)	24	22	25	25	23	23	22	23 ± 0.1
Pasture dominant (%)[5]	31.8 (31.1)	76.9 (58.5)	56.9 (57.5)	31.5 (38.6)	76.7 (73.8)	76.5 (69.8)	58.2 (62.5)	58.3 ± 7.6
Tussock dominant (%)[5]	33.6 (38.1)	12.4 (21.7)	36.4 (35.1)	56.8 (45.5)	17.5 (18.5)	14.0 (20.7)	15.3 (12.9)	26.6 ± 6.2
Shrub dominant (%)[5]	34.5 (30.4)	10.7 (19.8)	6.7 (7.4)	8.9 (15.3)	5.7 (7.6)	9.6 (9.4)	26.4 (24.2)	14.6 ± 4.2
Bare-ground[5]	0.00 (0.04)	0.02 (0.00)	0.00 (0.02)	0.00 (0.04)	0.07 (0.11)	0.00 (0.06)	0.13 (0.36)	0.06 ± 0.02
Shadow	0.14 (0.37)	0.00 (0.00)	0.02 (0.00)	2.85 (0.51)	0.02 (0.00)	0.00 (0.00)	0.00 (0.00)	0.32 ± 0.29
Aspect (mode)	NE	NE	NE	NE	NE	NE	NE	NE

[1] Estimated calving date based on analysis of activity profiles (refer to section 2.5.3)
[2] Mean distance travelled between GPS locations
[3] Mean neck collar temperatures
[4] COA as a percentage of the entire paddock area are presented in parentheses
[5] Vegetation % values based on (1) hind occupancy at each GPS location within the 50% COA and (2) % area distribution within the 50% COA (in parentheses). Dominant vegetation classes are described in Table 2.

Table 7: Summary of parameters recorded by each collared hind's GPS unit in 2009/10

Hind No.	459	374	567	606	95	161	599	674	Mean ± SEM
Calving date[1]									
Hind mean values									
Distance travelled (m)[2]	29.9	34.4	31.1	30.5	38.0	30.8	28.8	34.3	32.2 ± 1.1
Temperature (^{o}C)[3]	18.8	17.1	16.1	16.4	16.6	16.3	15.1	17.9	16.8 ± 0.4
Mean 50% COA									
Area (ha)[4]	4.3 (2.4%)	12.4 (6.9%)	12.1 (6.7%)	10.0 (5.5%)	5.6 (3.1%)	15.0 (8.3%)	7.4 (4.1%)	19.4 (10.8%)	10.8 ± 1.8
Perimeter (m)	1044	1514	1459	1539	1103	1693	1326	3204	1610 ± 241
Altitude (m)	812	527	691	702	793	735	759	561	698 ± 37
Slope (^{o})	16	26	34	29	27	30	27	23	26 ± 2
Pasture dominant (%)[5]	33.2 (18.0)	71.7 (67.7)	32.5 (27.2)	28.2 (23.8)	34.9 (42.6)	50.5 (62.9)	49.9 (37.4)	76.6 (68.0)	47.2 ± 6.6
Tussock dominant (%)[5]	65.0 (80.6)	14.6 (19.8)	60.7 (61.7)	68.8 (71.8)	61.5 (56.0)	47.5 (32.8)	46.8 (60.1)	14.5 (21.8)	47.4 ± 7.7
Shrub dominant (%)[5]	1.8 (1.4)	13.7 (12.4)	6.8 (10.8)	2.9 (4.3)	3.5 (1.4)	2.0 (4.2)	3.3 (2.5)	8.8 (9.8)	5.3 ± 1.5
Bare-ground[5]	0.00 (0.00)	0.00 (0.08)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.13 (0.39)	0.02 ± 0.02
Shadow	0.00 (0.00)	0.00 (0.00)	0.00 (0.20)	0.03 (0.08)	0.09 (0.00)	0.03 (0.09)	0.00 (0.00)	0.00 (0.02)	0.02 ± 0.01
Aspect (mode)	NE	NE	E	NE	E	NE	NE	NE	NE

[1] Not yet analysed
[2] Mean distance travelled between 15 min interval GPS locations
[3] Mean neck collar temperatures
[4] COA as a percentage of the entire paddock area are presented in parentheses
[5] Vegetation % values based on (1) hind occupancy at each GPS location within the 50% COA and (2) % area distribution within the 50% COA (in parentheses). Dominant vegetation classes are described in Table 2.

Table 8: Summary of individual calving information for 2008/09

Hind	Estimated	Searching duration		Birth/nurturing duration	
	calving date	Hours	Samples	Hours	Samples
459	13 Nov	19.3	77	13.3	53
374	17 Nov	447.3	1789	5.3	21
567	19 Nov	16.0	64	5.0	20
606	18 Nov	6.0	24	12.8	51
595	22 Nov	1.0	4	7.5	30
600	28 Nov	25.5	102	21.3	85
2365	12 Nov	1.3	5	124.3	497

Table 9: Hidden Markov model parameter estimates for 2008/09 calving season

Parameter	Hind							Mean
	459	374	567	606	595	600	2365	
π_{11}	0.9995	0.9983	0.9996	0.9996	0.9996	0.9997	0.9995	0.999
	(0.0005)	(0.0017)	(0.0004)	(0.0004)	(0.0004)	(0.0003)	(0.0005)	(0.0005)
π_{22}	0.986	0.999	0.987	0.962	0.699	0.991	0.782	0.915
	(0.014)	(0.001)	(0.014)	(0.039)	(0.378)	(0.009)	(0.282)	(0.122)
π_{33}	0.981	0.950	0.949	0.978	0.966	0.988	0.998	0.973
	(0.020)	(0.053)	(0.053)	(0.023)	(0.035)	(0.012)	(0.002)	(0.019)
μ_1	0.35	0.16	0.11	0.21	0.19	0.18	0.33	0.22
	(0.03)	(0.05)	(0.03)	(0.03)	(0.02)	(0.02)	(0.03)	(0.087)
μ_2	1.17	0.18	1.26	1.35	1.70	1.38	1.70	1.25
	(0.21)	(0.03)	(0.21)	(0.40)	(0.40)	(0.19)	(0.66)	(0.515)
μ_3	-0.70	-1.60	-1.43	-1.03	-0.81	-0.58	-0.64	-0.97
	(0.15)	(0.25)	(0.22)	(0.16)	(0.09)	(0.11)	(0.05)	(0.404)
μ_4	-0.14	-0.07	0.11	-0.16	-0.09	0.03	0.19	-0.03
	(0.02)	(0.02)	(0.03)	(0.03)	(0.02)	(0.03)	(0.03)	(0.130)
σ_1	1.29	1.26	1.34	1.28	1.20	1.22	1.33	1.27
	(0.02)	(0.04)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.051)
σ_2	1.67	1.13	1.65	1.93	0.68	1.68	1.13	1.41
	(0.14)	(0.02)	(0.14)	(0.28)	(0.29)	(0.12)	(0.43)	(0.437)
σ_3	0.89	0.83	0.87	0.97	0.48	0.87	0.99	0.84
	(0.10)	(0.14)	(0.15)	(0.11)	(0.07)	(0.07)	(0.03)	(0.169)
σ_4	1.09	1.09	1.29	1.19	1.02	1.18	1.24	1.16
	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.095)

Standard errors are given in parentheses below each regression parameter.

Table 10: Hind vegetation selection indices for 2008/09

Vegetation Class	Hind						
	459	374	567	606	595	600	2365
Pasture	0.7 *	1.4 *	1.2	0.7 *	1.4 *	1.3 *	1.3 *
Tussock	1.2	0.6 *	1.1	1.8 *	0.7	0.7	0.4 *
Shrubland	1.5	0.6	0.4 *	0.5 *	0.4 *	0.5 *	1.1
Marginal	0.2	0.1 *	0.1	3.5	0.2	0.1	0.2

Only indices followed by a star are statistically significant at P<0.05. Positive selection for a vegetation class is indicated by a value >1, whereas a value <1 indicates the vegetation was used less than in proportion to its availability.

Table 11: Hind vegetation selection indices for 2009/10

Vegetation Class	Hind							
	459	374	567	606	95	161	599	674
Pasture	0.7 *	1.4 *	0.7 *	0.7 *	1.1	0.9	1.0	1.3 *
Tussock	2.0 *	0.5 *	1.9 *	1.9 *	1.2 *	1.6	1.5 *	0.6 *
Shrubland	0.2 *	0.8	0.4 *	0.4 *	0.2 *	0.2 *	0.2 *	0.7
Marginal	0.0 *	0.0 *	0.0 *	0.2	0.2	0.0	0.1 *	0.1

Indices followed by a star are statistically significant at P<0.05. Positive selection for a vegetation class is indicated by a value >1, whereas a value <1 indicates the vegetation was used less than in proportion to its availability.

Table 12: Hind vegetation selection indices on date of parturition in 2008/09

Vegetation Class	Hind						
	459	374	567	606	595	600	2365
Pasture	0.1	1.3	0.3	0.4	0.2	0.4	0.9
Tussock	0.1	0.1	**3.5**	**2.6**	**4.4**	**3.6**	0.3
Shrubland	**6.0**	**2.4**	0.0	0.2	0.1	0.2	**2.8**

All indices were statistically significant at P<0.05. Positive selection for a vegetation class is indicated by a value >1, whereas a value <1 indicates the vegetation was used less than in proportion to its availability.

