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**Winter Home Range and Habitat Selection by Wapiti in
Fiordland National Park**

A Dissertation
submitted in partial fulfilment
of the requirements for the Degree of
Bachelor of Agricultural Science with Honours

at
Lincoln University
by
Samuel Michael Walter Harvey

Lincoln University
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Abstract of a Dissertation submitted in partial fulfilment of the requirements for the Degree of Bachelor of Agricultural Science with Honours.

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by

Samuel Michael Walter Harvey

Wapiti (*Cervus canadensis nelsonii*) were released in the head of the George Sound, Fiordland National Park, New Zealand, in 1905. There has since been little research carried out on the population and study would be beneficial, as the herd is of national importance for big game hunting. International literature was reviewed to provide a background on the key drivers of habitat choice in wapiti and red deer (*Cervus elaphus*). Literature suggests that wapiti movements and home ranges would be greatest during winter due to limited plant growth and forage availability. Literature also suggests that wapiti would prefer habitats at edges between forest and field, where habitat transition increases plant diversity, resulting in high forage densities. A GPS collaring study was carried out in order to estimate ranging behaviour and habitat selection by wapiti in Fiordland. Six animals were captured, collared and released in early- through to mid-2014, after which, location data was retrieved for the winter season (June, July, August). Home ranges and habitat utilisation were estimated using geographical data analysis packages. It was hypothesised that ranging behaviour would be reduced when compared to elk populations in North America due to milder winters, and better foraging, in Fiordland. Daily movement varied significantly, from 0.2-6 km, however, averages suggest that wapiti typically move little more than 500 m per day during winter. Home range size varied between animals in this study, ranging from 44-733 ha (100% MCP) or 58-1385 ha (95% KDE). These home ranges and daily movements were significantly lower than for elk studied elsewhere and were more comparable to those of red deer in Western Europe, which is consistent with the first hypothesis. It was also hypothesised that wapiti would prefer similar, forest edge, habitat composition to that which was previously observed overseas. A wide range of selection values were produced for different habitats suggesting that habitat preference varies between individual animals. 50% KDE core areas showed that transitional areas made up an important part of wapiti habitat choice which, is consistent with the second hypothesis.

Keywords: Wapiti, elk, *Cervus canadensis*, red deer, Fiordland, GPS, home range, daily movement, habitat selection, winter, North America, New Zealand, forage biomass, forest/field interface.

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Chapter 1

Introduction

1.1 Wapiti in New Zealand

Wapiti (*Cervus canadensis*) or elk are the largest round-antlered deer in the world. There are several sub-species of wapiti that have been described, with four separate groups in both North America and Asia. There have also been other subgroups that have become extinct as a result of hunting pressure, by humans. North American breeds include Roosevelt (*C. canadensis roosevelti*), Tule (*C. canadensis nannodes*), Manitoban (*C. Canadensis manatobensis*) and Rocky Mountain elk (*C. Canadensis nelsonii*). Asian breeds include Altai (*C. canadensis sibiricus*), Tianshan (*C. canadensis songaricus*), Manchurian (*C. canadensis xanthopygus*) and Alashan wapiti (*C. canadensis alashanicus*) (Geist 1998). Wapiti and red deer (*Cervus elaphus*) were previously classified as the same species, however, recent genometric study has identified them as two separate species (Ludt *et al.*, 2004). Both wapiti and red deer are ungulates, hoofed animals, in the genus *Cervidae*, referred to as cervids. There is much debate about the terminology for elk or wapiti with regard to the different subgroups and populations, however, for this report, North American animals will be referred to as elk whilst animals of the Fiordland herd will be referred to as wapiti.

Wapiti were first released in Fiordland in 1905 and were almost definitely *Cervus canadensis nelsonii* (Banwell 2001). Eighteen individuals were brought from Wyoming and released in the George Sound. These animals reproduced and subsequently colonised much of the area between Lake Te Anau and the West Coast, excluding the Murchison Mountains (Nugent *et al.*, 1987). Since their release wapiti have interbred with red deer to form hybrids of varying phenotypes (Angus 1995). The more aggressive nature of the rutting red stag and his greater sexuality during mating, enhanced his dominance over the more moderate wapiti bull (Banwell 2001). Other releases of wapiti in New Zealand have occurred at Kawau Island in the 1870's and Dunedin (Banwell 2001), however, both populations became extinct through hunting or natural death (Nugent *et al.*, 2010). It is thought that as a result of interbreeding, there is unlikely to be any pure wapiti left in the wild of New Zealand. Banwell (2001) stated that it would be difficult to find an animal with more than 60-70% wapiti-type genes.

Wapiti are the largest deer species present in New Zealand, males weighing 300+ kg and females weighing 200+ kg. Both sexes are bay coloured of body with a dark brown head, neck and legs. Bulls are larger of body compared to their red deer cousins and naturally produce superior

antlers, which makes for a more impressive trophy. This is reflected in the value of this species as a game animal, which exceeds that of any other species in New Zealand with hunters willing to spend \$1100 NZD per trophy animal shot, compared to red deer at only \$239 NZD per animal (Nugent 1988). Wapiti bulls are a different animal to hunt when compared with red deer as they produce a high pitched bugle as their mating call which is different to the guttural roar of a red stag. Hybrids of the two species produce a call that is an amalgamation of both a roar and a bugle. Successful management of both wapiti and red deer has been carried out, although somewhat intermittently, by the Southland Acclimatisation Society (1923-1935), the New Zealand Deerstalkers' Association (1954-1967) and the Fiordland Wapiti Foundation (2005-present). This has been done to ensure the preservation of wapiti genetics and phenotypes, so that the experience of hunting wapiti in Fiordland may be enjoyed by future generations.

Due to the inaccessibility and harsh terrain of Fiordland National Park there has been no farming or forestry in the area. This means that the issues of competition between wapiti and farming, which exist in North America, are not present here. Damage to the native grasslands was reported as deer numbers rose (Poole, 1951). By the late 1960's, high levels of deer had strongly modified grassland composition and structure (Rose & Platt 1987). Understory composition has also been recorded to have been modified by cervids, with preferred plants being almost completely removed from some areas and unpalatable plants being completely avoided (Stewart *et al.*, 1987). From 1969-1984 81% of the deer and wapiti population in Fiordland was removed through commercial hunting which was followed by a rapid regeneration of understory species (Banwell 2001). Live capture of wapiti from the Fiordland herd was carried out via helicopter during the late 1970's and early 1980's. These animals were then farmed as the Crown Herd which, was intended to supplement the national deer industry with terminal sires and to maintain the genetics of the Fiordland herd (Angus 1995). The Crown herd has however, never been used to maintain wild wapiti genetics and current New Zealand law prevents the intentional release of invasive species (Wild Animal Control Act 1977). The Crown Herd has therefore been used to provide terminal sires to the New Zealand deer industry. The New Zealand deer industry utilises wapiti terminal sires to improve meat production, by increasing growth rates of F1 and F2 progeny and thus total meat yield at slaughter. Wapiti of other types, including *C. Canadensis manatobensis* and *C. Canadensis roosevelti*, have also been imported to improve New Zealand farmed genetics (Yerex 1991). Escapee deer have subsequently interbred with wild populations, resulting in adjacent red deer populations having small amounts of wapiti genetics (Fraser *et al.*, 2003).

1.2 The Fiordland Wapiti Foundation

The primary aim for the Fiordland Wapiti Foundation (FWF) is to manage animal numbers in the Wapiti area of Fiordland National park. This is carried out through helicopter recovery operations. It also manages the Wapiti ballot for the rut period, and receives donations from hunters via the ballot (FWF annual report 2014). The FWF has been undertaking animal control within the wapiti area of Fiordland National Park since 2005. To improve the efficiency and effectiveness of this control work, FWF was granted approval, in 2007, to undertake an open-ended trial programme of capturing wapiti-type animals and fitting them with visual ear tags and electronic tracking devices. This was for the purpose of understanding seasonal movement, dispersal from family groups and exposing non wapiti-type animals, accompanying collared animals, to control options when collared animals are re-checked. Ron Peacock, a long-time member of FWF, was appointed by FWF as the project manager who subsequently found funding from both Pat Stratton and Brendon Cane, who were inducted into the research team. The original Department of Conservation consent (2007) identifies Judas Animal Control as the primary purpose of this project. Judas operations use marked animals, either with visual markers or fitted with tracking collars or both, which are released into the wild and can be relocated so that control options may be used on the individuals they interact with (Yockney & Nugent 2006, Crouchley *et al.*, 2011). All information used in this dissertation was supplied from data collected by the FWF in their Judas study.

Initial use of VHF tracking collars identified major limitations due to the remote and rugged topography within the study area and this limited the outcomes of the study. Thirteen bulls were captured between 2007 and 2008 and fitted with VHF collars, with all animals caught in the late autumn or early winter. Two bulls appear to have succumbed to misadventure and were found in water ways, appearing to have been washed downstream in heavy rain events. Four bulls were mistakenly shot by recreational hunters who were unaware that the animals were wearing a collar. The fate of the other bulls is unknown due to the ending of their collar battery life. Due to the cost of monitoring, only infrequent checking of locations occurred resulting in no standardisation in data received, or reliability in analyses. Many previous studies of elk movements overseas have also relied on very high frequency (VHF) telemetry (Craighead *et al.*, 1973, Witmer & deCalesta 1983, Green & Bear 1990, McCorquodale 2003). More recent studies have used GPS technology (Moeller 2010, Cleveland *et al.*, 2012, Starr 2013), allowing for predetermined fix rates and lowered labour intensiveness. It was decided, as a result of the failure of VHF methods, that future location studies should use GPS collars with data upload capabilities.

1.3 Home Range and Wapiti

The home range is a term used to describe the area in which an animal uses for all of its living functions. There has been much study with regard to trying to understand home ranges and their drivers with a particular interest in attempting to quantify the area used by animals (Jennrich & Turner 1969, Anderson 1982, Pepin *et al.*, 2004). There have also been increasing amounts of study on home ranges of North American elk over the last 50 years (Toweill & Thomas 2002). There has, however, been no research on wapiti home ranges in Fiordland as this study is the first of its type in New Zealand. The limited amount of study on wapiti in New Zealand has focused on population density (Nugent *et al.*, 1987), impacts on vegetation (Rose & Platt 1987, Stewart *et al.*, 1987), numbers shot (Nugent 1992) and to a lesser degree, diets (Poole 1951). This is possibly because all species of deer are introduced and have been managed as invasive species (Latham *et al.*, 2014). This will soon change, however, with the induction of the New Zealand Game Animal Council (Game Animal Council Act 2013) and the reclassification of wapiti in Fiordland as a “Herd of Special Interest”. Accordingly, the findings of this study will be of benefit to both the FWF and the New Zealand Game Council. It is possible that due to similarities between wapiti and red deer, and the crossbred nature of the Fiordland wapiti herd, range use may be similar between the two species.

1.4 Chapter summary

Chapter 2: Literature Review

To study wapiti in New Zealand, a literature review is first provided of the previous studies on wapiti and deer ranging behaviour overseas, ending with the specific research questions for this dissertation.

Chapter 3: Material and Methods

Chapter three provides a general description of the study area with an in-depth explanation of how this study was carried out, both physically and analytically. It also includes reasoning as to why certain methods were selected along with some of the limitations.

Chapter 4: Results

Chapter four provides all the results taken from this study, with a brief explanation of what can be seen in each figure, table or plate.

Chapter 5: Discussion

Chapter five explains why the results were observed using definitive reasoning behind the drivers of wapiti ranging behaviour. This chapter also discusses the limitations of this study and subsequent suggestions for future improvement of wapiti location studies.

Chapter 2

Literature Review

2.1 Summary

The objectives of this review are to evaluate home ranges and some of their key drivers in elk and deer in North America, Asia, Australia and Europe. Literature suggests that home ranges of cervids are at their greatest during winter seasons when forage production drops, due to low soil temperatures and snow cover, limiting plant biomass and access to forage. A key parameter toward home range is daily movement, literature has shown daily movement to be maximised during winter as animals travel further to find patches of sufficient forage density. Habitat selection is also forage driven with animals preferring areas close to the edge of forests where food availability is maximised.

2.2 Introduction

Literature on ranging of elk in North America and of red deer in Australia, Asia and Europe was reviewed to identify home ranges and habitat selection across seasons, with particular focus on winter as this was when we studied animals in Fiordland. The elk studied elsewhere were predominantly larger of body than those in this experiment, as they were of pure North American elk genetics whilst those in the Fiordland herd are of a smaller bodied cross-bred nature. This may result in a significant difference between results observed here and in North America but, this provides the only viable means for cross comparison with movements of other wapiti. The animals in this study were more comparable in size to red deer studied elsewhere. Comparison of home ranges is difficult between studies due to heterogeneity between sites and the selection of differing home range estimation methods. The information compiled within this literature review may be of further use to the Fiordland Wapiti Foundation in gaining a better understanding of what factors drive ranging in wapiti and how habitat is utilised.