Figure 1: Topographical map of the study paddock at White Rock Station

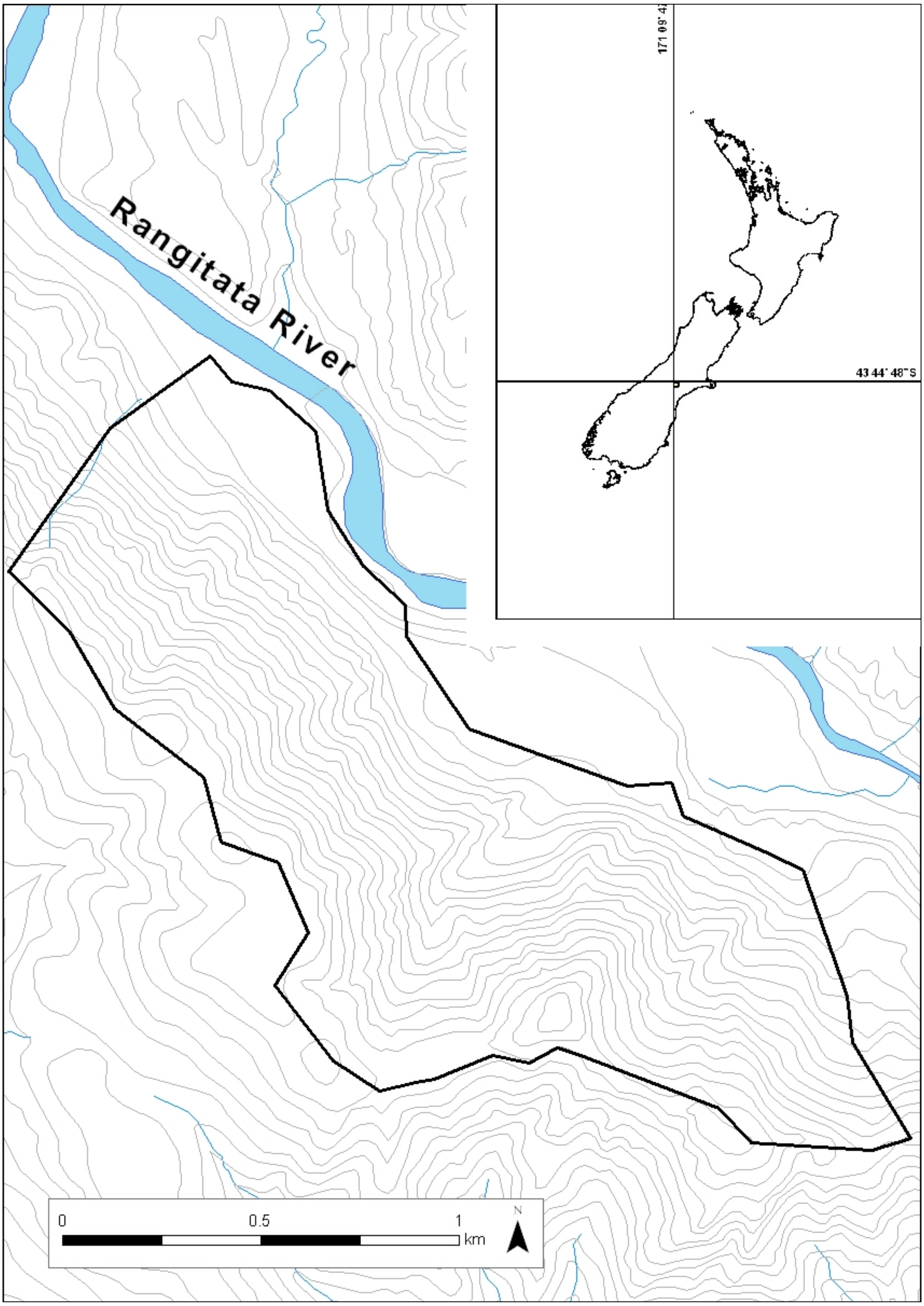


Figure 2: Object-based (Scale 30) unsupervised classification with 25 preliminary vegetation classes.

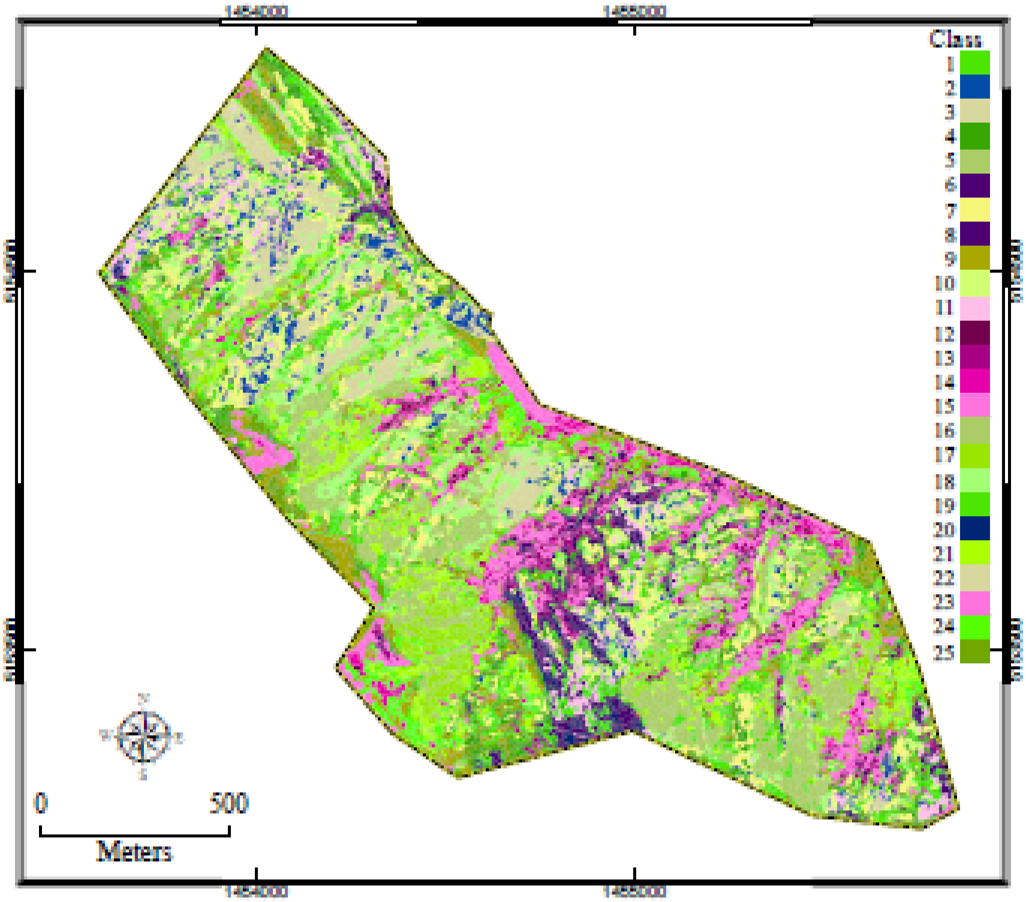
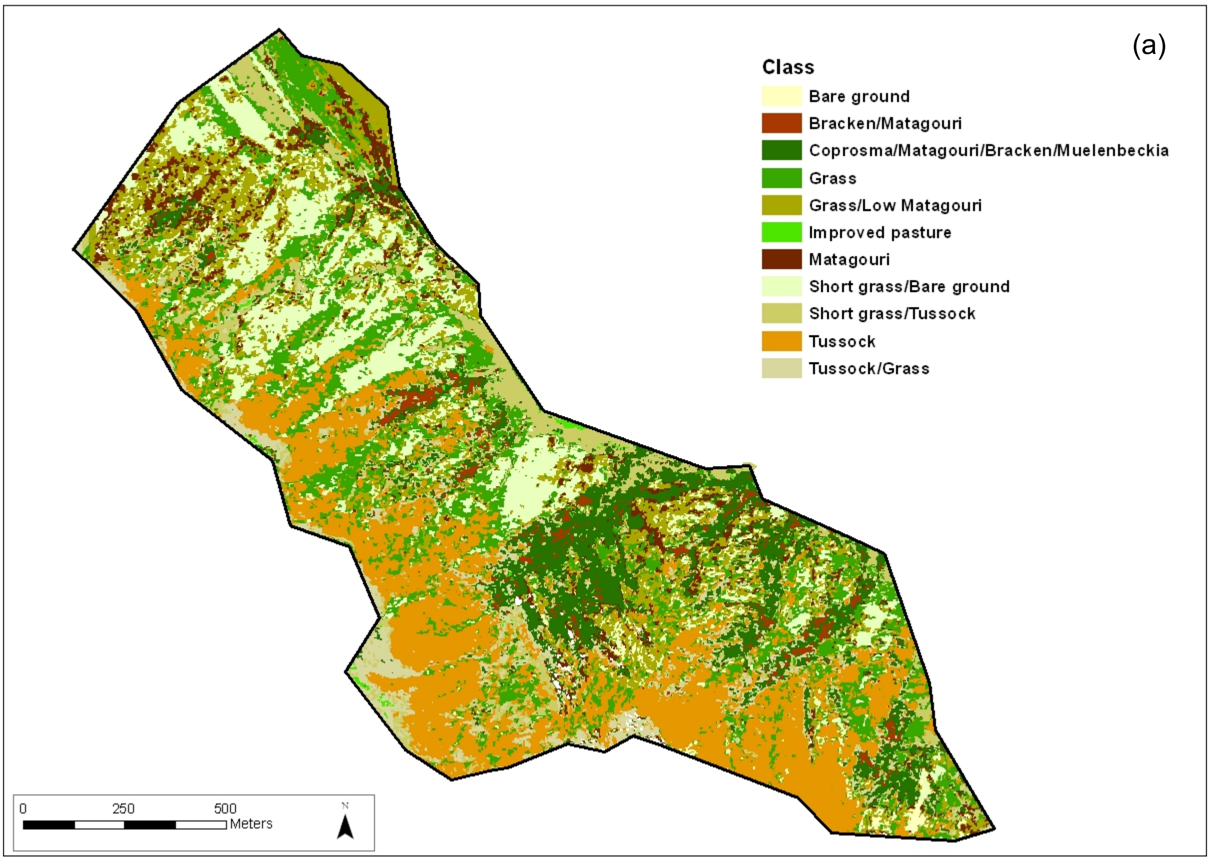


Figure 3: Vegetation (a) and elevation (b) maps of study paddock at White Rock Station



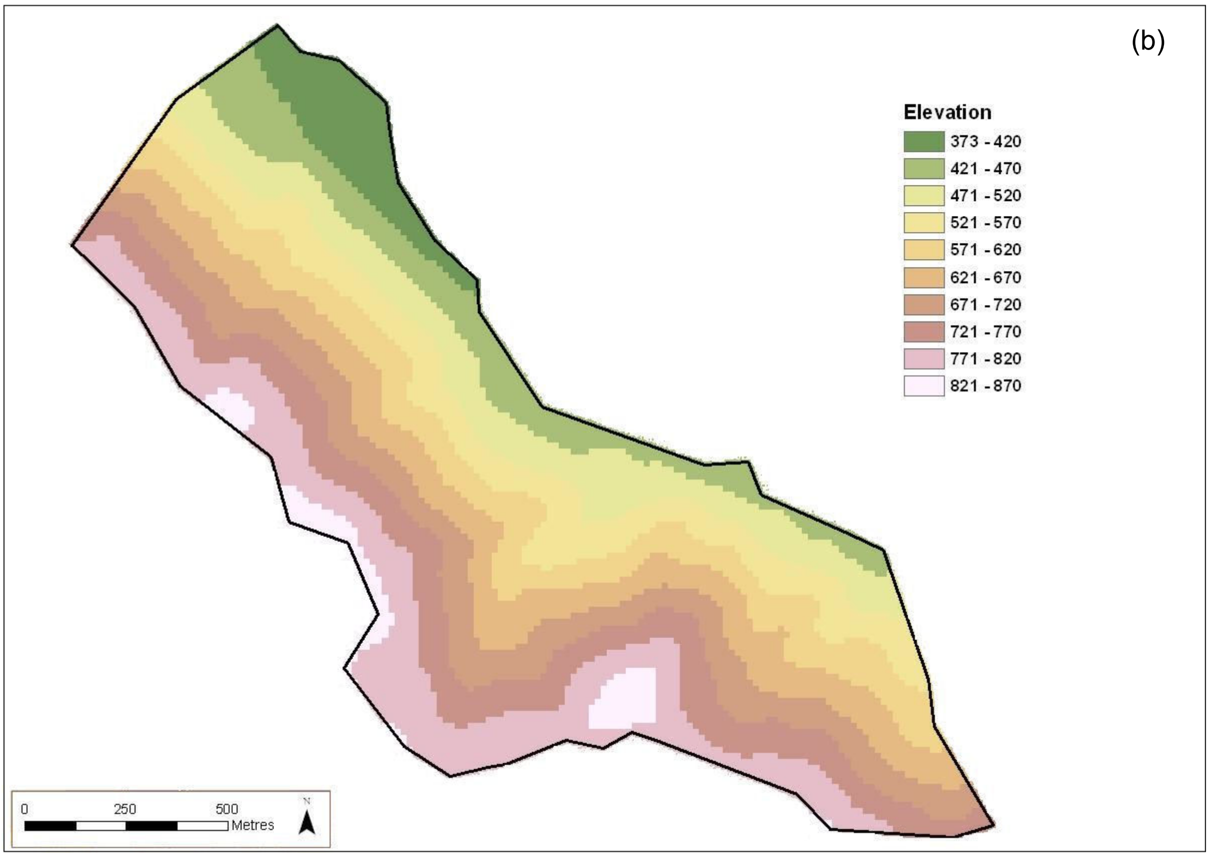

(b)
Elevation
373 - 420
421 - 470
471 - 520
521 - 570
571 - 620
621 - 670
671 - 720
721 - 770
771 - 820
821 - 870
0
250
500
Metres
N

Figure 4: Home ranges of the hinds in 2008/09. Shaded areas represent the 95%, 80%, 50% and 20% core occupancy areas (areas of increasing intensity of use, respectively).

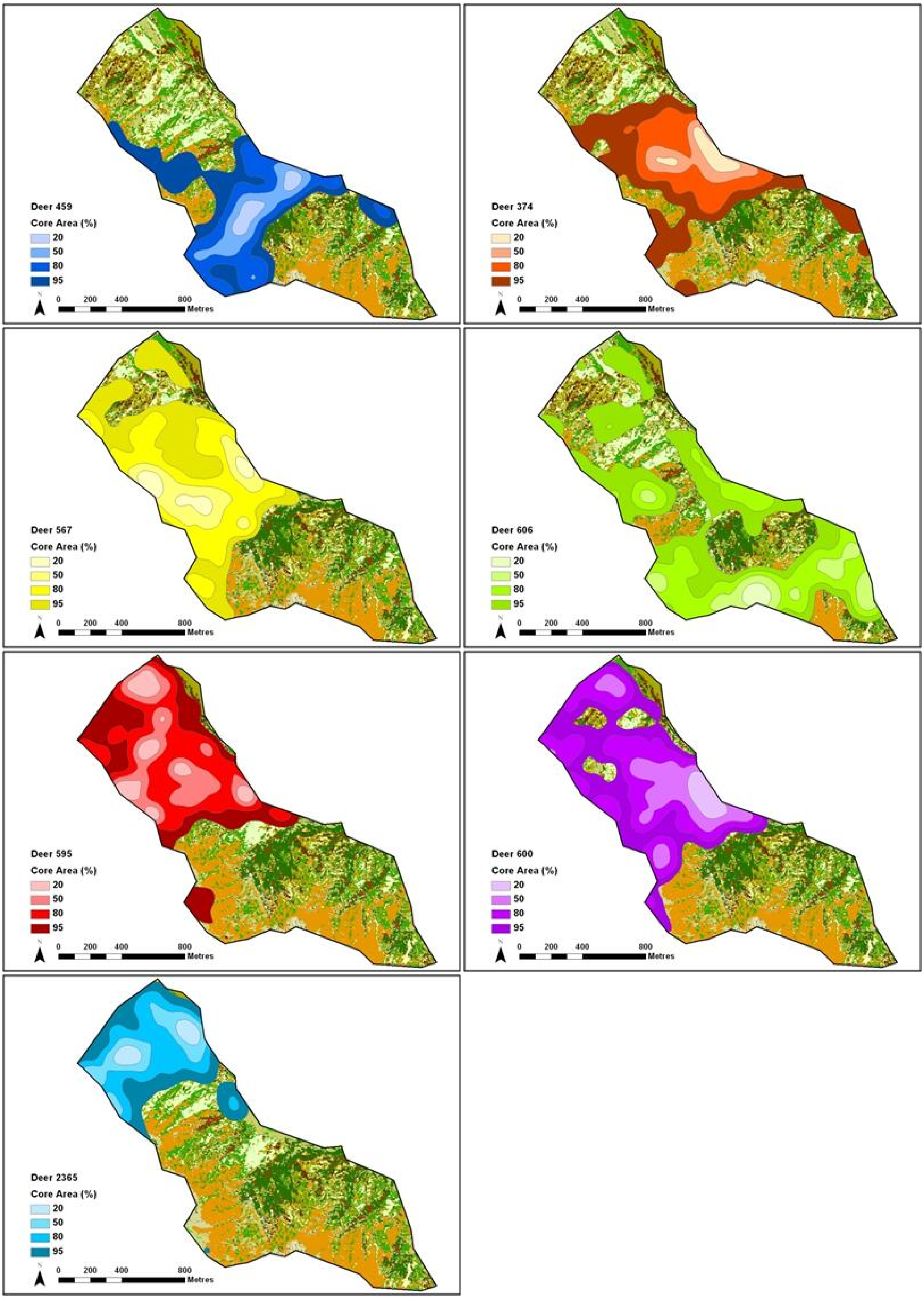


Figure 5: Pie charts of vegetation occupancy for each hind in 2008/09, based on 12 specific vegetation classes

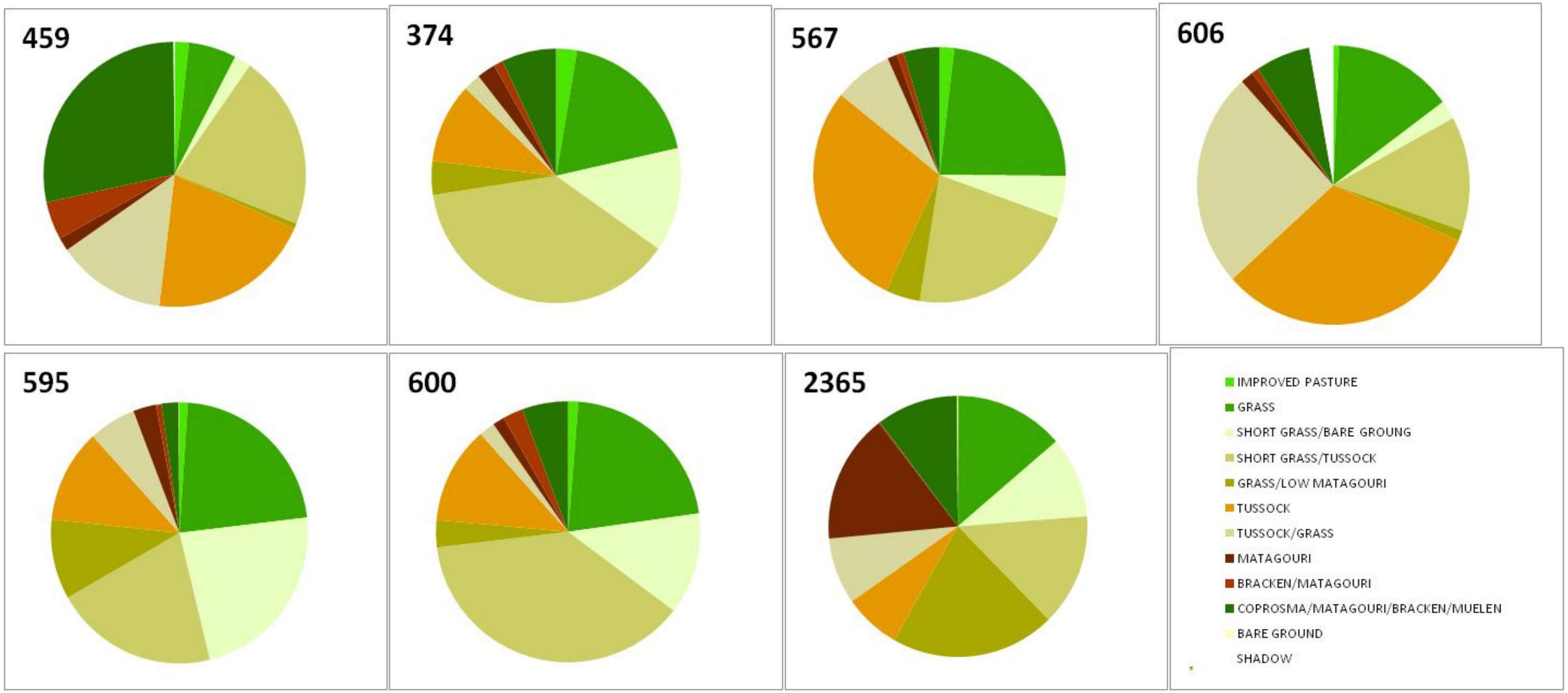


Figure 6: Home ranges of the hinds in 2009/10. Shaded areas represent the 95%, 80%, 50% and 20% core occupancy areas (areas of increasing intensity of use, respectively).