Winter ranging in North American elk is determined by the animal's ability to satisfy nutritional requirements whilst being heavily influenced by snow cover. It is expected that wapiti ranging in Fiordland will be determined by similar, yet slightly different, factors when compared with elk in North America. This is because, there are certain pressures present in North America that are absent in New Zealand such as predation by animals, danger from roads, human presence year-round and residential/farming expansion. Ungulate habitat selection is a function of the interrelationships of behavioural and environmental variables which, in turn, differ from one population to another (Peek et al. 1982). This suggests that, although different populations may have similar home range

drivers, the parameters contributing to behaviour will vary on a case by case basis, limiting the validity of cross-referencing between populations.

Home ranges of wapiti bulls and red deer stags are generally larger than cows or hinds. This may be due to females requiring a range that only provides resources necessary for raising young whilst males require a large range to facilitate finding as many breeding females as possible. Annual home ranges of North American elk are larger than those of red deer studied elsewhere. This is likely the result of climate-induced migration in North America whilst in Australia, China and Europe, where red deer home ranges have been studied, large-scale movement is less common.

2.3 Body of Review

2.3.1 Home range

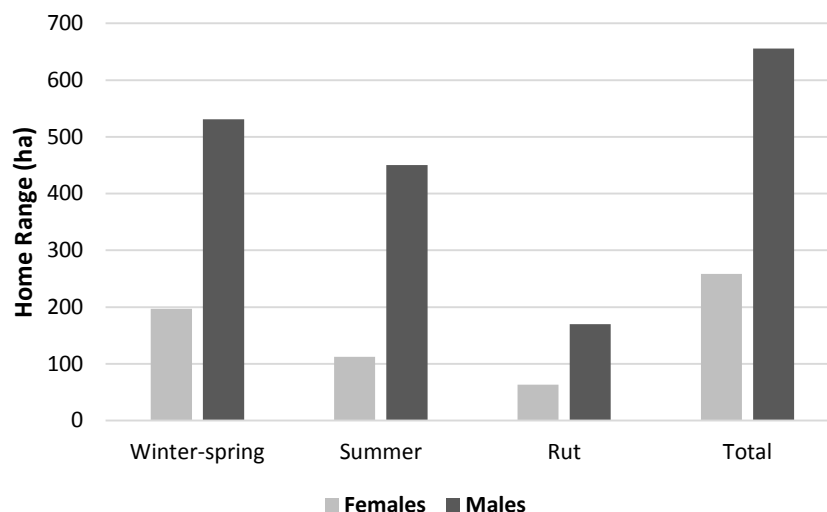
Ungulate home ranges are often greatest during winter, this is likely to be a result of reduced resource availability. During this period low soil temperatures reduce net primary production (McLaren & Cameron 1996) and snow cover reduces the availability of forage species in open habitats. Forage density will dictate how far an animal needs to travel in order meet its daily foraging needs. Elk home ranges show little variation in the proportion classified as forage even though there may be a wide range of home range sizes (Jones & Hudson 2002). This suggests that forage may be an important factor in determining home range size and location. As forage production is limited during winter months elk may move more to find areas of sufficient forage biomass, thus increasing the total area utilised. Wickstrom *et al.*, (1984) found that elk were reluctant to expend feeding effort in grass swards of low biomass regardless of digestibility. This would mean that the effect of low forage availability on travel would be amplified during winter as wapiti would increasingly reject patches of low forage biomass. The concept mentioned for Wickstrom *et al.*, (1984), above, is known as the forage density threshold. This concept has been analysed, and is thought to be a major factor in forage selection, but limited knowledge on this topic means that no “set values” have been identified for deer (Focardi *et al.*, 1996). Anderson *et al.*, (2005) reported large (>2000 ha) home ranges in elk across three sites in North America during winter. The sizes of home ranges in this study were highly variable both within and between sites which is likely a result of the different suitability of each environment to ungulate life.

Table 1: Elk winter home range sizes in hectares across three North American sites.

Site	N	Winter home range size (ha)		
		Mean	Minimum	Maximum
Alberta	9	10104	2713	22927
Wisconsin	11	2841	1415	7893
Yellowstone	24	17974	2181	43973

Sourced from Anderson *et al.*, (2005)

Observations of Anderson *et al.*, (2005) are similar to those of Carranza *et al.*, (1991) who showed that red deer (*Cervus elaphus*) home ranges in Spain were 100-350 ha larger during winter-spring when compared to summer or rut periods. Carranza *et al.*, observed home ranges often ten times smaller in red deer than Anderson *et al.*, (2005) when observing elk. Carranza *et al.* (1991) reported home ranges of around only 250 ha with high densities between 0.5-1 deer/ha. Smaller home ranges might be reflective of superior suitability of environments for ungulates, especially where high animal densities are observed within a population. This may be the case when comparing home ranges of ungulates at different latitudes, which was a key difference between Anderson *et al.*, (2005) and Carranza *et al.*, (1991). Red deer, in the Spanish study, were exposed to a Mediterranean climate whilst elk, in the North American study, were exposed to a more temperate continental climate. A milder climate would result in less harsh fluctuations in temperature across seasons and result in superior living conditions.

**Figure 1: Home ranges of red deer hinds compared to stags in Spain during one year. Sourced from Carranza *et al.*, (1991).**

The findings of Carranza *et al.*, (1991) are supported by those of Bocci *et al.*, (2010) who observed winter home ranges were 70.5% larger, on average, than summer ranges for resident red deer in the Swiss Alps, from 2002-2004, see Table 2. This study also observed that the summer home range was 65.5% larger than winter range during 2004. This may be a result of the mild winter experienced that

year followed by a dry summer. Mild winters with less snowfall allow above-average plant growth and therefore forage biomass resulting in animals having to travel less to find sufficient feed. Mild winters are also followed by dryer summers resulting in reduced plant growth which may result in a feed deficit causing animals to travel further to meet intake demands.

Table 2: Home range sizes (ha) of radio-tagged resident red deer hinds in the Swiss Alps.

Year	N	Annual		Winter		Summer	
		Median	Range	Median	Range	Median	Range
2002	5	189	99-379	134	102-189	78	30-469
2003	3	137	64-593	148	100-242	53	30-98
2004	6	212	74-471	58	35-190	96	56-319

Sourced from Bocci *et al.* (2010)

The results of Bocci *et al.*, (2010) were similar to Amos *et al.* (2014) where it was observed that home ranges of red deer in Southern Queensland, Australia, were greater in winter than summer or the rut. Amos *et al.*, (2014) also observed that home ranges of males were greater than females. This difference was only statistically significant during 2011-2012, when home ranges were smaller overall. This may be due to different requirements for resources by the different sexes within their home ranges. Home ranges of female ungulates typically encompass the area required to feed and raise young, whilst home ranges of male ungulates encompass an area required to feed and find as many breeding females as possible. Male cervids also typically remove themselves from female home ranges outside of the breeding season, whilst resident females can utilise much of the same home range year-round. This is likely the case in this study. 2011-2012 were highly productive years so high forage biomass would have meant that excessive travel was not required to find food. As a result sexual differences in ranging would have been more pronounced during this time as the travel of hinds would have dropped whilst stags would still be protecting their territories, even though travel to find feed was reduced.

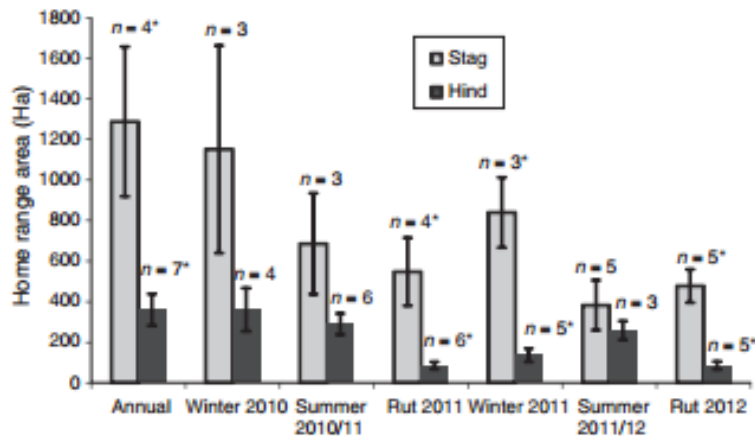


Figure 2: Mean annual and seasonal home ranges (95% local convex hull, LoCoH) of red deer, showing number of individuals and standard error at Cressbrook Dam Reserve, south-eastern Queensland, 2010-2013. * indicates a pair where males and females were significantly different from each other using a two-sample t-test for unequal variance. Sourced from Amos *et al.*, (2014).

Stags have larger home ranges than hinds during summer, autumn and winter in temperate old growth forest, dominated by spruce (*Picea abies*), in Poland. The results of Amos *et al.* (2014) were similar to those produced by Kamler *et al.* (2008). Results from this study were however, contradictory to those of Bocci *et al.*, (2010) and Amos *et al.*, (2014) where the home ranges of stags were greatest during autumn followed by summer and then winter. This is a result of sexual behaviour during the autumn rutting period. During the rut stags increase their activity to defend territories and travel greater distances to find breeding females for harem formation. Results from this study show that autumn home ranges of stags were 78% larger, on average, than during summer or winter.

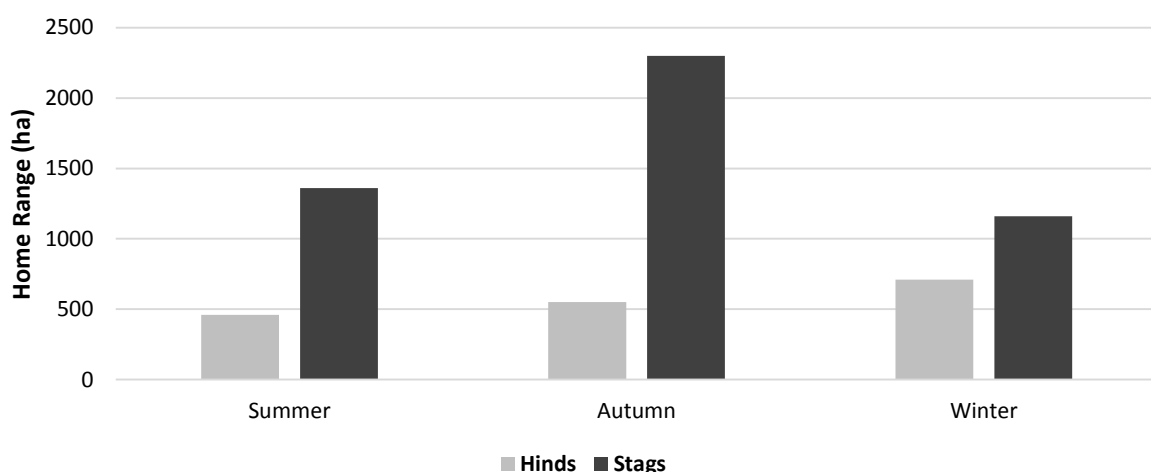


Figure 3: Home ranges of red deer hinds compared to stags in temperate old growth forest of Poland during one year. Sourced from Kamler *et al.*, (2008).

Results of Carranza *et al.*, (1991), Kamler *et al.*, (2008) and Amos *et al.*, (2014) were all inconsistent with those produced by McCorquodale (2003) who found that elk cows had greater annual home ranges when compared with adult and sub adult bulls, however, this difference was only observed when home ranges were measured using 90% adaptive kernel (ADK) estimates. This study also showed that ADKs were consistently larger for all animals when compared with MCPs. Kernel methods result in overestimation of home ranges however, overestimation is less significant when compared to other methods such as MCPs in most cases. Overestimation of home ranges by kernel methods is likely when incorrect models are selected for home ranges estimation (Amos *et al.*, 2014). Seasonal migration of elk is common in North America, where animals travel between seasonal ranges to meet nutritional requirements. Many have assumed that male elk migrate to winter range later than females, and only when deep snow forces them to abandon summer ranges (Murie 1951, Adams 1982). This indicates that bull elk may be able to tolerate harsher winter weather than cows. Bull elk are 40% larger than cows, at maturity, meaning they have a lower surface area:mass ratio which is a key parameter in cold tolerance. The larger frame of bull elk also gives them greater strength and length of leg so they can travel through deeper snow with greater ease. If elk home ranges were measured during a winter period where cows had begun to migrate but bulls were still in residency then home ranges of cows could be observed to be larger than that of bulls. This study also found that home ranges of sub-adult bulls were generally greater than adult bulls or cows. After weaning, juvenile males will travel large distances to establish new territories. During this time they will be driven from areas by older resident bulls, thus increasing their ranging to a more 'nomadic' behaviour (Toweill & Thomas 2002). This study showed sub-adult bulls to have 35% larger winter home ranges, on average, when compared to adult bulls.