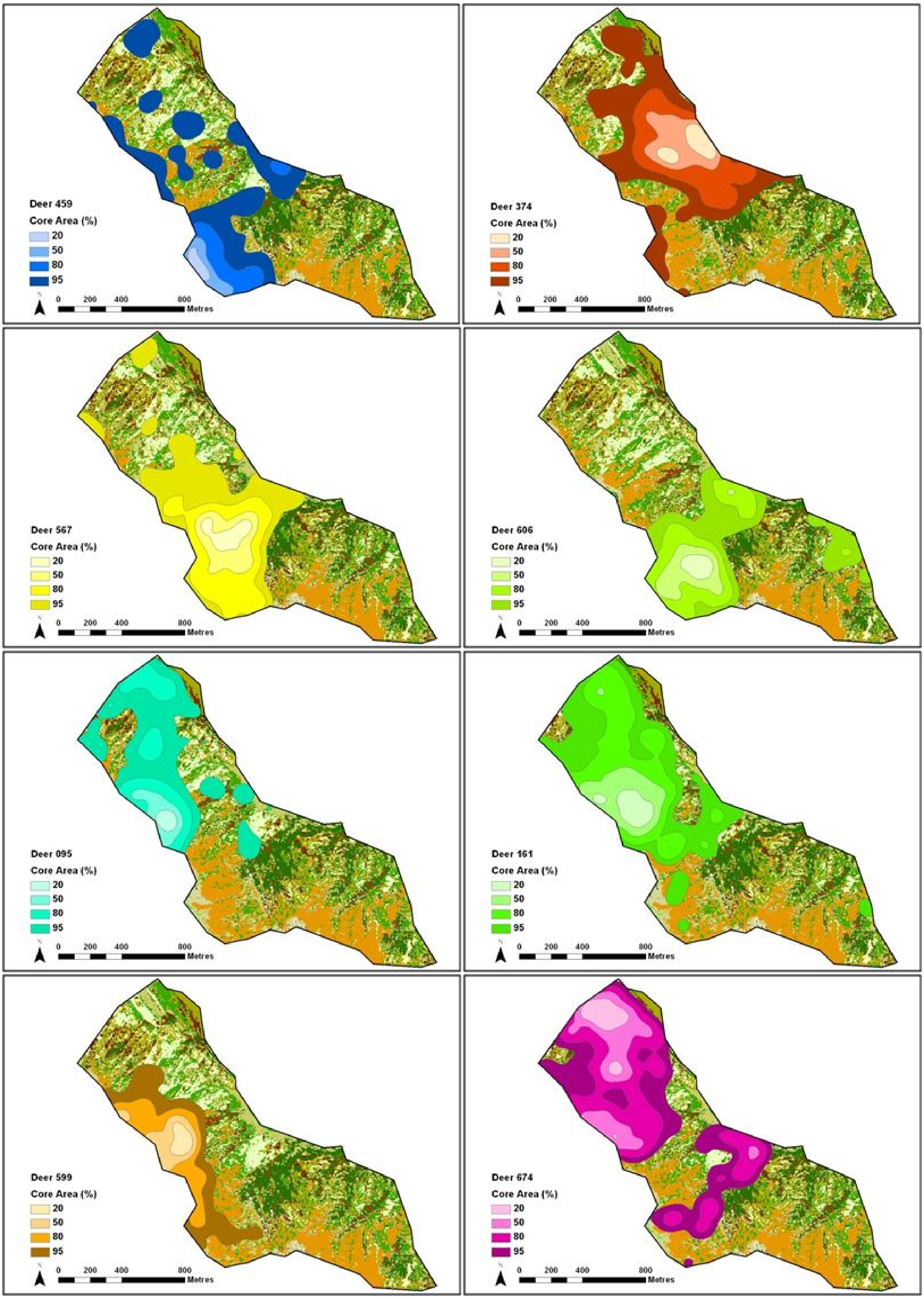


Figure 7: Pie charts of vegetation occupancy for each hind in 2009/10, based on 12 specific vegetation classes

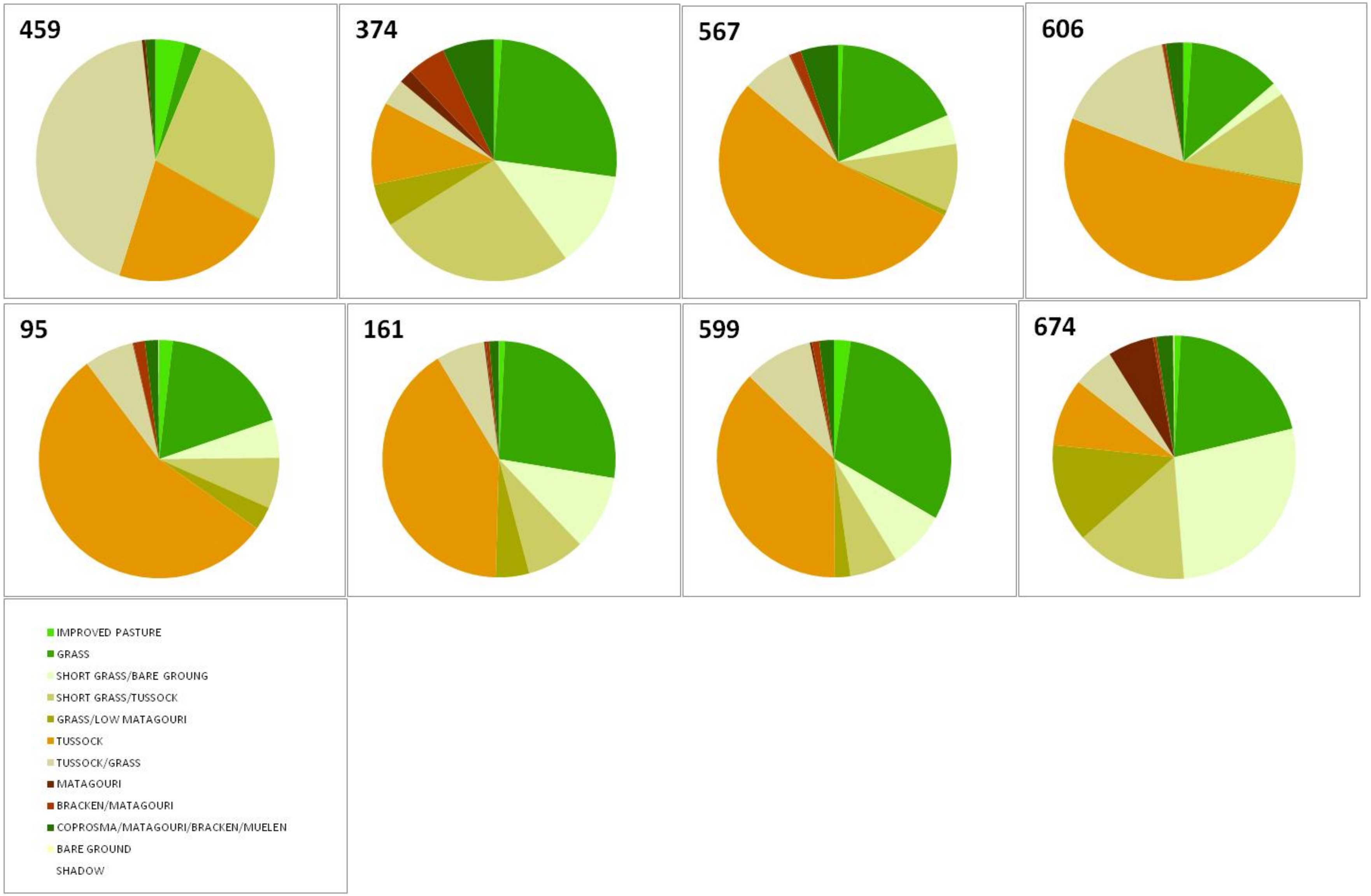
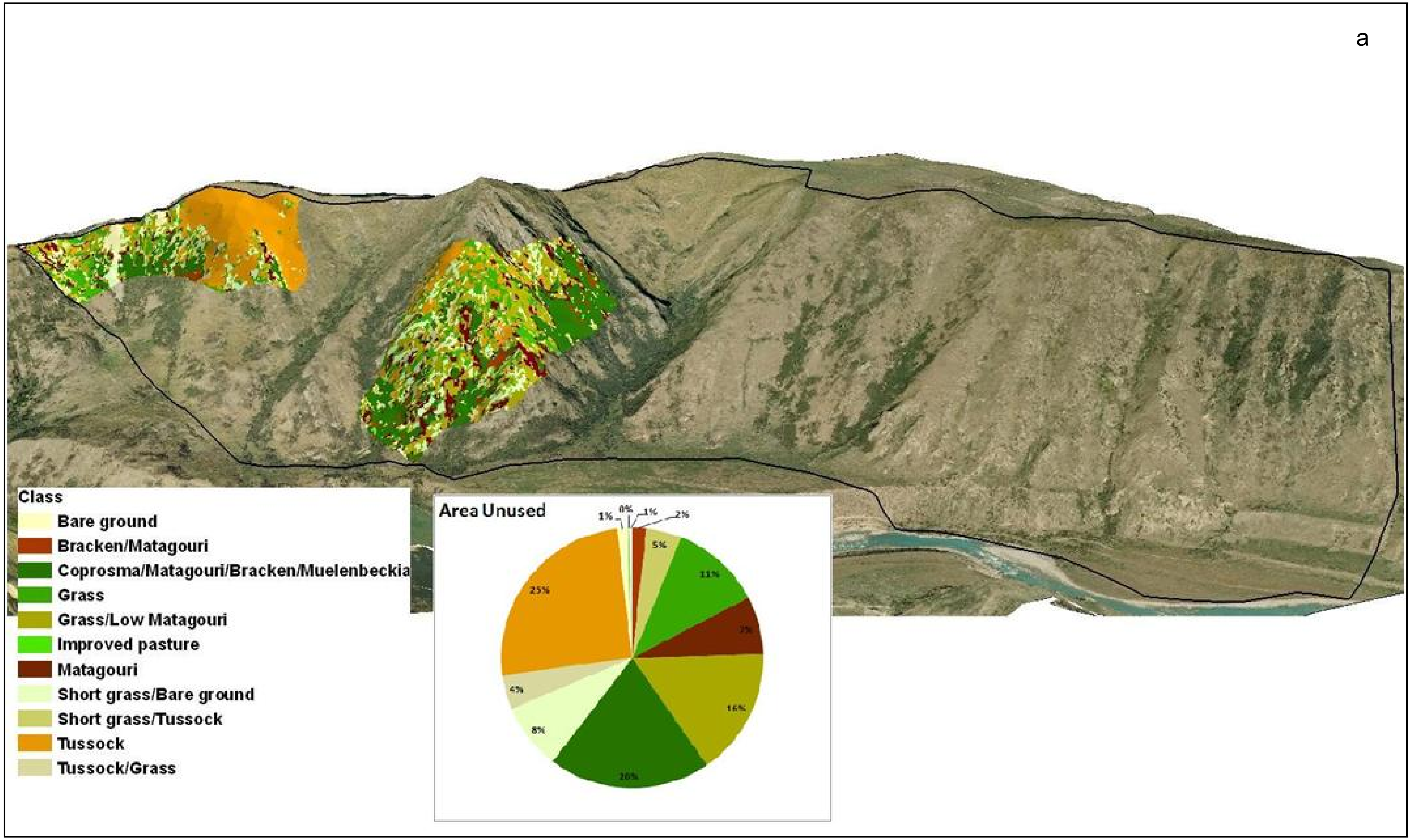


Figure 8: Three-dimensional image of the area not used by the GPS tracked hinds, showing its (a) vegetation and (b) slope classes (degrees).




b
Slope
0 - 3
4 - 7
8 - 15
16 - 20
21 - 25
26 - 35
36 - 47

Figure 9: Distance travelled between samples (log scale) over time in 2008/09, with respective one day moving averages (red line), and mean levels for the given calving behavioral state calculated by the Viterbi algorithm (green line).