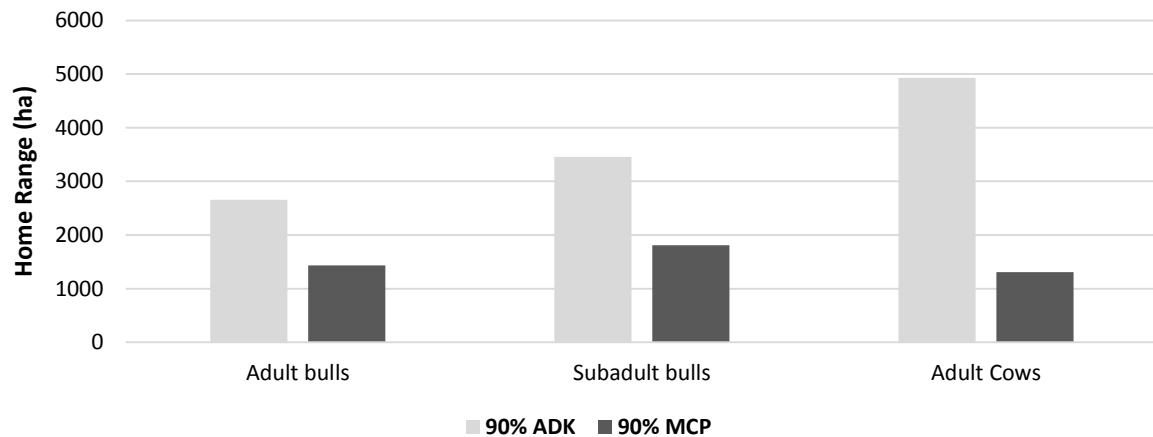


Figure 4: Winter home-range estimates (ha) for radiomarked adult (>5 yr) and subadult (<4 yr) male elk and adult female elk in the Cascade Range of south-central Washington, USA, 1992-1999. Home ranges were estimated using 90% adaptive kernel estimates and 90% minimum convex polygons (MCP). Adapted from McCorquodale (2003).

Observations of Kamler *et al.*, (2008) were similar to those of Luccarini *et al.*, (2006) who showed that home ranges were smaller during winter when compared with all other seasons for red deer in the Italian Alps (see Figure 5). Results from Luccarini *et al.*, (2006) also showed that home ranges estimated using MCPs were larger than when estimated using KDEs. This is because MCPs are a general technique that creates a simple polygon based on the outermost locations in a data set. KDEs are a more precise form of home range estimator which not only take into account the areas where locations occurred but also the areas where locations did not occur, thus limiting the overestimation of home range. MCPs will therefore, in theory, estimate larger home ranges when compared with KDEs.

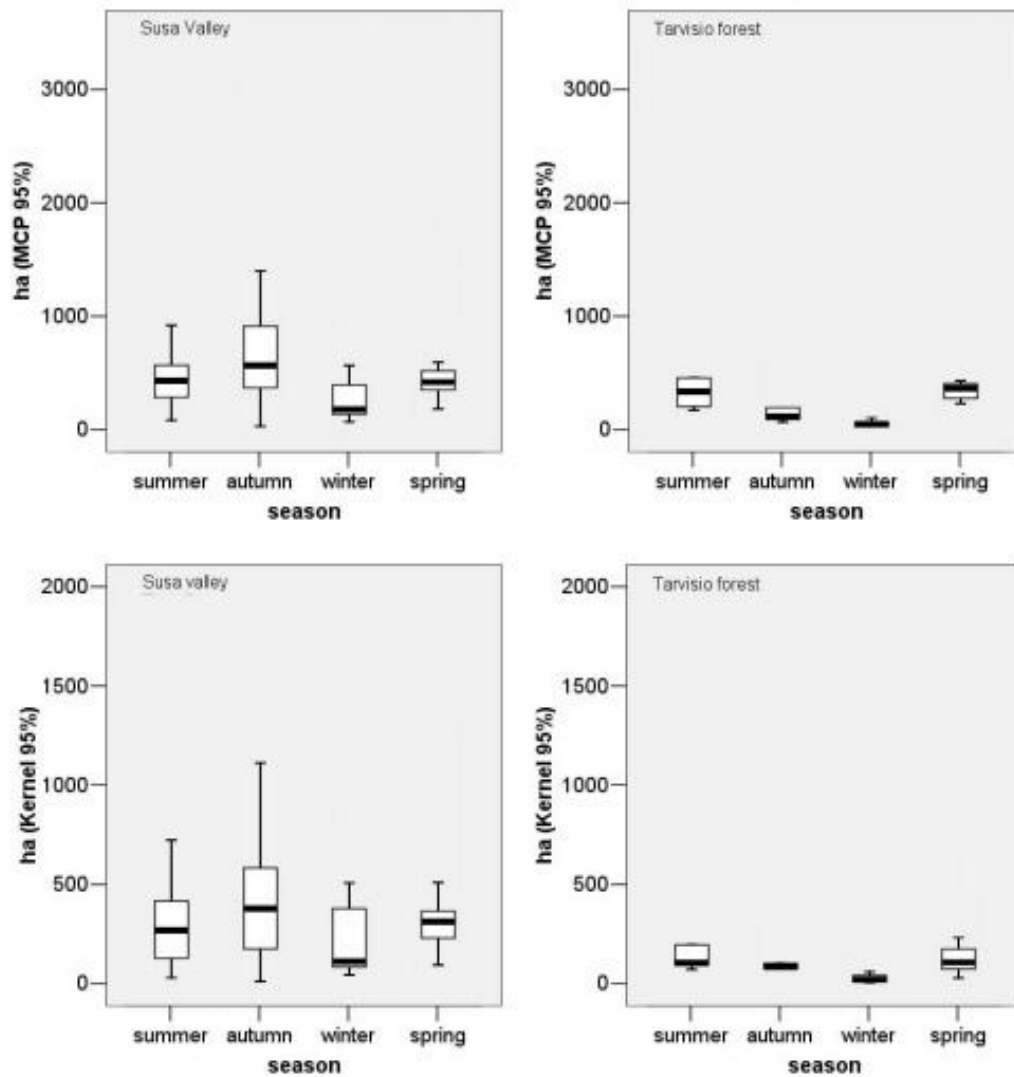


Figure 5: Seasonal home range sizes of red deer recorded in the Susa valley (left side) and Tarvisio forest (right side), Italian Alps, evaluated using both MCP 95% (above) and Kernel 95% (below). Sourced from Luccarini *et al.*, (2006).

Studies have suggested that MCPs have no place in modern home range studies. This is because MCPs have a high level of fluctuation in providing accurate estimations. The MCP method is the oldest method that has been commonly used in home range studies (White and Garrott 1990). As the MCP has been significantly present in the history of home range estimation, the continued use of this method will allow cross-comparison with historical observations. It may therefore be beneficial to calculate home range size using both MCPs and more descriptive methods such as KDEs, as was carried out by Amos *et al.*, (2014). Findings of Luccarini *et al.*, (2006) were similar to those of Amos *et al.*, (2014) who found that 95% MCPs estimated annual home ranges of red deer 112% larger than when estimated using 80% kernels, refer to table 3.

Table 3: Home-range data from wild red deer collared at Cressbrook Dam Reserve, south-eastern Queensland for ~1 year or more between March 2010 and March 2013 Mean area, s.e. and/or a range for three annual home-range estimators and one overall estimator are given. Kernel, kernel utilisation distribution, MCP, minimum convex polygon.

	Hind	Stag
N	7	4
Number Months Collared	17.2 (11.9-21.4)	15.7 (11.5-22.7)
Annual Home Range (ha) (95% MCP)	682 (274-1372)	6018 (1192-15799)
Annual Home Range (ha) (80% Kernal)	314 (147-769)	2898 (620-8422)

Sourced from Amos et al., (2014)

As previously discussed the MCP continues to be used although less frequently, in modern science, refer to Table 4 below. Home ranges are likely to be greatest for North American elk which carry out seasonal migrations. This is because migratory elk change home ranges to match seasonal climates and forage availability. North American elk will migrate up to 150 km (Vore 1990) and in doing so vastly increase annual home range size. This also suggests that seasonal home ranges of elk would be greatest during autumn/winter when climate began to trigger large-scale movement. Results of Moeller (2010) showed annual home ranges, estimated using MCPs, were 4924 ha greater, on average, for migratory elk when compared to non-migratory elk from 2004-2008.

Table 4: Minimum Convex Polygon (MCP) home range estimates for migratory and non-migratory elk for years 2004 – 2008 and life home range comparisons for Western Washington elk in the upper Cowlitz River valley.

Year	Mean MCP Area (ha)		Difference (ha)
	Non-migratory	Migratory	
2004	840 (N=3)	5800 (N=14)	4960
2005	540 (N=7)	5400 (N=15)	4860
2006	1100 (N=5)	5400 (N=23)	4300
2007	1100 (N=8)	5500 (N=27)	4400
2008	1400 (N=8)	7500 (N=24)	6100
Mean	996	5920	4924

Sourced from Moeller (2010).

In conclusion elk and deer home ranges vary between countries and study areas, possibly as a result of the different qualities of each habitat. Home ranges are difficult to compare between studies due to inconsistency in habitat quality, sampling regime and method of estimation. Seasonal home range is likely to be greatest during winter when forage availability is limited resulting in greater travel.

2.3.2 Habitat selection

Elk habitat use is conditioned by topography, weather, cover, the need to avoid predators, biting insects and hunters, and biological factors-such as forage quality and cover quantity. Habitat use is also a characteristic of its availability (Hobbs & Hanley 1990), thus habitat selection is largely based on the habitat composition of an environment. Studies of elk habitat selection have shown a preference for open areas that are close to forests. This is likely a result of preference for areas that have a high forage availability whilst also allowing hiding cover and escape routes. Findings of Craighead *et al.*, (1973) show that open areas, such as marsh and meadow, are important for feeding whilst closed canopy forest is more important for bedding, refer to table 5. This is because open areas on the forest/field border have highest plant diversity and therefore production. This means that elk can attain a high intake of preferred plant species whilst reducing energetic costs of travel. The preferential use of lodgepole pine (*Pinus contorta*) forest for bedding is most likely due to this habitat type providing sufficient hiding cover. Elk prefer to bed in areas where hiding cover reduces the risk of detection by predators. Forest areas also allow for fast travel through the landscape and escape routes from predators. Forested areas may represent a significant amount of selected habitat in elk (Craighead *et al.*, 1973); however, forested areas often make up a large proportion of elk study areas and are thus reflected as a large proportion of the area utilised.

Table 5: Winter Feeding and Bedding activity of elk related to habitat, taken from 24 hour activity.

	Percentage of time habitat was utilised				Total hours observed
	Lodgepole Pine	Marsh	Thermal Areas	Meadows	
Feeding	33	48.4	18.6	NA	36.6
Bedding	50	32	18	NA	19.4

Sourced from Craighead *et al.*, (1973)

The results produced by Craighead *et al.*, (1973) were similar to those of Witmer & deCalesta (1983) who showed that cow elk selected highly ($E \approx 0.2-0.4$) for clear-cut areas. Elk selected for old growth forest less so; however, this forest type contributed to a large proportion of what was available (35-45% of total habitat) and was thus reflected in the habitat usage. In this study, mixed forests were completely avoided, this is because this was a rare feature (0-5% of total area) so observations in this habitat type were much less likely. This study showed significant variation in habitat preference between animals on northern and southern ranges. This highlights the complexity of habitat preference which is not solely driven by vegetation type.

Table 6: Winter habitat utilisation by cow elk, Coos County, Oregon 1978-79. Selection is measured by the proportion of habitat used/proportion of habitat available. Where -1 is completely avoided, 0 is no preference and 1 is highly preferred.

Cover type	Habitat Selection	
	Northern Range	Southern Range
Old Growth	-0.06	0.12
Mixed Forest	-	-1.00
Hardwood	-0.19	0.09
Sapling-pole	-1.00	-0.19
Brushy clear-cut	0.42	0.18
New clear-cut	-0.15	0.20

Adapted from Witmer & deCalesta (1983).

It has been shown that elk prefer “ecotone” habitats, at the interface between bush and open areas, where grazing availability is maximised. Studies in the Wasatch Mountains of Utah demonstrated that both frequency of plant species and herbage biomass at an edge was two times greater than 46 m into a meadow (Winn 1976). Levels of elk activity have also been known to decrease with increased distance from the interface of forest and non-forest communities (Marcum 1975, Winn 1976, Leckenby 1984). Knowles and Campbell (1982) also indicated that elk need security before feeding in an area, regardless of its grazing condition. The findings of Craighead *et al.*, (1973) and Witmer & deCalesta (1983) are both supported by those of Poole & Mowat (2005) who found that elk preferred non-forested stands and deciduous stands, to a lesser degree, over all other vegetation types and selected against logged areas and larch stands, refer to Figure 6. Elk selection for Douglas-fir (*Pseudotsuga menziesii*), pine (*Pinus spp.*), and cedar (*Cedrus spp.*)-hemlock (*Tsuga spp.*) stands was similar. Twenty nine percent of deer tracks and 33% of elk tracks were in areas with little canopy cover in late winter.