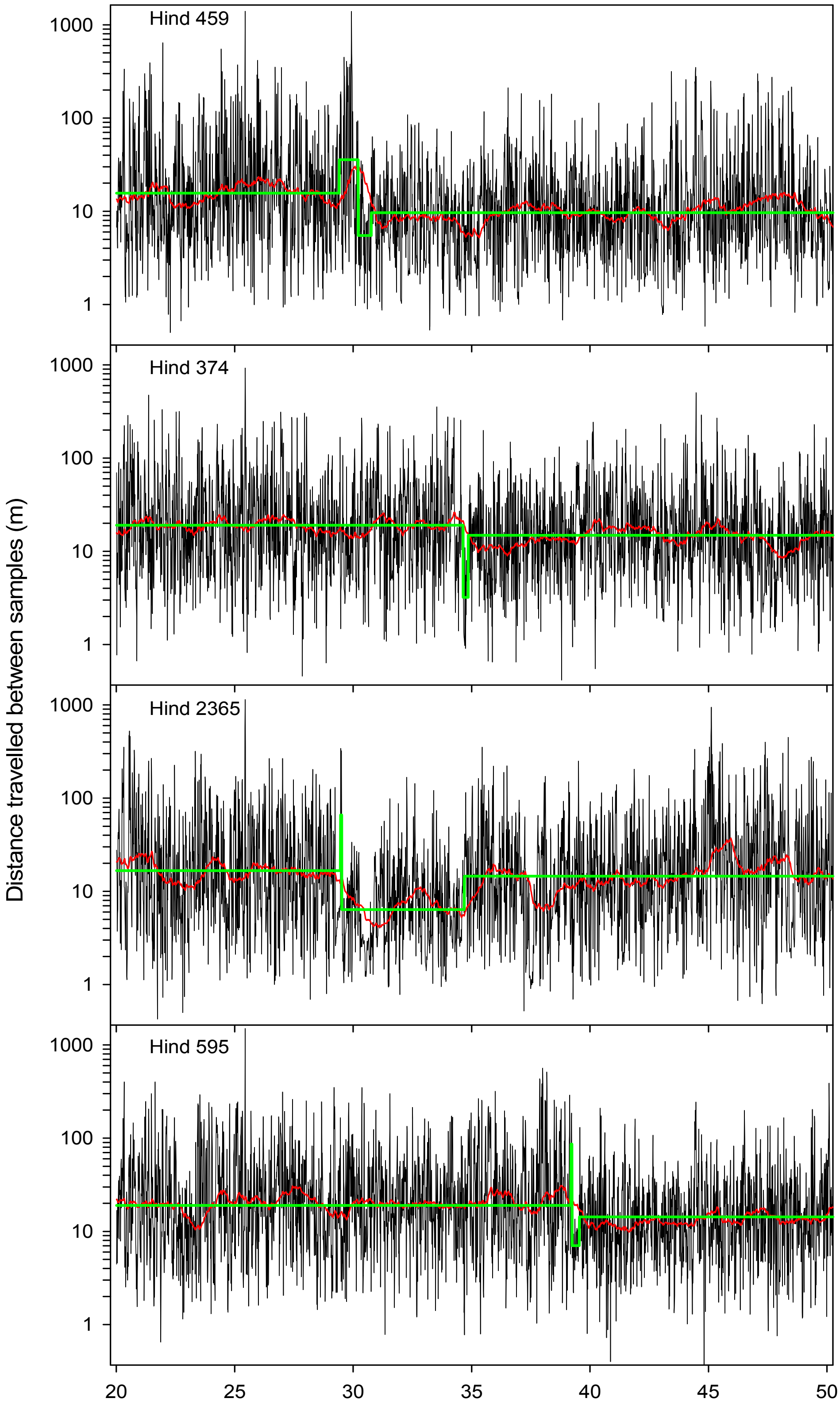


Figure 9: continued

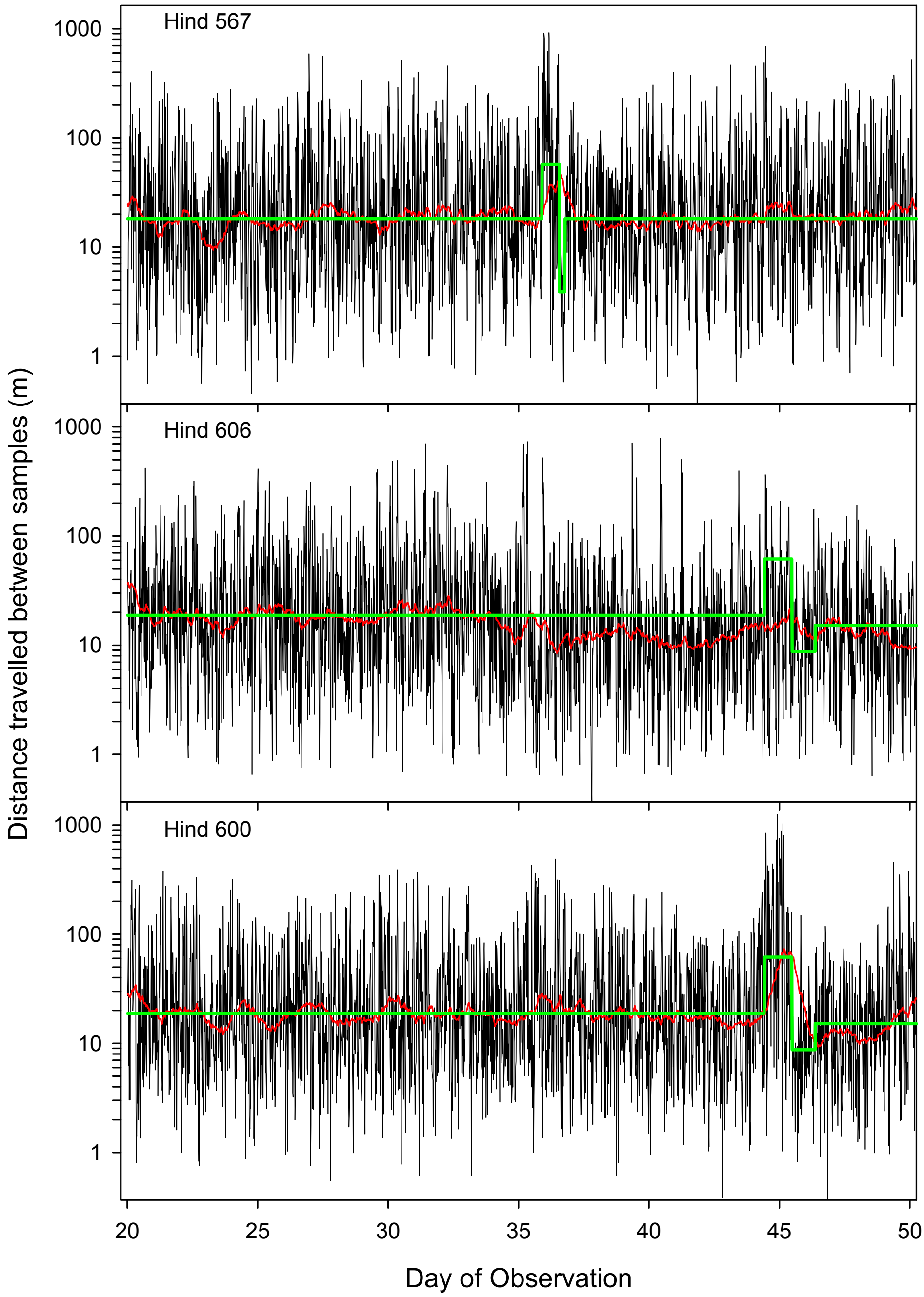

Hind 567
Hind 606
Hind 600
Distance travelled between samples (m)
1000
100
10
1
20
25
30
35
40
45
50
Day of Observation

Figure 10: Position of hinds for 24 hours (a) prior to estimated calving time and (b) subsequent to estimated calving time in 2008/09. The estimated birthing site is indicated by the letter B. Hinds denoted by: 459 (black), 374 (red), 567 (aqua), 606 (pink), 595 (blue), 600 (yellow), 2365 (green).

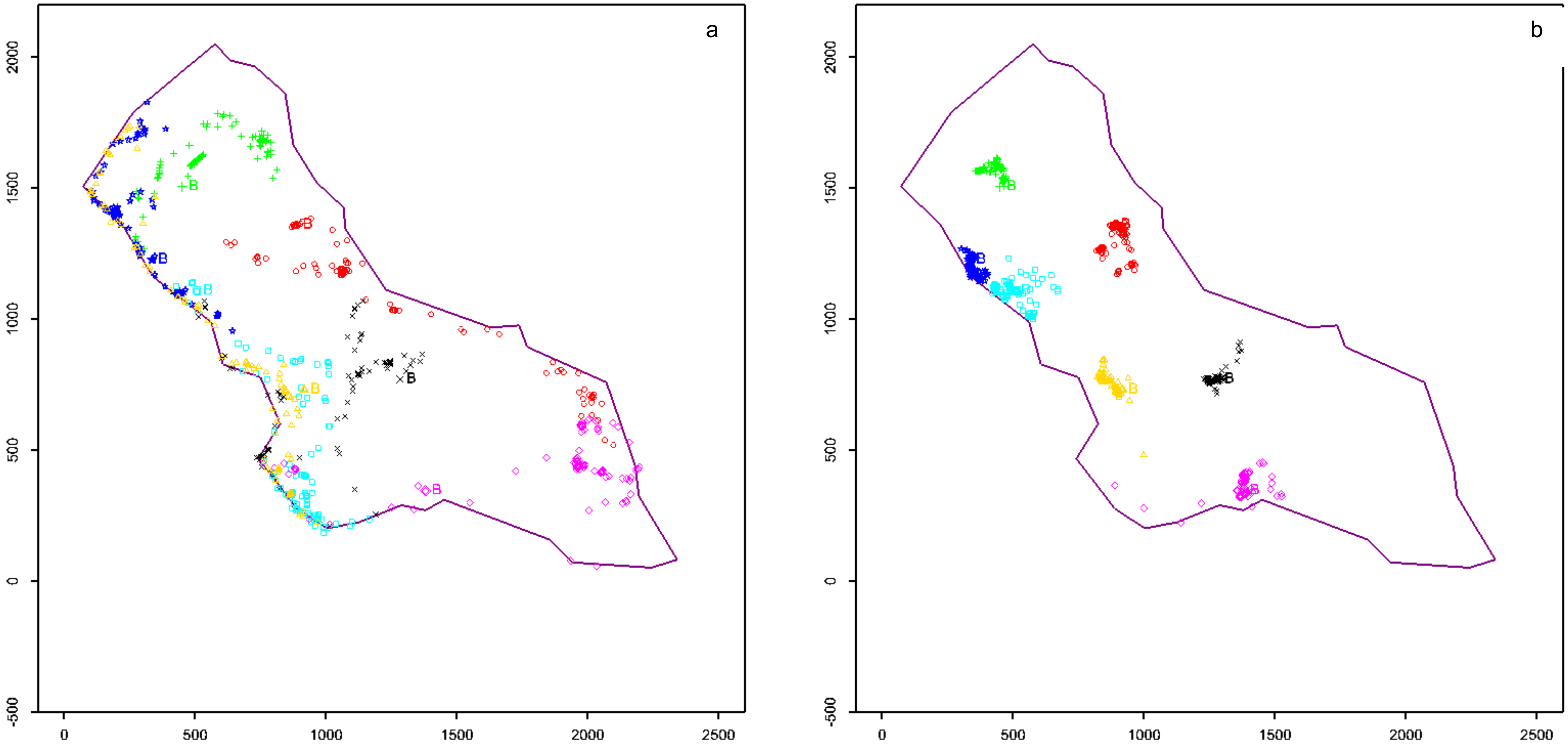


Figure 11: Pie charts of the vegetation occupied by each hind on their respective putative calving dates in 2008/09.