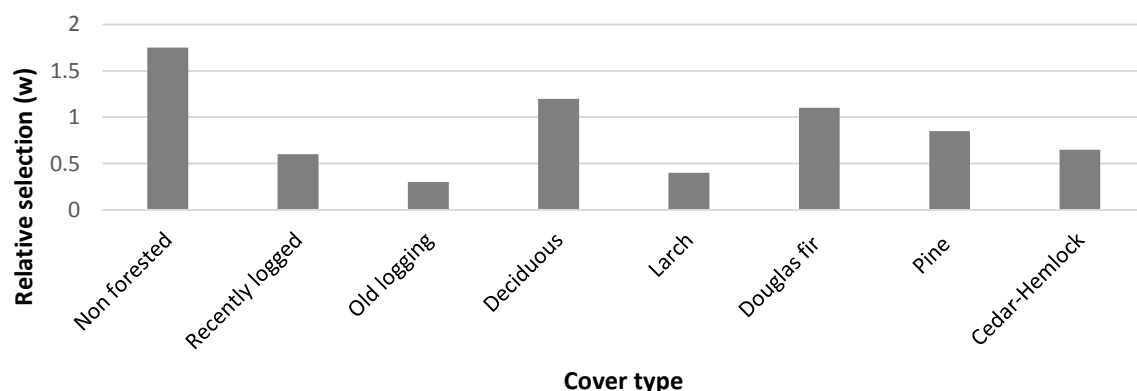


Figure 6: Selection for cover types (see text for description) during late winter by deer (white-tailed and mule deer combined) and elk in southeastern British Columbia, 2000-2002. Selection (w) is measured as proportion used/proportion available. Sourced from Poole & Mowat (2005).

It is important to note that when evaluating habitat selection by the proportion of what is used compared to the proportion of what is available the informative capabilities of the analysis are limited. These analyses estimate habitat selection in the third order which is just the proportional use. It does not take into account how an animal selects between the resources in its environment, which is known as the second order. As an animal's actual preference for different resources cannot be estimated simply from the resources it used, third-order selection estimates are limited. Results of Poole & Mowat (2005) were similar to Beck *et al.*, (2013) which showed a partial preference for sagebrush (*Artemisia spp.*)-meadows during winter, see Figure 7. This study also showed no preference for other habitats. Habitat use by elk during winter was also proportional to the availability of the habitat within the environment.

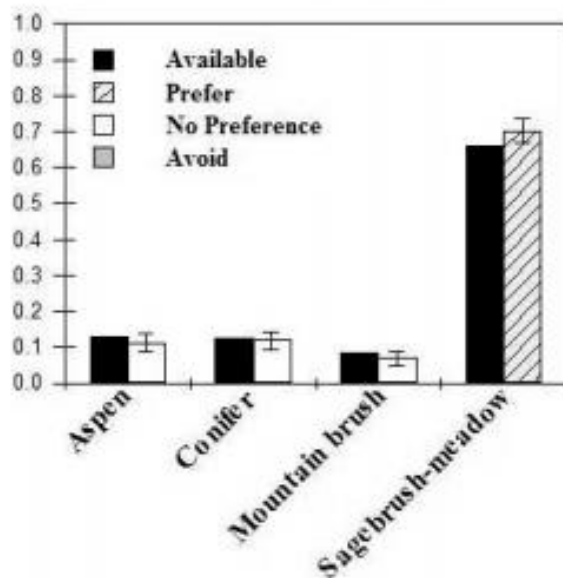


Figure 7: Proportions of aspen, conifer, mountain brush, and sagebrush-meadow cover types at elk-used and available locations during winter in north central Utah, USA, 1993–1997. Error bars depict Bailey's 95% confidence intervals estimating preference, use proportional to availability, and avoidance of different habitat types by season. Sourced from Beck *et al.*, (2013).

Results of Poole & Mowat (2005) are contradictory to those of Zhang *et al.*, (2013) who showed that red deer (*C. elaphus alxaicus*) utilised areas of greater hiding cover at the greatest intensity during winter. This may be a result of the arid climate and harsh winter of the Helan Mountain region where this study took place. In such a climate, selection for the closed canopies of cold evergreen coniferous forest dominated by *Picea crassifolia* may allow for avoidance of travel through deep snow and even superior access to some forms of forage. This study also found that deer preferred areas of low canopy cover at the greatest intensity during summer. Human disturbance in this region has been minimal

since the 1970's when this area became a state nature reserve (Jiang *et al.*, 2007). This would suggest that open areas of higher forage production could be utilised without the disturbance of hunting or logging.

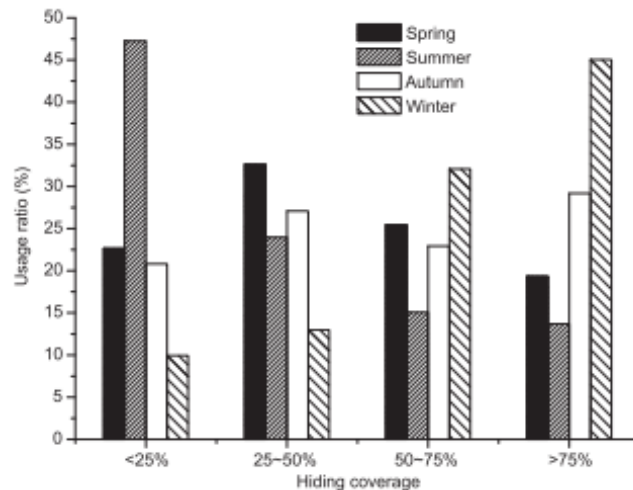


Figure 8: Seasonal changes in the usage ratio of hiding coverage of red deer in the Helan Mountain region, China. Sourced from Zhang *et al.*, (2013).

Elk may select for areas of low to moderate human modification even when natural habitats are available. This is because developing areas located in elk territory are often in the early stages of encroaching on routes of heavy travel and areas of importance. Elk presence is often reduced after human encroachment has become severe enough to substantially modify the natural environment. Elk also exhibit a risk trade-off where they will expose themselves to greater levels of risk from one factor to reduce the risk of another (Toweill & Thomas 2002). Elk have been shown to move closer to developed areas when wolf numbers are high. In doing this they increase their exposure to humans but reduce their exposure to wolves which are less present around human settlements. Starr (2013) showed that elk utilised low to moderately developed areas at a disproportionately high rate when compared to the availability of these habitat types within the landscape, see Figure 9. Results from this study were also consistent with findings of Craighead *et al.*, (1973), where forests accounted for a large proportion of habitat use, followed by open areas. This supports the theory that forest and open areas, together, are important within the lives of elk.

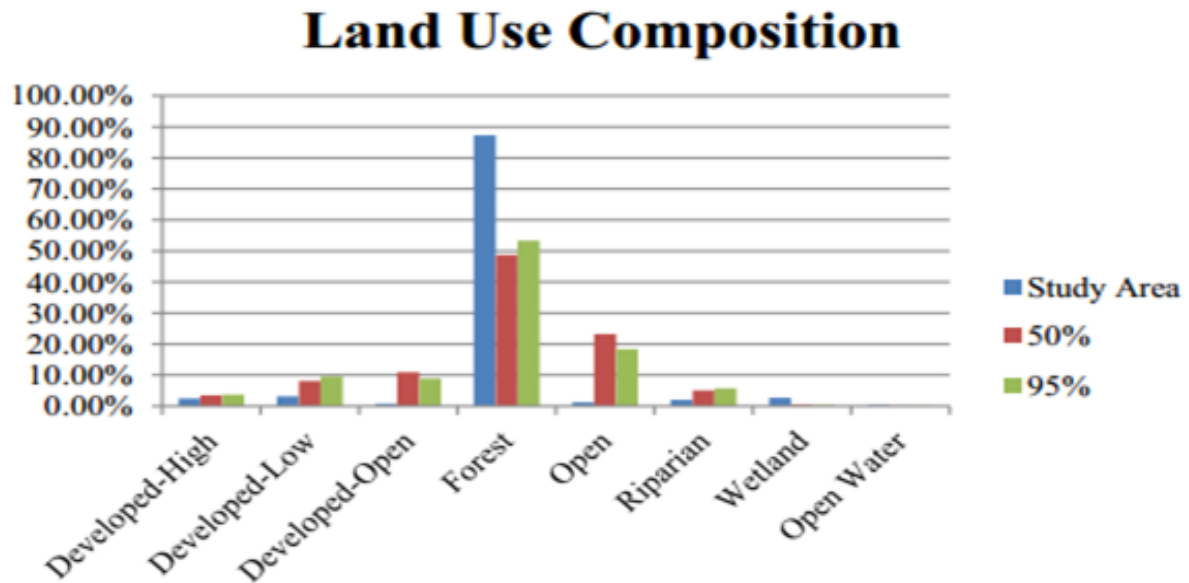


Figure 9: Composition of land use by elk within a 363 km² study area in Washington State, US. Sourced from Starr (2013).

In conclusion it can be seen that during winter elk prefer habitat close to the forest/field interface where plant diversity and production is greatest and proximity to hiding cover allows for escape. Forest areas may also provide a valuable habitat type for bedding, which requires hiding cover, and facilitate travel across the landscape.

2.3.3 Habitat selection and snow cover

It has been hypothesised that elk select for forest with closed canopies to reduce heat loss during winter (Sweeney & Sweeney 1984). Peek & Scott (1985) contradicted this suggesting that thermal cover would have an insignificant effect on energy requirements. They concluded that security cover was important in the presence of human disturbance (Peek & Scott 1985). In Western Alberta, Morgantini & Hudson (1979) concluded that habitat selection by elk in winter was not a response to thermal environment, but governed by human disturbance. Results of Jones & Hudson (2002) suggest that elk did not select for thermal cover requirements at any scale.

Cook *et al.*, (1998) found there was no difference ($P > 0.05$) in weight loss as water, fat or protein by yearling elk kept in four types of thermal cover during winter. This is because elk are ruminants, animals with four-chambered stomachs, and produce heat through the process of digestion. So long as elk receive sufficient feed, thermoregulation can continue as heat is being produced from rumination. This study found that higher amounts of fat were lost when compared with water and protein during thermal cover treatment. This is because during winter fat acts as a reserve to supplement energy production as low plant growth and forage availability can result in feed

deficit. It is therefore concluded that elk select areas with snow depths based on energetics of movement and forage availability.

Table 7: Average change in amount of water, fat and protein content of the ingesta-free body of yearling elk in the winters of 1992-93 and 1994-5 in northeastern Oregon.

Component	Thermal cover treatment				P
	Zero	Moderate	Dense	Combination	
Water (kg)	0.7	0.15	-1.1	-0.4	NS
Fat (kg)	-5.35	-6.4	-9.7	-7.6	NS
Protein (kg)	-0.9	-1.2	-2.2	-1.6	NS

Sourced from Cook *et al.*, (1998)

Snow depth and cover, and not elevation, appear to govern distribution of elk on winter ranges (Adams 1982, Boyce 1991). Elk move to satiate dietary requirements and will therefore move to areas where snow cover does not limit access to forage. Messer *et al.*, (2008) found forage to be a fundamental resource required by elk during winter whilst the fundamental constraint was snow pack which, reduced availability of forage and elevated the energetic cost of acquiring forage. The energetic costs of travel in snow for mule deer (*Odocoileus hemionus*) and elk are influenced by the velocity at which the animal travels, the depth to which it sinks, and the density of the snow (Parker *et al.*, 1984). Heavier snow presumably inhibits locomotion by increasing drag on the legs or body (Coady 1974) and may also reduce the capability of the animal to travel by wading, as in powdery snow, and necessitate lifting the legs to higher levels (Parker *et al.*, 1984), increasing energy use. Serrouya & D'Eon (2002) stated that elk avoid areas with snow depths >75 cm as they were unable to find any elk tracks in snow at this depth during an ungulate tracking study. Sweeney & Sweeney (1984) observed that elk used areas of lower snow depth (<40 cm) 81% of the time during winter. This study also observed 20% of elk in using snow depth greater than 70 cm. This was due to observations taking place the day after heavy blizzards which meant animals had not had enough time to move to areas of lower snow depth.

Table 8: Proportions of elk use of areas with different snow depths, as assessed during 19 flights over Missionary Ridge, Colorado, during three years.

Date	N elk sighted	Snow Depth					
		<40 cm		40-70 cm		>70 cm	
		% area	% elk	% area	% elk	% area	% elk
1971-72	300	57	97	23	2	20	1
1972-73	295	28	64	22	15	50	21
1973-74	376	62	81	25	19	13	0
Total	971	49	81	23	13	28	6

Sourced from Sweeney & Sweeney (1984)

The results of Sweeney & Sweeney (1984) are supported by later findings of The Ungulate Technical Advisory Team (2005) who showed that elk movement was impaired in snow depths of 40-70 cm and critically restricted above 70 cm. Kelsall (1969) observed snow depths in excess of two-thirds of chest height resulted in severe movement restriction of moose and white-tailed deer. This suggests that chest height plays a large part in ungulate movement through snow. Elk chest height is estimated at around 85 cm (Telfer and Kelsall, 1984), thus elk movement is likely to be severely restricted in snow depth above c. 56 cm. As movement is impaired in snow depths above the threshold level it is expected that elk will move to areas of lower snow depth to conserve energy. Studies investigating the distribution of ungulates in relation to snow pack have been limited by a lack of fine-scale metrics to characterize dynamic spatial and temporal changes in snow pack across the landscape (Messer *et al.* 2008).