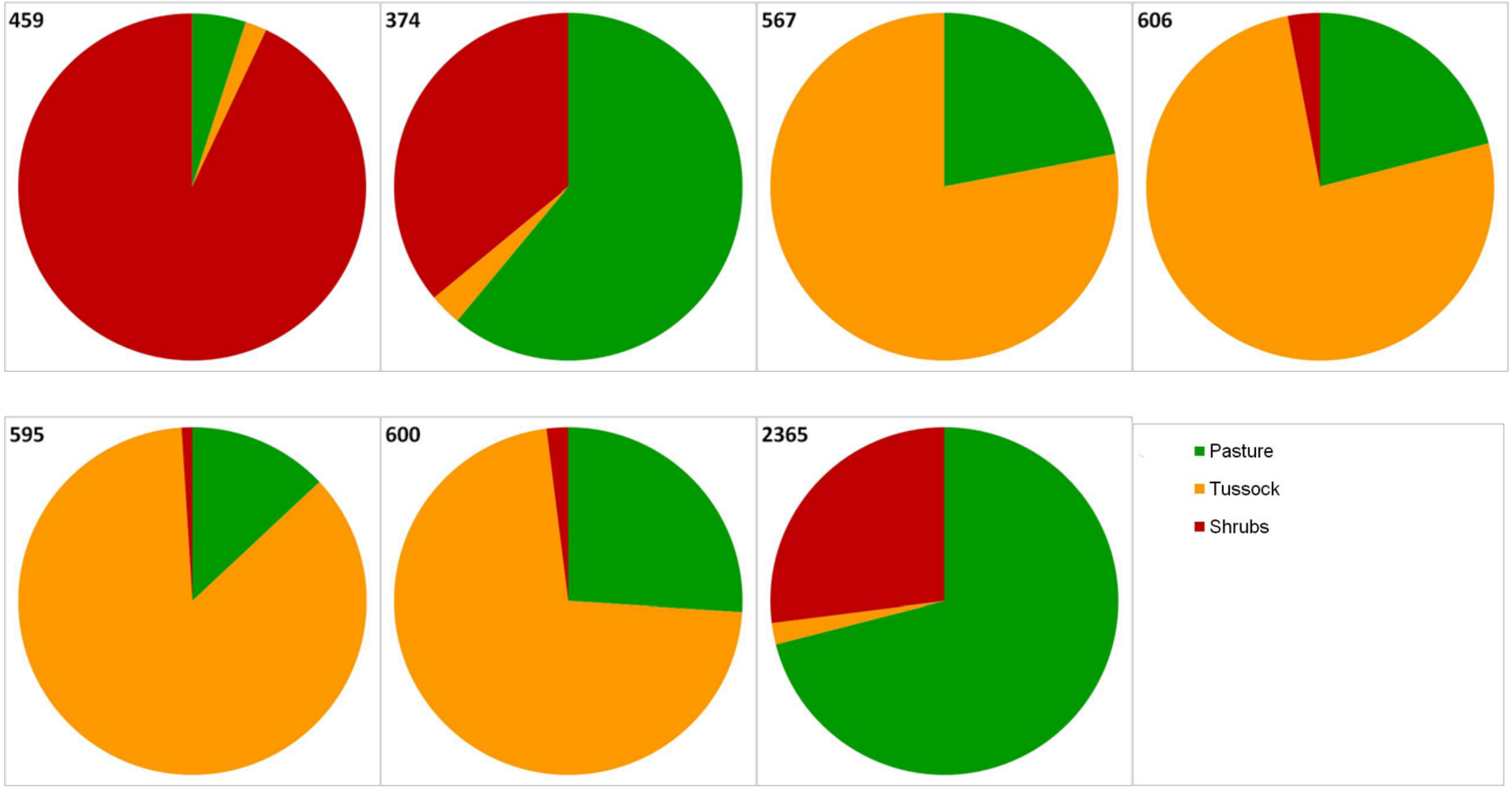


Figure 12: Hind diurnal activity patterns averaged over the entire study period in 2008/09. Hinds denoted by: 459 (blue), 374 (red), 567 (aqua), 606 (rust), 595 (purple), 600 (blue/grey), 2365 (green).

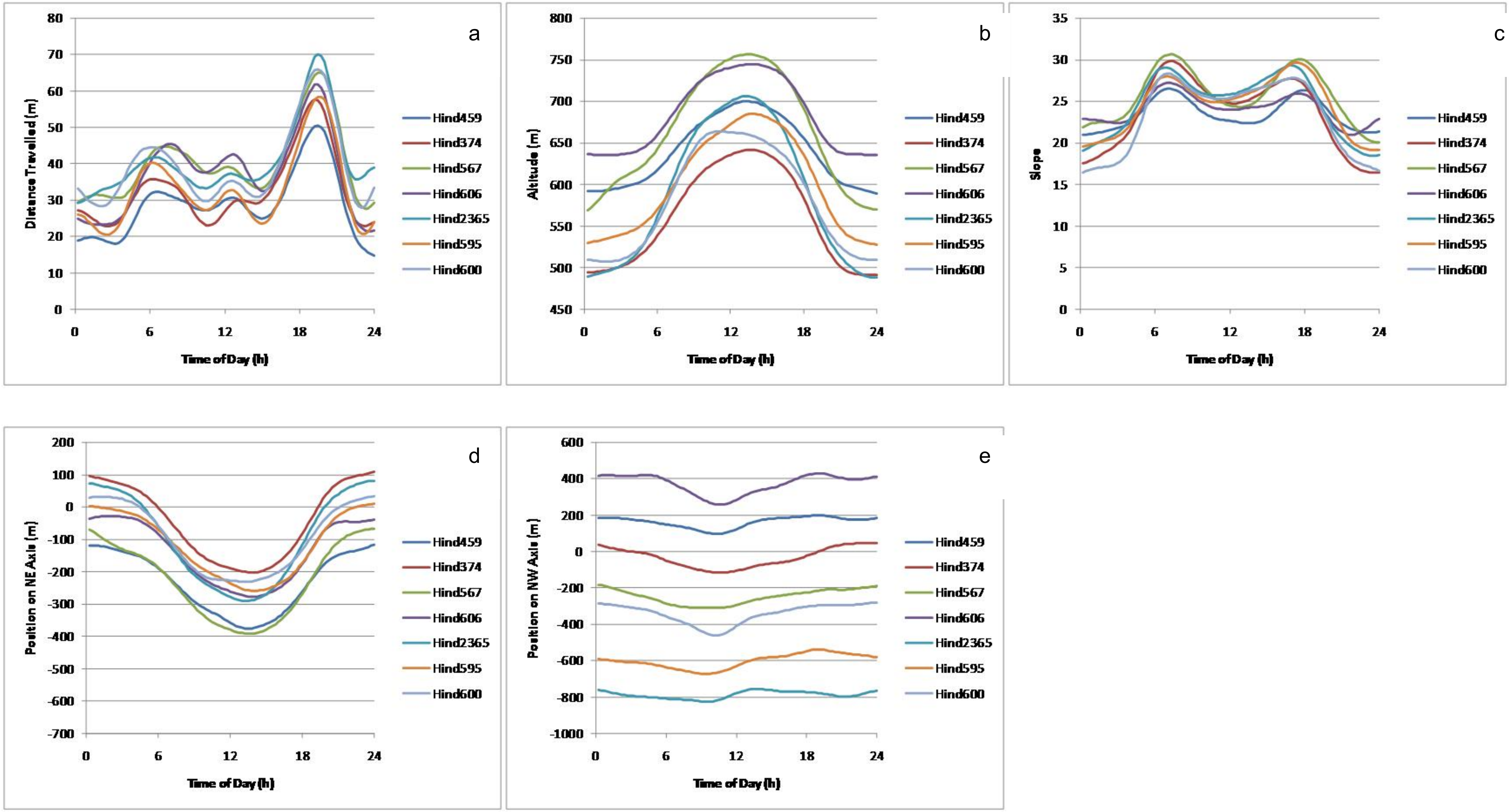


Figure 13: Hind diurnal vegetation occupancy patterns averaged over the entire study period in 2008/09. Hinds denoted by: 459 (blue), 374 (red), 567 (aqua), 606 (rust), 595 (purple), 600 (blue/grey), 2365 (green).

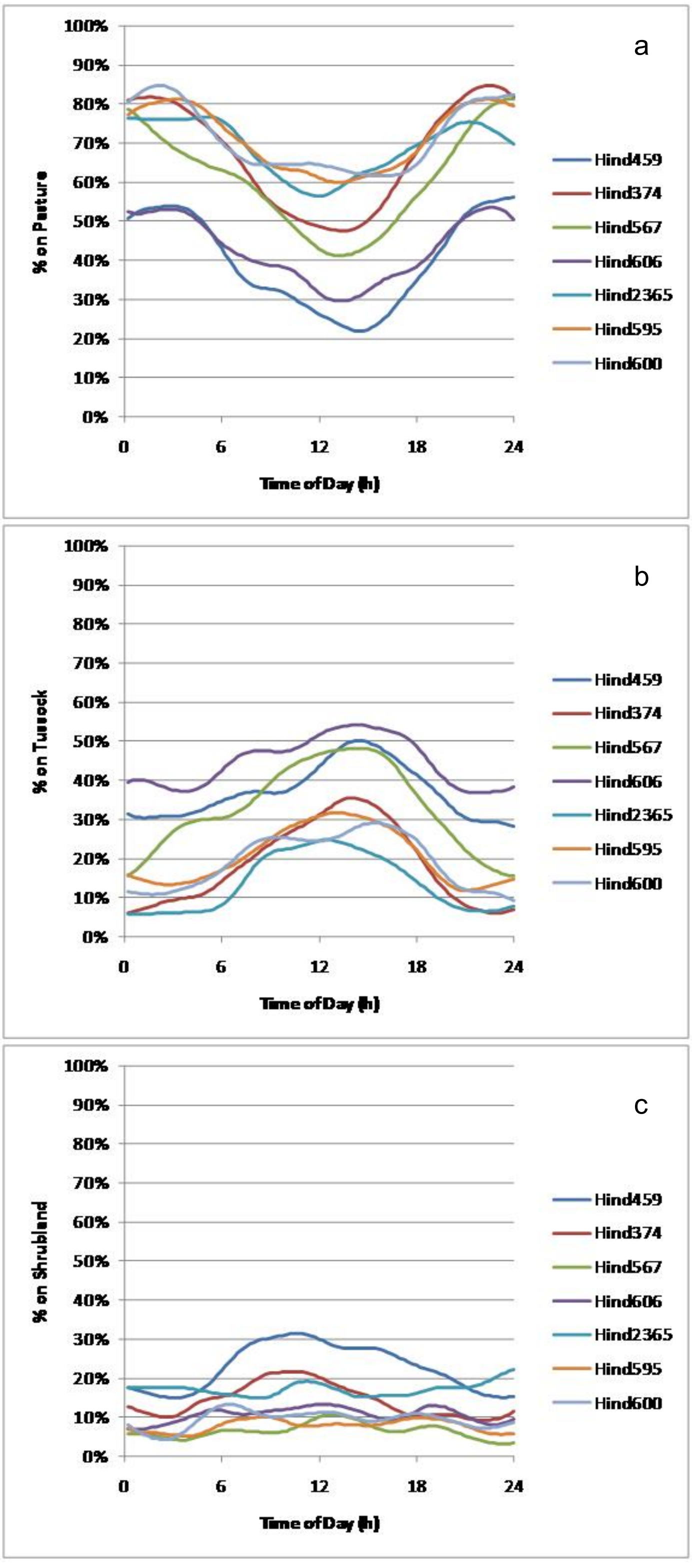


Figure 14: Hind diurnal activity patterns averaged over the entire study period in 2009/10. Hinds denoted by: 459 (purple), 374 (green), 567 (aqua), 606 (grey/blue), 95 (blue), 161 (red), 599 (rust), and 674 (pink/red).

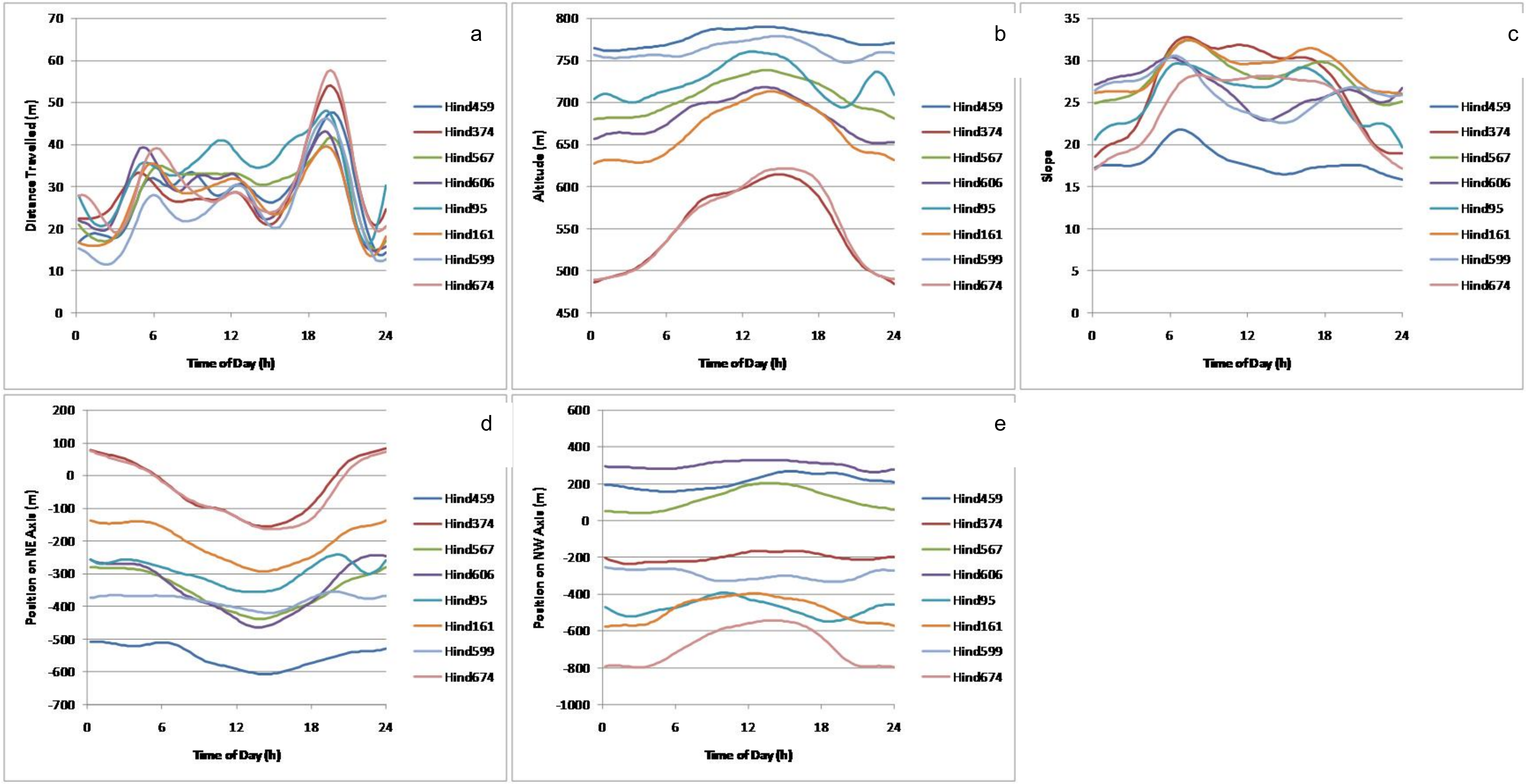


Figure 15: Hind diurnal vegetation occupancy patterns averaged over the entire study period in 2009/10. Hinds denoted by: 459 (blue), 374 (red), 567 (aqua), 606 (rust), 595 (purple), 600 (blue/grey), 2365 (green).

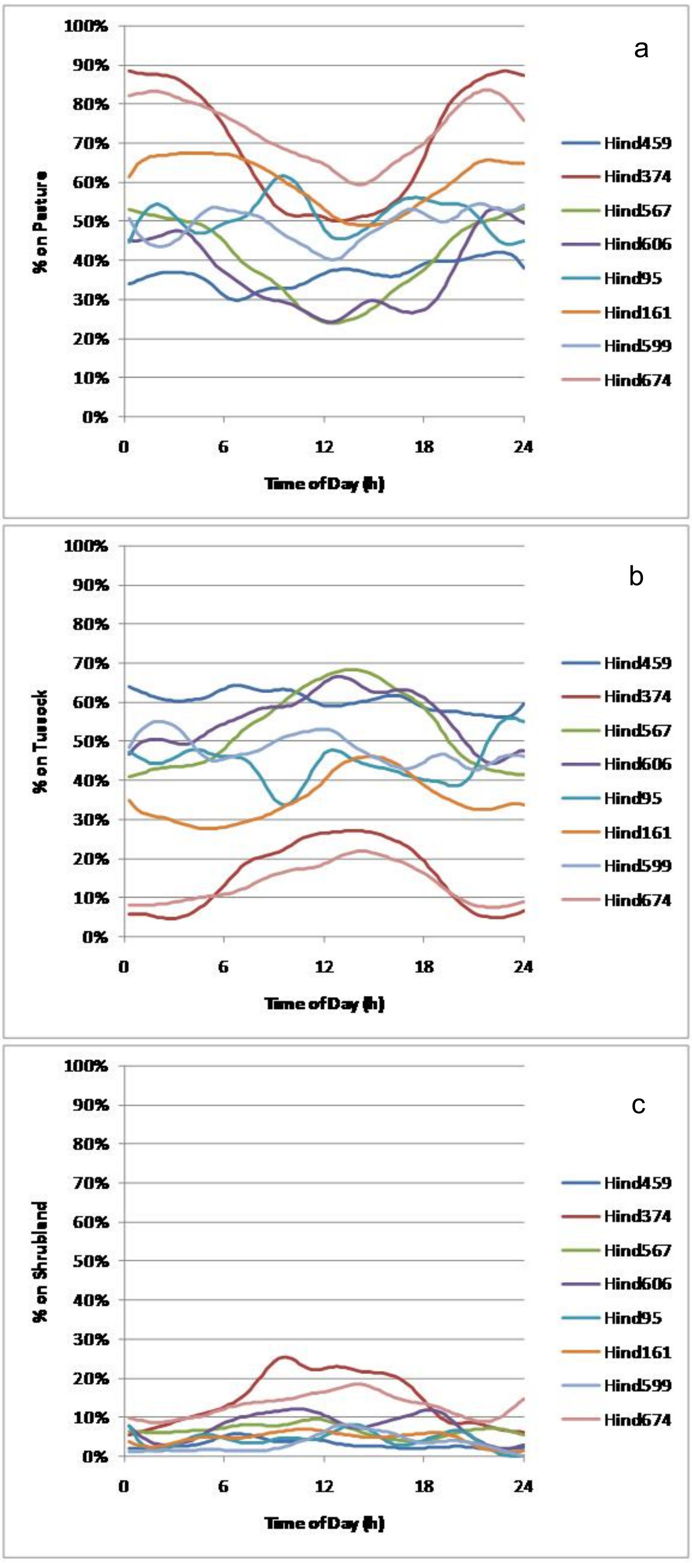


Figure 16: Hind diurnal activity patterns for successive monthly (30 day) periods in 2008/09.