Table 9: Implications of different snow depths for mobility of ungulate species.

	Species and Snow Depth Limit (cm)		
	Deer	Elk	Moose
Nominal: snow does not inhibit movements	<25	<40	<60
Inhibiting: snow deep enough to inhibit movements	25–50	40–70	60–90
Critical: snow deep enough to severely restrict movements	>50	>70	>90

Sourced from Ungulate winter range technical advisory team (2005).

In conclusion it can be seen that the snow cover not only limits travel by wapiti but also access to forage plants. It can be seen that forested areas may have little effect on habitat choice by elk for thermal cover however, wapiti may use forest more to avoid travel through deep snow during winter months. It is likely that wapiti in New Zealand will also avoid travel through areas with deep snow as Fiordland is subject to harsh winters.

2.3.4 Daily Movement

As previously shown, ranging by elk and deer increases in winter as forage biomass is reduced. This is likely to be reflected in the distance of daily travel. Craighead *et al.*, (1973) reported daily travel of 4.15 km by cow elk during October, this was 69% higher than the prior measurement in August. The positive trend in the graph suggests that daily travel would continue to increase, reaching a peak in winter, December-January, see Figure 10. It is likely that increases in movement were a result of reduced forage availability towards autumn and winter. A reduction in daily movement would be expected in cows during the rut as bulls regulate the movement of their harem through herding. As

cows were being measured in this experiment, the increase in movement is likely to also be a result of harem breakup and increased movement. Location studies such as this risk creating bias within results when low sample sizes (≤ 5 days/month) are used. This study, unfortunately, did not measure distance travelled by elk during the peak of winter.

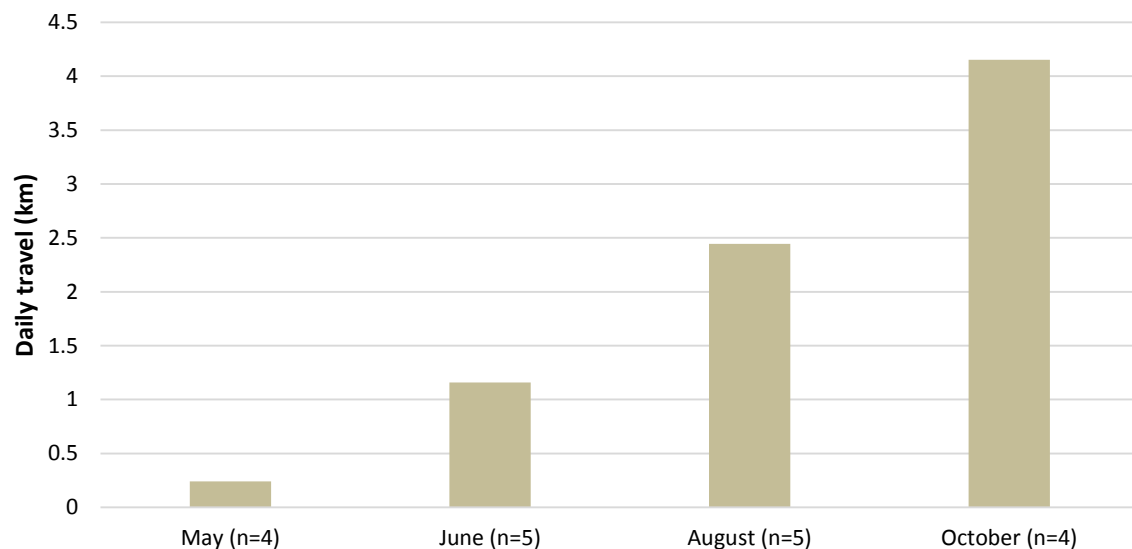


Figure 10: Daily Movements of elk related to time of year in Yellowstone National Park, 1965. Where n is the number of days where daily travel was observed. Sourced from Craighead *et al.*, (1973).

Results of Craighead *et al.*, (1973) are contradictory to those of Carranza *et al.*, (1991) who showed no significant difference in daily movements between winter-spring and summer, as seen in Figure 11 below. This may be a result of the habitat in the study of Carranza *et al.*, (1991) being superior to that of Craighead *et al.*, (1973). As previously mentioned, habitats complimentary to the requirements of ungulates may reduce the requirement travel, e.g. higher forage production, would reduce the effects of seasonal fluctuations on forage availability and the requirement to travel to seek food.

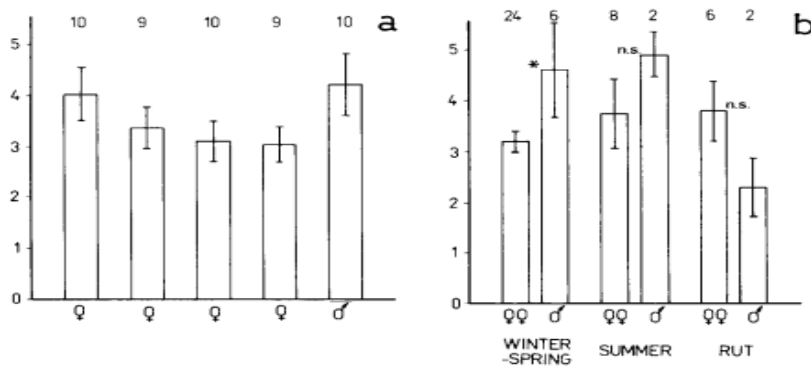


Figure 11; Daily movements (km) of red deer during the year (a) and (b) comparing a male with females, for each season. * indicates a significant difference. Sample size (number of complete 24-h cycles) is indicated above the bars. Sourced from Carranza *et al.*, (1991).

Observations of Carranza *et al.*, (1991) are not supported by those of Amos *et al.*, (2014) who observed 14% greater daily travel by red deer hinds when compared with stags in winter-spring. This may be the result of increasing feed demands by hinds in late pregnancy or post-parturition. During late pregnancy and the course of lactation the energy requirements of hinds increase to produce milk for the fawn. An 80 kg red deer hind at peak lactation requires 32.4 MJME/day which is greater than the maintenance requirement of a typical 150 kg red deer stag at only 24.4 MJME/day (Adam *et al.*, 1996). In this case a hind would be required to consume an extra kilogram of dry matter above the requirement of a stag in order to maintain production if forage quality was 8 MJME/kg DM. If forage availability was limited then the hind may be forced to travel further than the stag to attain the extra feed requirement. It is therefore possible that movements of wapiti cows in Fiordland may increase in the winter/spring months when energy requirements are increasing.

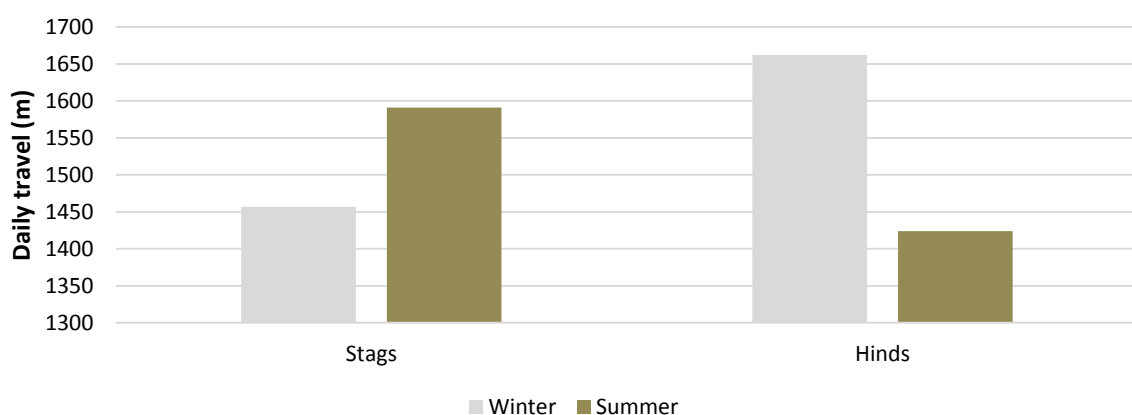


Figure 12: Mean daily distance travelled by red deer during winter and summer at Cressbrook Dam Reserve, south-eastern Queensland between March 2010 and March 2013. Adapted from Amos *et al.*, (2014).

Interestingly, daily travel does not only fluctuate throughout the year but also throughout the day. Most deer populations have been shown to be crepuscular, most active during dawn and dusk. Elk demonstrate peaks in feeding at sunrise and sunset, with more feeding at night during winter than summer (Green & Bear 1990). This is because sunrise and sunset provide optimum foraging times when sunlight is limited, thus reducing risk of exposure to predators. Ager *et al.*, (2003) observed greater velocity and more intense diurnal fluctuations in movement of elk when compared to white-tailed deer (*Odocoileus virginianus*). This is due to the large size of elk, which need to move at a greater rate to consume a larger volume of feed to meet their intake requirements. Based on the findings of Bronson *et al.*, (2005) maintenance requirements of elk are c.36 MJME/day whilst requirements of white-tailed deer are c.10 MJME/day.

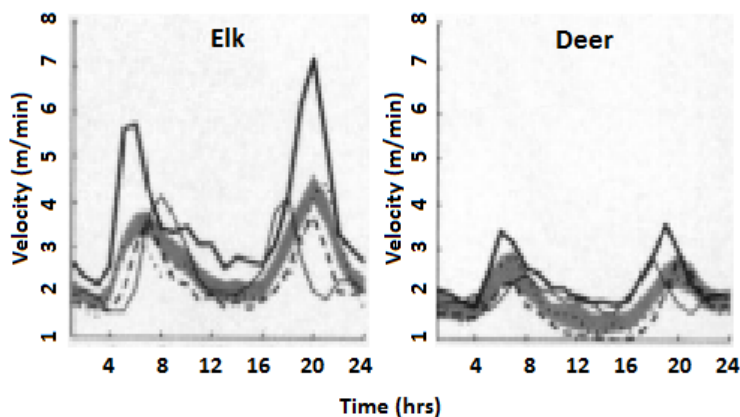


Figure 13: Mean velocity of elk and deer by hour-month intervals. Heavy line = April 15-May 14, dotted line = June 15-July 14, dashed line = August 15-September 14, thin line = October 15-November 14, grey band = 95% CI. Adapted from Ager *et al.*, (2003).

Similar results to Ager *et al.*, (2003) were produced by Amos *et al.*, (2014) who observed crepuscular peaks in the velocity of red deer. These were also contradictory to those in Figure 13, above, as activity peaks were most pronounced during winter rather than spring. This is a result of winter increasing the diurnal behaviour of ungulates. Both in Mediterranean and northern populations deer are more diurnal in winter (Clutton-Brock *et al.*, 1982, Carranza *et al.*, 1991). This is because during winter there are only two functions in ungulate habitat selection, the first being forage biomass and the second being predator avoidance. As forage production is lowest during winter it is expected that movement will be at its most extreme during active periods to maximise intake. It is also expected that to avoid predator detection animals will reduce their activity during at-risk times of day.

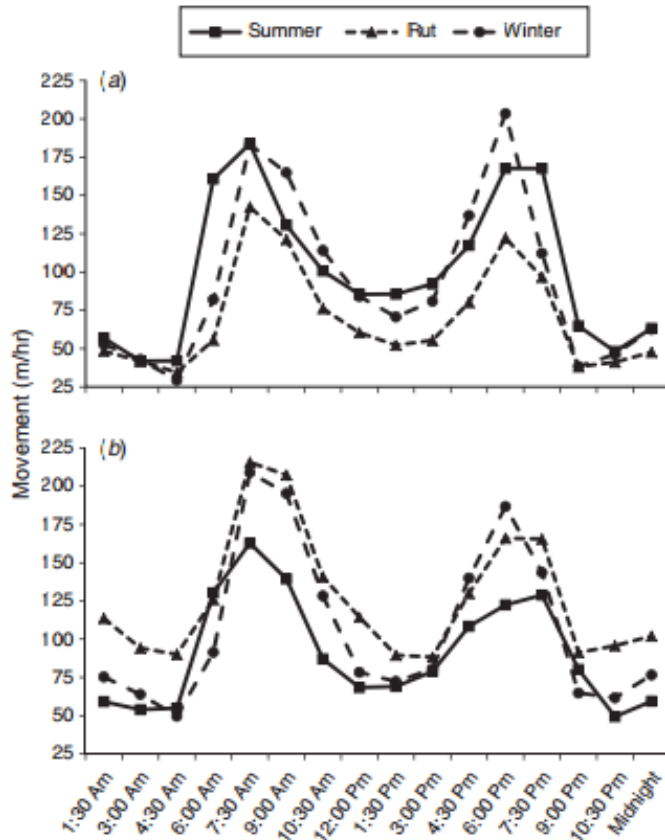


Figure 14: Mean daily movement of (a) wild red hinds and (b) stags for the summer, winter and rut seasons at Cressbrook Dam Reserve, south-eastern Queensland between March 2010 and March 2013. Sourced from Amos *et al.*, (2014).