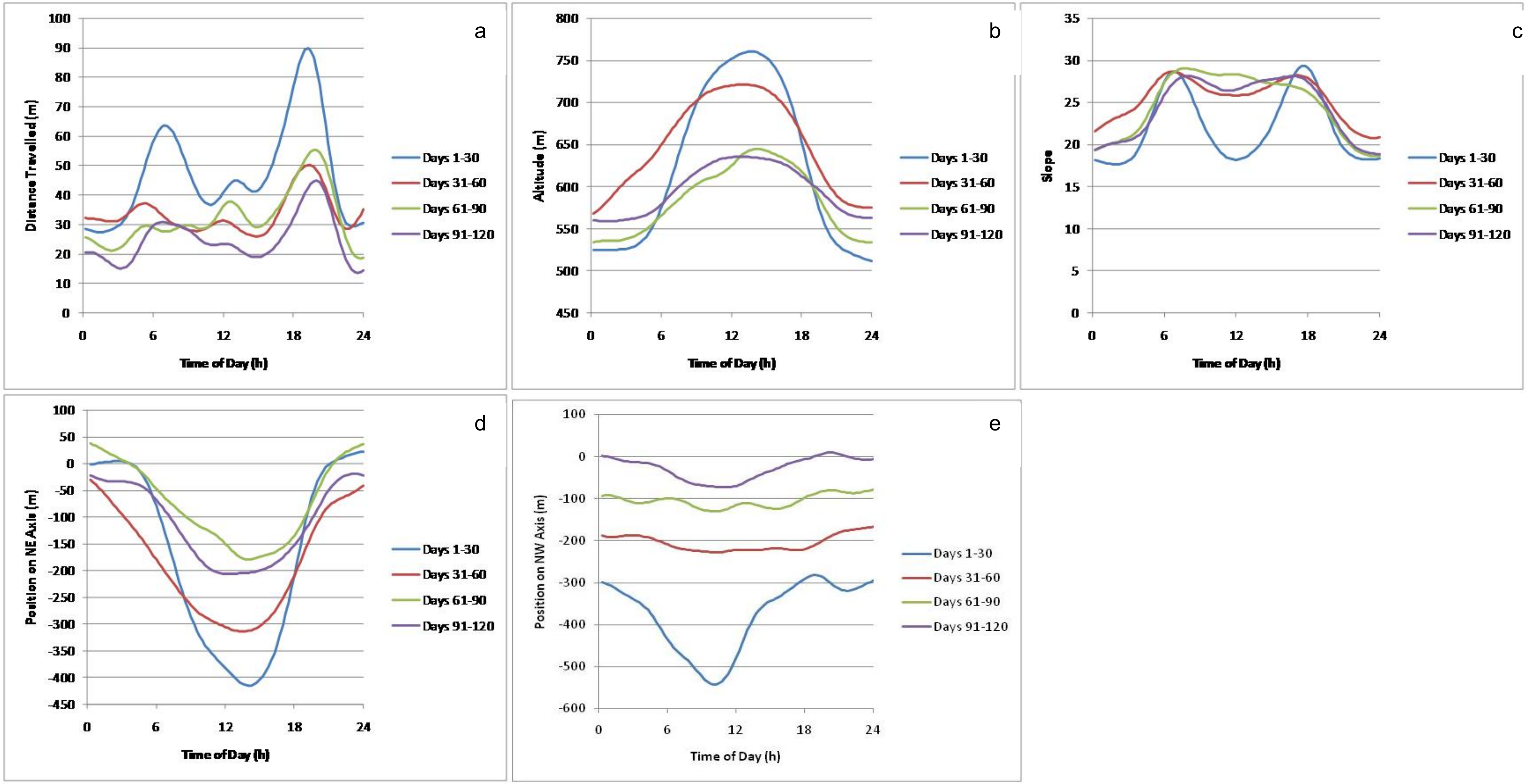


Figure 17: Hind diurnal vegetation occupancy patterns for successive monthly (30 day) periods in 2008/09.

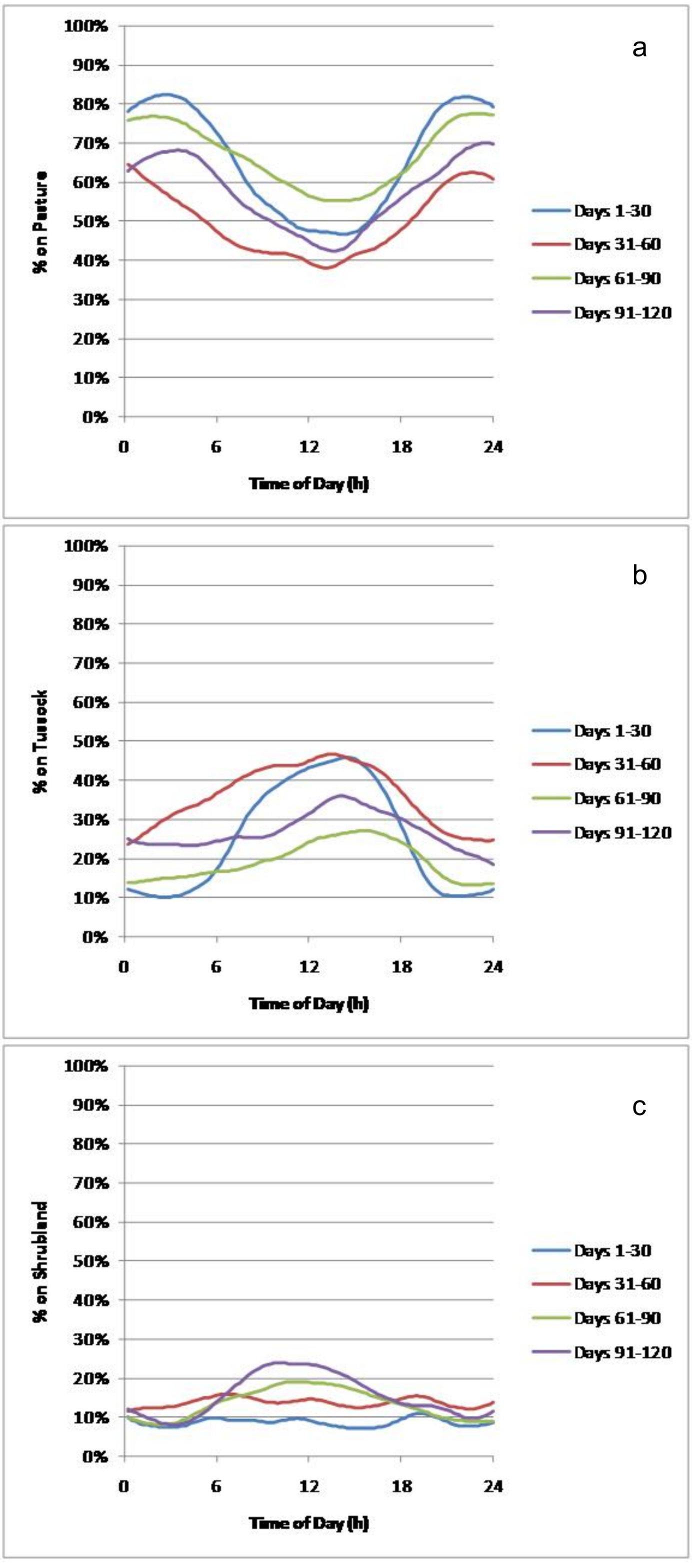


Figure 18: Hind diurnal activity patterns for successive monthly (30 day) periods in 2009/10.

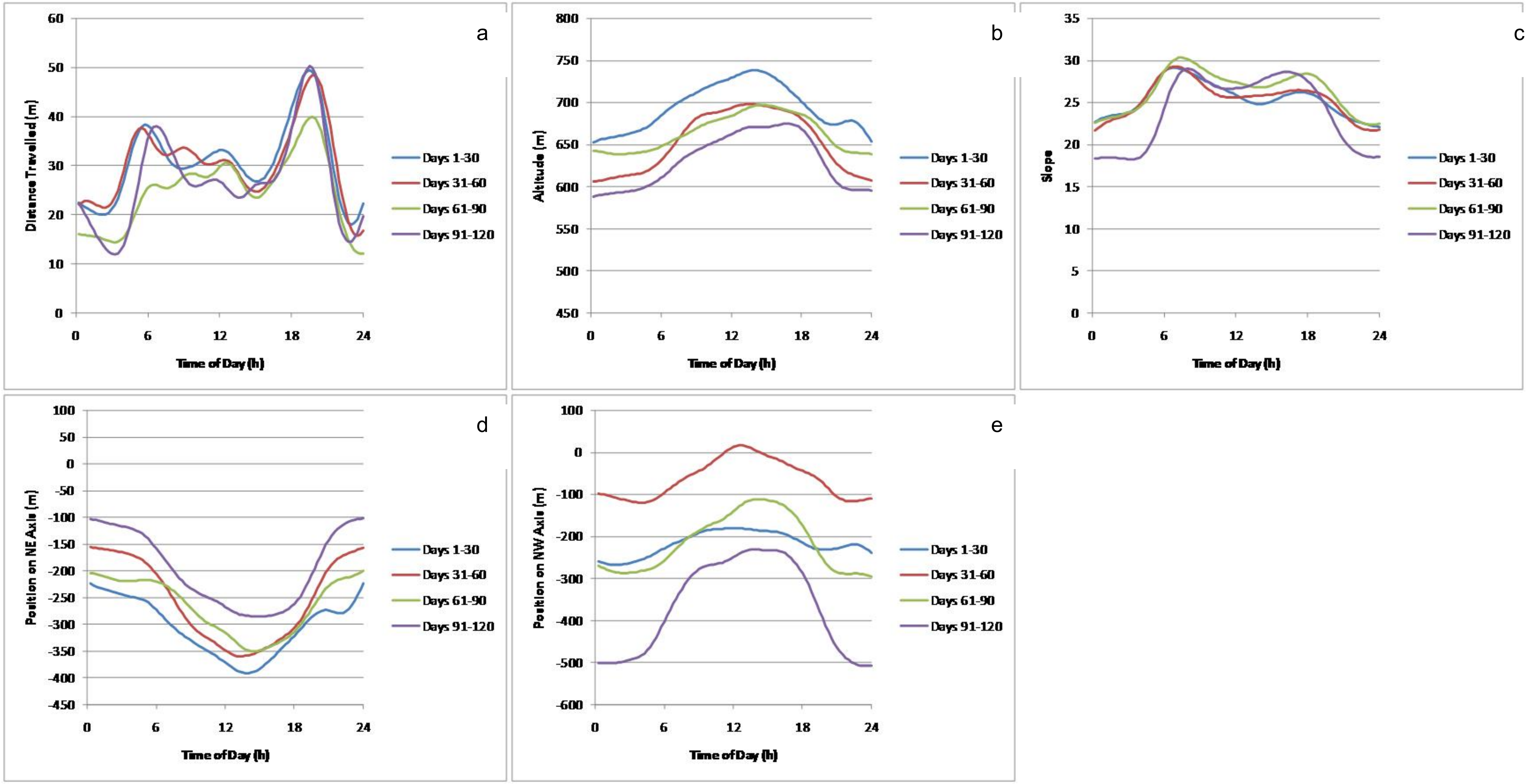


Figure 19: Hind diurnal vegetation occupancy patterns for successive monthly (30 day) periods in 2009/10.