In conclusion, it can be seen that elk and deer move greater distances throughout the day during winter as forage biomass is limited. Distance of movement may be reduced provided the environment produces sufficient forage. Distance travelled by bulls may be greatest during the autumn rut when defending territories and breeding females. Movement of female elk may significantly increase from winter through spring as energy requirements for pregnancy and lactation increase. These animals have also been shown to exhibit crepuscular activity, which is likely a predator avoidance strategy.

2.3.5 Conclusions and Implications

In conclusion, it can be seen that forage availability is a key driver of elk and deer ranging behaviour. During winter months movements and subsequently ranges may increase as plant growth is reduced, making sites of sufficient biomass harder to find. It can also be seen that elk prefer habitats close to the forest/field interface where plant diversity and production are highest and proximity to hiding cover is sufficient.

Observations from previous studies in North America, Europe, Asia and Australia varied significantly. This is likely driven by varying forage availabilities at the different areas studied. It is also likely driven by winter severity as snow cover limits access to forage and increases the energetic expense of travel. Other factors, including predation, hunting, interspecific and intraspecific competition and general human presence, will also fluctuate between studies and cause further variation in results.

None of these types of study have been carried out in New Zealand before, therefore it is difficult to make assumptions based on previous findings, knowing that pressures faced by individuals will differ between populations along with the habitats available to them. It is hypothesised that wapiti in Fiordland will exhibit significantly lower ranging when compared to elk and deer elsewhere as winters are less severe there, enabling increased plant growth. Animal densities are also lower in New Zealand, due to careful management, resulting in less direct competition for food.

It could be suggested that wapiti in Fiordland would prefer open habitats and venture further from the forest edge compared to animals elsewhere due to a lack of predators, apart from humans. This would however, not take into account the other benefits of staying close to the forest including maximising forage efficiency, near the forest edge, or the importance of bedding in areas that provide hiding cover. It is therefore hypothesised that wapiti in Fiordland will select habitats reflecting boundaries between forest and open areas, as has been shown elsewhere.

Dissertation Aims and objectives

This study intends to use GPS collaring of wapiti to measure daily movement, home range size (Objective 1) and habitat selection during winter (June-August) in Fiordland (Objective 2). Results will be used to make suggestions for the improvement of methods used by the Fiordland Wapiti Foundation in future location studies. This research will provide us with a greater understanding of how wapiti utilise their home range in a unique environment without predation or competition with human industries.

Chapter 3

Materials and Methods

3.1 Study sites

The six study sites in this project were all located in Fiordland National Park, the largest national park in New Zealand. Fiordland National Park is located in the South West of the South Island of New Zealand and encompasses 1.2 million ha. Fiordland is steeply contoured, rising from sea level on the west coast, and 200 m at Lake Te Anau in the east, up to over 1800 m at some of the highest peaks. The alpine landscape strongly reflects glaciations within the last 1 million years, with many ice-cut benches and bedrock slopes, moraines, and cirque basins (Rose & Platt 1987). This region has the highest annual rainfall of anywhere in New Zealand, with c. 11 m per annum in coastal areas. Rainfall decreases moving in from the coast so that the eastern parts of this region receive roughly 5 m of rain each year (Molloy 1988). Soils are generally of low fertility with more fertile areas in patches of sediment deposition as expected with recently glaciated terrain (McLaren & Cameron 1996).

The alpine zone is most extensive in central regions near the main divide and in the east, where the grasslands extend from the *Nothofagus* timberline (c.900-1200 m) to about 1500 m (Rose & Platt 1987). *Nothofagus* beech trees are dominant in many locations, silver beech (*Nothofagus menziesii*) in the fiords and red beech (*Nothofagus fusca*) in the inland valleys. In the understory there are a wide variety of shrubs and ferns, including crown fern (*Blechnum discolor*), areas of scrubby herbs above the treeline. Above the treeline, there are extensive areas of tussock herbfields as well as bog vegetation around the numerous tarns and small wetlands. There are nine different species of *Chionochloa* snow tussocks and a wide variety of alpine herbs (Poole 1951). Shrublands contain genera such as *Dracophyllum*, *Coprosma*, and *Olearia*. Alpine grasslands are dominated by snow tussock *Chionochloa crassiuscula*, *C. pallens*, *C. flavescens*, *C. acicularis*, and *C. oreophila*. Herbfields contain genera such as *Phyllachne*, *Donatia* and *Oreobolus* which are prominent near the upper limits of grassland (Rose & Platt 1987).

The study sites were located in the Upper Glaisnock River, Edith River and Bligh Sound hunting blocks, at the centre of the wapiti area. The study sites were dominated by indigenous forest and tall tussock grassland with a scattering of subalpine shrub land and small patches of alpine grass/herb fields. There were also large patches of broadleaved indigenous hardwoods however these were rare within the landscape.

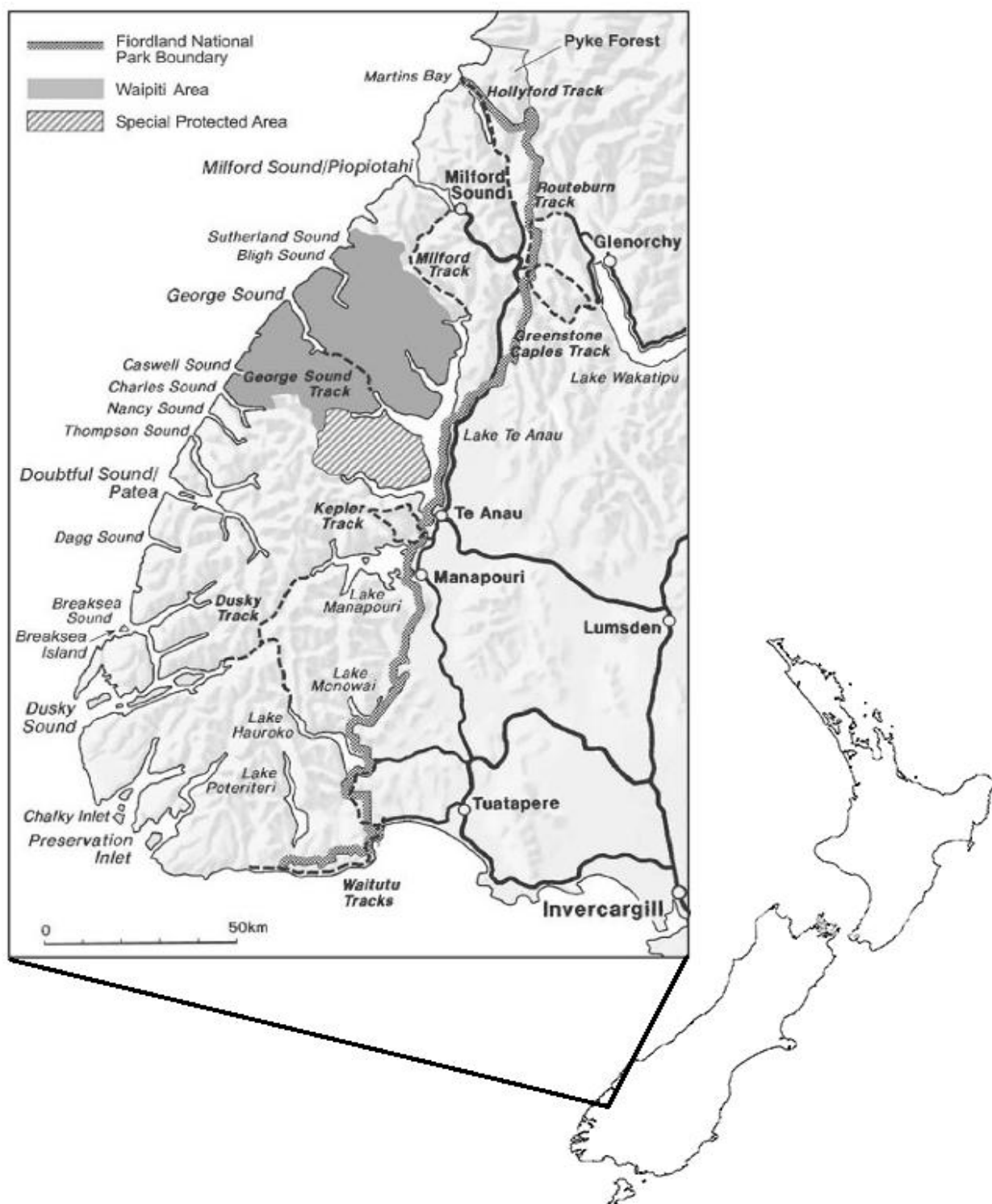


Plate 1: Location of study area in Fiordland National Park

3.2 Animal Handling Procedures

3.2.1 Helicopter Capture

Two collaring events were carried out to attain a study population. The first collaring event was carried out on February 27th with an objective to capture three cows. This date was selected as the area had been closed to helicopter activity for two weeks pre-bugle period to give animals time to settle and be clear of the forest edge. As cows were the target animal observation of calves at foot was carried out and if possible these animals were also captured for tagging. The second collaring event was aimed at collaring bulls and locating a cow that was lost after the first collaring event. Bulls were captured on May 30th which was approximately six weeks post rut when males were settling down.



Plate 2: Helicopter with capture weapon in foreground and animals being herded for capture.

Animals were located by helicopter (AS350 Type Aircraft) in open tussock areas which facilitated observation and capture. The helicopter pilot had several decades of experience in live-capture of deer so was used as an additional member of the research team. Animals were selected on wapiti-type features then captured with a handheld quad-barrel net gun using a .308 Mauser (sp) action (Alpine helicopters, Wanaka, New Zealand), fired from the helicopter. This entangled the limbs and brought the animal down to prevent further escape. Upon capture, animals were blindfolded, legs restrained with heavy leather straps by wrapping the front hock with the back hock. Animals were then slung under the helicopter, still entangled in the net, and flown to a suitable area where the fitting of the collars could take place. If the opportunity arose the animals were weighed via the load scale on the helicopter.



Plate 3: Edith 2 cow with legs strapped. Photo credit Brendon Cane

3.2.2 Anaesthetising

All animals were anaesthetised to facilitate direct handling, this ensured that the animals did not injure themselves or the research team. Once captured, animals were blind folded with soft muslin cloth which had an immediate calming effect. An intramuscular injection of Stresnil was then administered at a rate of 2 mL by a trained member of the research team. When flown to the processing site the animals were also positioned in such a way to allow for relaxed breathing and if possible placed in the shade to assist cooling. Antlers were removed from two males for safety reasons due to their aggressive nature. Hard antler is the antler when growth has ceased, calcification has occurred, and the skin, nerve and blood supply are no longer functional. This is when the antler has no live skin at its base. Hard antler can be removed above the pedicle without causing any pain or bleeding (Code of Animal Welfare 1992). Captured males were in hard antler meaning there was no need to anaesthetize them. Antlers were removed with a regular meat saw above the coronet. This was mainly for safety reasons during handling.



Plate 4: Pitt River bull, after drug administration, prior to antler removal and collaring. Photo credit Brendon Cane.

3.2.3 Tagging and collection of demographic data

All animals were also sampled for DNA analysis to estimate their percentage of wapiti-type genes. Hair samples were extracted by tugging hair free of the body with the follicle in place and then placed in a paper bag. Samples were analysed using Elk Test 3.0 (Genomnz, Mosgiel, New Zealand) allele assaying to identify the percentage of elk-type genes at AgResearch, Mosgiel, refer to Table 10 below. By analysing the DNA profile of the animal in relation to known allele frequencies of the natural populations of elk and red deer, the proportion of elk is estimated and the results presented in the form of a Genometer™ (Genomnz, Mosgiel, New Zealand).

Adult animals received two ear tags which were colour coded specifically to each individual. Calves that were caught at foot received one ear tag and were sampled for DNA analysis but no further action was taken. This would enable future visual identification of animals by staff or hunters without the need for intrusive observation. Bulls also received an ear tattoo as a form of non-removable identification. This would mean that if bulls were shot by hunters and collars were subsequently lost the culprit could be identified through their mounted trophy, even if ear tags had been removed.



Plate 5: Sedated and ear tagged Taheke cow with GPS collar fitted.

3.2.4 Capture, Handling and Collaring Effects

The capture, handling and collaring of animals has been shown to affect animal behaviour, particularly short term movement responses (Dennis & Shah 2012). It is recommended that tracking devices should weigh no more than 5% of an animal's body weight (Kenward 2001). This allows for unimpeded movement with an insignificant change in behaviour in the long term. It has been shown that over the long-term, appropriately sized devices have little or no effect on behaviour and movement (Kenward 2001). Wapiti are large-bodied ungulates, which means they can tolerate heavier devices however, there is relatively little research on the effects of collaring on ungulates. Blanc & Brelurut (1997) showed a 40% reduction in grazing activity by red deer (*C. elaphus*) hinds during the first eight days after GPS collaring. Furthermore, Morellet (2009) showed a 26% increase in home range size estimates (95% KDE) of roe deer (*Capreolus capreolus*) during the first 50 days after collaring when the first 10 days were rejected. For data retrieved from a collared animal it must be assumed that the animal's movement is normal (Morellet 2009). Whether animals carrying collars ever behave in a 'normal' fashion, compared to their behaviour pre-capture, is clearly difficult to demonstrate and is a necessarily common assumption which must be considered when studying the behaviour of wild animals (Morellet 2009). The winter observation period began on June 1st, one day after the second collaring event. This meant that the Edith 2 cow and the three bulls may still have been moving in response to collaring. The Taheke and Edith 1 cows were collared three months prior to the study, which would have been sufficient time to allow adaption to collars. These animals were however, in close contact with helicopters on May 30th for a routine inspection of the Taheke cow, and the locating of the Edith 1 cow to capture the Edith 2 cow. This means that these two cows may also have received

sufficient stimuli to illicit short term behavioural response. To address this concern data points during the first week of June were visually assessed and not found to fall outside the regular areas of use. Daily movement was also assessed for the first week and found not to be significantly lower due to potential reduction in activity. In fact, movement was generally lower in July when compared with June. The long nature of this study which yielded a high number of GPS fixes may have also reduced systematic bias associated with potential outlier measurements at the start of this study.

3.2.5 Global Positioning System (GPS) collars

The GPS was developed in 1973 by the U.S. Department of Defence, where an exact location can be calculated through the time taken for location data to travel between a GPS device and GPS satellites in orbit around earth (Garmin 2014). GPS collaring has become increasingly widespread among wildlife researchers, especially those investigating spatiotemporal behaviour of medium- to large-sized mammals (Blackie 2009). Elk were a central species in the development of animal tracking technologies as their large body mass meant they could tolerate the weight of the heavy archetypical location devices from which today's technology has developed (Craighead *et al.*, 1973). Earlier studies of elk relied on VHF telemetry, using manual radio tracking, but over the last two decades there has been a general move to GPS. In scenarios where access is limited, manual radio tracking is unlikely, in most cases, to fulfil the location sampling requirements in terms of accuracy, acquisition rate, and sample size. GPS technologies allow for large amounts of accurate location data with reduced labour costs, when compared with other telemetry methods, even in remote and inaccessible areas. Although GPS considerably enlarges tracking possibilities, this technique remains expensive (Girard 2002). The expensive nature of GPS study has subsequently limited the sample population size of this study.

The use of GPS technologies in 'Judas' animal control has been growing over the last decade, and has proved effective in the control of red deer (Morrison *et al.*, 2007) and feral pigs (*Sus scrofa*) (Yockney & Nugent 2006, Crouchley *et al.*, 2011). Judas studies, such as this, use traceable animals, with visual markers or tracking gear, to determine the location of other animals that they interact with, so control may be carried out. So far in the Judas sector of this study, no animals have been killed, although red deer control has been operating simultaneously to the study.



Plate 6: The Taheke cow with GPS collar visibly showing the animal's VHF channel and ID number.

Six adult wapiti, three bulls and three cows, were collared with iridium GPS collars (Sirtrack, Hawkes Bay, New Zealand) and used for the study of home range, habitat use and daily movement. The GPS collars weighed <1000 g which is significantly less than 5% of any of the animals' weights, which is consistent with the directions of Kenward (2001). Prior to collaring the study animals the collars were placed on farmed wapiti to ensure each GPS unit was fully functional. GPS units were attached by belt-like straps around the neck with a fluorescent orange finish which facilitates ease of spotting study animals. Measurement of neck circumference of farmed Fiordland wapiti was carried out in order to identify suitable collar lengths for study animals. Collars were configured for a neck diameter range of 300-400 mm although collars fitted to smaller animals were too large and had to be adjusted by adding extra belt holes with a cordless drill. The collars were fitted loosely enough to allow growth without constriction around the neck, whilst ensuring that they could not slip off over the head. After collaring, tagging and sampling, all animals were released in a docile state whilst recovering from anaesthetic.



Plate 7: Releasing the Wild Natives bull. Photo credit Ron Peacock

Data received from collars included 2-dimensional (2-D) location as latitude and longitude in decimal degrees, date and time of location, horizontal dilution of precision (HDOP), and number of satellites (Numsat) used to obtain each location. GPS fixes were sent from collar, via satellite, to the Sirtrack database at the end of each day. This data was displayed online on a topographical map with data points that could be downloaded in Lat/Long format.

The GPS collars had an accuracy of 3.5-12 m (Sirtrack, New Zealand, personal communication). Topography, vegetation, and animal behaviour may influence signal transmission between GPS satellites and receivers, influencing fix acquisition and location error and may result in a systematic bias in location data (Moen 2001, D'Eon 2002). Canopy cover, such as was present in the indigenous forests of the study area, has been shown to reduce GPS accuracy (Cain *et al.*, 2005) and cause increased fail rates in fix attempts (D'Eon *et al.*, 2002). Stationary evaluation of collar accuracy at specific study sites can provide valuable information (Moen *et al.*, 1996) however, this was not carried out for this study as the research team were unaware of this method. It has however, been shown that even when stationary evaluation is carried out there can be a significant difference in the error of fixes during stationary tests and free-ranging animals (Blackie 2009). Cain *et al.*, (2005) examined 35 journal articles using GPS telemetry collars and established a mean fix-success rate under stationary tests of 94.8%, whereas studies on free-ranging animals had mean success rates of 69.3%.

In order to maximise battery life the research team programmed the GPS collars for long intervals (six hours) between fix attempts. This is a factor previously shown to result in lower fix-success rates (Cain *et al.*, 2005, Mills *et al.*, 2006). Effective use of GPS transmitters will require study-specific assessment of the trade-offs between sampling needs versus transmitter efficiency and longevity (Mills *et al.*, 2006). Previous research suggests that data on movement distance and home-range size estimation is lost when using sampling frequencies of increasing length (Mills *et al.*, 2006). Fix-rates were determined by Ron Peacock, Pat Stratton and Brendon Cane to satiate two specific requirements, firstly that fixes provide sufficient data for home range estimation, and secondly that battery life is preserved for the maximum possible course of the study. GPS devices with short fix intervals (<1 hr) can use ephemeris data from the previous fix attempt which reduces the time which is taken to acquire a GPS location when compared with devices using longer fix intervals (Blackie 2009). To conserve battery power, GPS receivers integrated into wildlife telemetry collars typically are programmed to attempt to obtain a location for 90-180 seconds. If the receiver is unable to obtain a location in this time period, the fix attempt is classified as unsuccessful and the receiver is shut down until the next scheduled fix attempt (Blackie 2009). As devices with longer fix intervals need to acquire new ephemeris data the chances of taking longer than the programmed fix time are greater and therefore the chance of fix attempt failure. If a successful fix is not obtained for several consecutive

attempts this will maximize battery expenditure and lead to premature battery failure (Blackie 2009). For the cows, during the first 11 days of winter, collars were automatically programmed for 18 fixes per day, with an inconsistent time between fixes. This was changed to five fixes per day with a fix interval of six hours so that all animals had a standardised fix rate. Longer fix intervals (6–12 hr) are adequate for coarser data needs such as home range analysis (Mills *et al.*, 2006). The fix attempts were programmed to begin at 23:00 Greenwich Mean Time (GMT), on the day prior to measurement, for cows and at 00:00 GMT, on the day of measurement, for bulls. The inconsistency of scheduled times was overlooked in this study as the time difference was only one hour, and 24 hour movements could still be attained for all animals. Furthermore it was decided that although GMT was used, which is three hours out from New Zealand Standard Time (NZST), six hour fix intervals meant that circadian patterns could still be measured.

3.3 Analysis of GPS data

3.3.1 Data quality screening

Inaccuracy within GPS studies can result from error between the recorded location and actual location, and missing locations which result from failed fix attempts. This can lead to systematic bias and erroneous conclusions. The effects of canopy closure on GPS errors remain predominant, reducing fix attempt success by up to 37% and location precision by 12–17 m on average (Frair *et al.*, 2010). Topography is also important, but less so than canopy, reducing fix attempt success by up to 8% and location precision by 10–13 m (D'Eon *et al.*, 2002, Cain *et al.*, 2005). It is also possible that there may be an interaction between topography and canopy closure (D'Eon *et al.*, 2002). Collar orientation alone tends to have a negligible effect on GPS errors in open areas (Frair *et al.*, 2010), but can reduce fix attempt success by up to 80% and location precision by up to 17 m under dense canopy cover (Heard *et al.*, 2008; Jiang *et al.*, 2008). This study did not take error into account during analysis although it is estimated that accuracy of locations was within 3.5–12 m of the recorded point based on the circular error probability value (CEP), where accuracy is based on the probability of a fix falling within a set circle (Sirtrack personal communication). As GPS analyses have been shown to create bias with a misrepresentation of data, by the sample, fix attempt success rate was calculated for all animals. Fix attempt success rate was calculated as the percentage of successful fix attempts out of the total possible number of fixes, based on the programmed fix attempt schedule.

To estimate accuracy HDOP is an important parameter that can be used in location studies to identify fixes with a low level of confidence. HDOP is calculated through geometry between satellites used to acquire a fix. A greater angle of geometry, as a result of greater distance between satellites,

will result in a lower HDOP and greater confidence in the location (Moen *et al.*, 1996). It is recommended by the manufacturer that when using these devices, fixes with a HDOP greater than 10 should be viewed with caution as confidence for these points is low (Sirtrack® 2010). Threshold HDOP would probably be in the range of 4 to 6 for most studies (Moen *et al.*, 1996). GPS studies have used a range of HDOP values from 0-10 however there is no standard value and a threshold value should be selected to match the data. Based on these findings, GPS locations with HDOP values greater than 5 were selected for removal however, HDOP's were rarely greater than four, and never greater than five. It was therefore concluded that the fixes obtained provided a sufficient level of accuracy so no fixes were omitted from this study. In this situation the rejection of points with a marginally high HDOP would likely have caused more bias (Whyte 2013).

Sample confidence can also be improved through screening based on the dimensional nature of fixes. GPS devices record whether the solution is in two-dimensional (based on three satellites) versus three-dimensional mode (based on four or more satellites, which includes a correction based on device elevation; Frair *et al.*, 2010). On average, two-dimensional locations exhibit less precision (error < 36 m) than three-dimensional locations (error < 12 m) (Moen *et al.*, 1996, D'Eon *et al.*, 2002, Graves & Waller 2006, Lewis *et al.*, 2007, Sager-Fradkin *et al.*, 2007, Jiang *et al.*, 2008), thus 2-D locations are often analysed separately from 3-D fixes or even deleted. The number of satellites used to acquire fixes was observed and found to be in 3-D mode for all locations, averaging 5.6 satellites per location, with as many as 9-11 satellites used for some locations. Accordingly, no locations were rejected based on the dimensional nature of fixes.

The fix-rate changed over the course of the study from around 18 to 5 fixes per day. Statistical results are reliable only if the whole sampling regime is standardized (Borger *et al.*, 2006). This meant that data from the start of the experiment, days 1-11, had to be subsampled down to no more than five fixes per day to allow for a balanced experimental design throughout the study. Data was then subsampled to ensure each 24 hour period, where daily movement was measured, had five fixes with a six hour interval, which ensured standardisation in sampling. Days with sufficient successful fixes were often distributed unevenly across the winter. Where successful fixes were distributed unevenly, data was also subsampled to ensure even distribution across the study duration. This meant that two animals, Saints Creek bull and Edith 2 cow, had insufficient movement days (<10 days/month) for daily movement analysis and were subsequently rejected from this measurement. To increase sample size, measurement between larger intervals can be carried out. This would have reduced the number of days rejected for insufficient fixes and potentially prevented the rejection of the two animals from daily movement analysis. This would however, have resulted in increased time between fixes and subsequent underestimation of daily travel. This method was therefore rejected in order to gain the

most accurate estimation of daily movement with the data that was available, whilst maintaining standardisation within sampling.

The screening of data based on successful location attempts can lead to the rejection of accurate data, leading to systematic bias (D'eon & Delarte 2005). It is therefore possible that by using the methods described in this paragraph, there may be an under-representation of locations from certain areas and habitat types where fix attempt and/or accuracy was impeded.

3.3.2 Serial Autocorrelation

Autocorrelation is the cross-correlation of a signal with itself, or in movement studies, where the interval between fix attempts is too short to allow independence between data points. Autocorrelation can produce deceptively low estimates of certainty, over-fitted models and result in spurious conclusions (Fieberg *et al.*, 2010). Location studies attempt to avoid autocorrelation by ensuring fix intervals are long enough to allow movement between fixes. Autocorrelation is also avoided by carrying out study over a wide period of time which prevents aggregated data from affecting the final result. To reduce the chance of autocorrelation in this study, location data was collected over a period of three months with fix intervals sampled six hours apart, which was deemed to be sufficient to allow independence between fixes (Dave Latham, Landcare Research, pers. comm.). As detailed above, for the first 11 days of winter, fix intervals were less than one hour for all three cows, this was deemed too close to allow independence between points. This data was subsampled to allow six hour fix intervals with five fixes per day, which also improved standardisation.

3.3.3 Home range estimation

Home range is described as the area that provides all the resources for living required by an animal. Estimates of the area of home ranges and territories have been a regular feature of studies of the natural history of terrestrial vertebrates (Jennrich & Turner 1969). The more a home range deviates from a smooth unimodal distribution, the larger sample size it will require for accurate estimates (Seaman 1996). Studies of home range size often estimate whether the true home range has been fully revealed through incremental area analysis (Laver & Kelly 2008) which, identifies a threshold value for the minimum number of fixes required to accurately estimate a home range. This study did not use incremental area analysis as high numbers of fixes can be used to reduce the chance of misrepresentation of home ranges (Mills *et al.*, 2006). It was determined that the high number of locations in this study (between 182-328 per animal) would be sufficient to estimate home range during the three months of winter.

The 100% minimum convex polygon (MCP) is the smallest convex polygon containing all the observed positions and the area within this polygon is the estimated home range size (Jennrich & Turner 1968). This method is common as it is easy to use and interpret, however it is also flawed as it does not take into account areas of little or no use. This method is limited by sample size bias, as home range will continue to increase with number of observed positions (Anderson 1982). The MCP is limited by its process of drawing a circle around the available data points, which in doing so creates a convex shape which is unlikely, especially in a heterogenous environment (Anderson 1982). MCPs will tend to provide a semi-realistic home range if the actual home range is convex however, if the home range is not convex then MCPs will overestimate home range (Anderson 1982). The MCP is also limited as it does not take into account the areas where locations did not take place within the range. These factors show that MCPs will generally result in overestimation of home ranges. MCPs were used to estimate home range size in this study as it has been used many times in the past for determination of elk home ranges (Craighead *et al.*, 1973, Ager *et al.*, 1983, McCorquodale 2003,, Anderson *et al.*, 2005, Moeller 2010) and thus allows for cross-comparison. MCPs were created in ArcGIS, a spatial modelling program, using the Minimum Bounding Geometry tool. Using the convex hull option, the smallest polygon that encompasses all the input points is drawn. When the tool is run on a feature class in a geodatabase, the areas and perimeters are automatically calculated.

The kernel density estimator (KDE) is another home range calculation technique and has the desirable qualities of directly producing a density estimate, and being uninfluenced by effects of grid size and placement (Silverman 1986). KDE's have begun to replace MCP's in modern location studies due to their tendency to estimate closer to an animal's actual home range. KDE's not only measure the areas around GPS locations but take into account the areas where locations did not occur, creating a concave area rather than a convex. Furthermore, because it is nonparametric, it has the potential to accurately estimate home ranges of any shape, provided that the level of smoothing is selected appropriately (Seaman & Powell 1996). The KDE was used as it provides more accurate results than MCP's (Hemson *et al.*, 2005, Nilsen *et al.*, 2007) and as it has become the more frequently used method for home range estimation in modern science. Thus the inclusion of KDE's would allow for cross comparison with MCP's to determine their appropriateness in this study. Using the Geospatial Modelling Environment (Beyer 2012) in ArcGIS 10.3, 95% KDEs were created. It is recommended that Least Squares Cross Validation (LSCV) bandwidth is used to smooth parameters. Least Squares Cross Validation can result in the drawing of numerous small perimeters around individual points resulting in fragmentation of the data frame, which occurred in this case as seen in plate 8 below. This issue can be resolved using fixed smoothing with reference bandwidth (Hemson *et al.*, 2005) which in this case was the solution to fragmentation, as seen in plate 8 below.

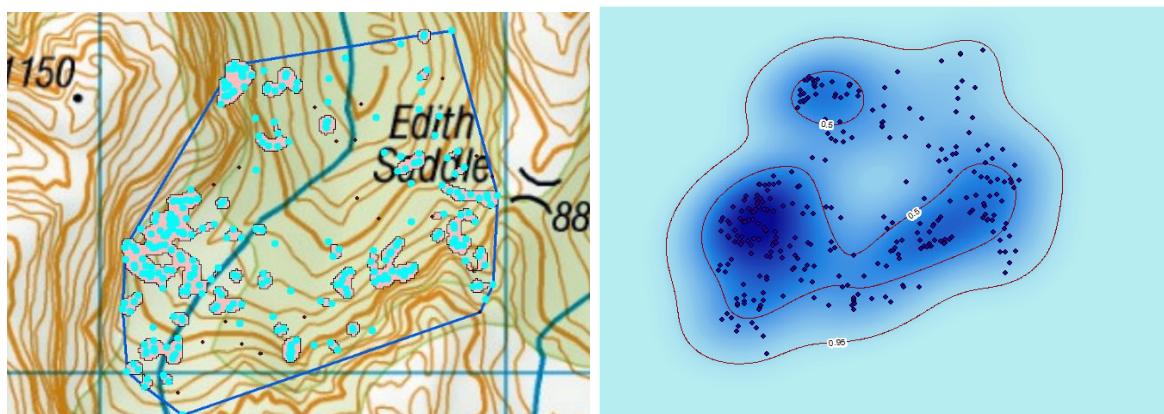


Plate 8: Home range estimated using Least Square Cross Validation bandwidth (left) versus Reference bandwidth (right). Note the fragmentation of the groupings within the left image.

3.3.4 Habitat use

Modern ecological research often involves the comparison of the usage of habitat types or food items to the availability of those resources to the animal. Widely used methods of determining preference from measurements of usage and availability depend critically on the array of components that the researcher, often with a degree of arbitrariness, deems available to the animal (Johnson 1980). Habitat utilisation was measured in this study to identify whether a preference of habitat type, based on vegetation Landcover, existed in Fiordland wapiti. Individual fixes were overlaid using ArcGIS onto mapped habitats from Landcover database (LCDB) version 4. Individual point counts for each landcover type were determined using the Spatial Join tool in ArcGIS 10.2 with the LCDB layer as the target layer and the point layer at the join layer. This operation created an attribute in the output layer that held the number of points in each polygon. With the attribute table of the output layer, the Summarize command was used to create a table that combined all the landcover types into one record and summed all the point counts for that landcover type. Data was composed of large amounts of locations for relatively few individuals; therefore, we examined third-order habitat selection (usage of various habitat components within the home range; Johnson 1980) for individual elk within each season, rather than pooling among animals (White and Garrott 1990, Aebischer *et al.*, 1993, Manly *et al.*, 1993).

The use of particular habitats, in proportion to the availability of those habitats at the study site, was determined using Ivlev's index of electivity (E) (Strauss, 1979). For each animal, preference/avoidance was defined by:

$$E = (U - A) / (U + A)$$

Where U is the percentage of locations in one land cover class (used) and A is the percentage of the class in the MCP (available). The degree of preference or avoidance is shown by the degree of deviation in a positive or negative direction from a value of 1 (Krebs, 1989).

3.3.5 Daily movement

Few researchers have attempted to document small-scale movement of ungulate species (Pepin *et al.* 2004). It has been estimated that real movement distances of red deer can only be estimated accurately with fix intervals of short to moderate length (15-240 min) (Pepin *et al.*, 2004). It was decided that although there was a large interval (6 hours) in this study movement estimation could still be carried out, although results would be limited by the high level of uncertainty. It is important to note that the measurement of simple straight line distance between points does not take into account the vertical displacement of an animal. Furthermore it does not take into account the tortuous route that is travelled between points, resulting in a general underestimation of actual distance travelled (Pepin *et al.*, 2004, Borger *et al.*, 2006). The best way to strictly calibrate straight-line distance travelled by an animal would be to track it in snow, parallel to a continuous GPS location series, and to compare cumulated straight-line distances with real distances travelled (Pepin *et al.*, 2004). This technique was not used as harsh weather, and avalanche-risk, during the winter season prevented ground work by the research team.

Measurement of daily movement was carried out for each month of winter for four of the study animals, two bulls and two cows, as two of the animals provided insufficient data (<5 complete 24 hour observation periods in any given month). Estimation of distance between coordinates was carried out using a coordinate distance calculator (www.boulter.com). Total distance of daily movement was estimated by summing the straight-line distance between five successive points for each 24 hour period. This would increase the standardisation of sampling and ensure that the distance was measured over a circadian period.

To generalize beyond the actual observed locations it is necessary to estimate where the animal could have been in the times between observations (Seaman *et al.*, 1996). Fractal distance is the potential distance travelled between two points above the observed straight line distance, which are then modelled through a random walk sequence (Loehle 1990, Gautestad & Mysterud 1993). These values can be used to improve accuracy of movement models. Accuracy of estimating fractal

distance is reduced with increasing time between locations. As the fix intervals were so high (6 hours) in this study, it was deemed pointless to calculate the fractal distance between points.

Chapter 4

Results

4.1 Study Animal demographic information

Table 10: Demographic information of study animals

Animal Name	Date of capture	Capture location	Weight (kg)	Age (yrs)	Wapiti-type genes	Status
Cows						
Edith 1	27/02/2014	Edith head basin	182	7	62%	Alive
Edith 2	30/05/2014	Edith head basin	180	4	52%	Alive
Kakapo	27/02/2014	Kakapo creek head basin	120*	3	30%	Dead
Taheke	27/02/2014	Upper Taheke head basin	150*	4	48%	Alive
Bulls						
Saints Creek	30/05/2014	Tributary of the Worsley	140*	3	32%	Alive
Wild Natives	30/05/2014	Unnamed tributary of the Wild Natives	240*	3	48%	Alive
Pitt River	30/05/2014	Head of Oilskin Pass	180	7	38%	Alive

*Weight was not measured so visual estimation was carried out.

4.1.1 Edith 1 cow

This is an older female with strongly wapiti-type phenotypic characteristics. She possesses a long dark face, neck ruff, dark legs, large rump patch and a short tail. She is sympatric with a three year old hind, thought to be her daughter, who was caught during the second collaring event. During the second collaring event this cow was located using the VHF capability in order to locate animals sharing the same range. During this event the first Edith cow was the only animal exposed for several passes of the helicopter. It is thought that this cow may have learned to avoid the helicopter by staying hidden even whilst cornered with the helicopter hovering at about 10 m above the ground.

4.1.2 Kakapo cow

This was a young cow which showed some wapiti-type characteristics. Her features included a long dark face, dark legs, and large rump patch with a short tail. At capture, she was observed running with her calf, which was not caught. This cow was captured on February 28th and ceased transmission on April 2nd GMT. Her body was found on May 30th via VHF, during the second collaring event, with what was very apparent a bullet hole in her front shoulder. Her head was tucked under her front leg which

impeded GPS fix attempts and was the reason no fixes were recorded after April 2nd. Her collar was retrieved and disarmed and then used in the collaring of the Edith 2 cow.

4.1.3 Edith 2 cow

This is a young cow with strong wapiti-type characteristics. This cow was observed prior to capture running with a calf at foot, which was not captured. It is thought that this cow may be the daughter of the first Edith cow as the two are sympatric and are similar looking animals with a similar proportion of wapiti-type genes, as seen in Table 10. As previously mentioned, the second Edith cow was collared using a recycled collar after the Kakapo cow was found shot dead. To capture this cow five passes were made with the helicopter without seeing any deer, apart from the already collared Edith cow. On the fifth pass, five deer emerged from cover including the cow which was eventually captured.

4.1.4 Taheke cow

This is a young cow of moderate wapiti-type characteristics and genetics. This cow was observed prior to capture running with a male calf at foot, of around three months of age. During capture the net entangled both the calf and mother at the same time. The calf was ear tagged and sampled for DNA analysis and then released. The calf was found to have less wapiti-type genes than its mother, 29% compared to 48%. This cow shares habitat with the Wild Natives bull, however, observation of GPS fixes does not place them in similar areas at the same time. This suggests that the two animals do not interact.

4.1.5 Saints Creek bull

This is a small stag of mainly red deer type features with the pale coat associated with wapiti. This is a small animal of similar size to an average red deer. At capture it had 12 point antlers of average light timber. This type of animal provides no benefit to the trophy genetics of the Fiordland wapiti herd (Ron Peacock personal communication 2014, Pat Stratton personal communication 2014). It is intended that this animal be culled prior to the next breeding season to prevent its red deer-type genetics from being passed to the next generation.

4.1.6 Wild Natives bull

This bull is big and very well built with all the phenotypic characteristics of a good wapiti male. At capture this bull possessed average sized 12 point antlers measuring approximately 38 x 38 inches. This bull shows great promise for the future in growing into a trophy animal. Although he possesses

the traits of a strongly wapiti-type animal, DNA analysis showed that he had less than 50% wapiti-type genes (<Genomnz>), refer to Table 10. This bull also shares range with the Taheke cow.

4.1.7 Pitt River bull

This is another small stag of mainly of red deer-type characteristics. At capture this stag had small 12 point antlers with very light timber. The old age of this animal along with the small body and poor antler formation suggests that he has never been, and never will be, a trophy animal. Because of these poor traits he will be culled to prevent passing of red deer-type genes to the next generation.

4.2 Daily Movement

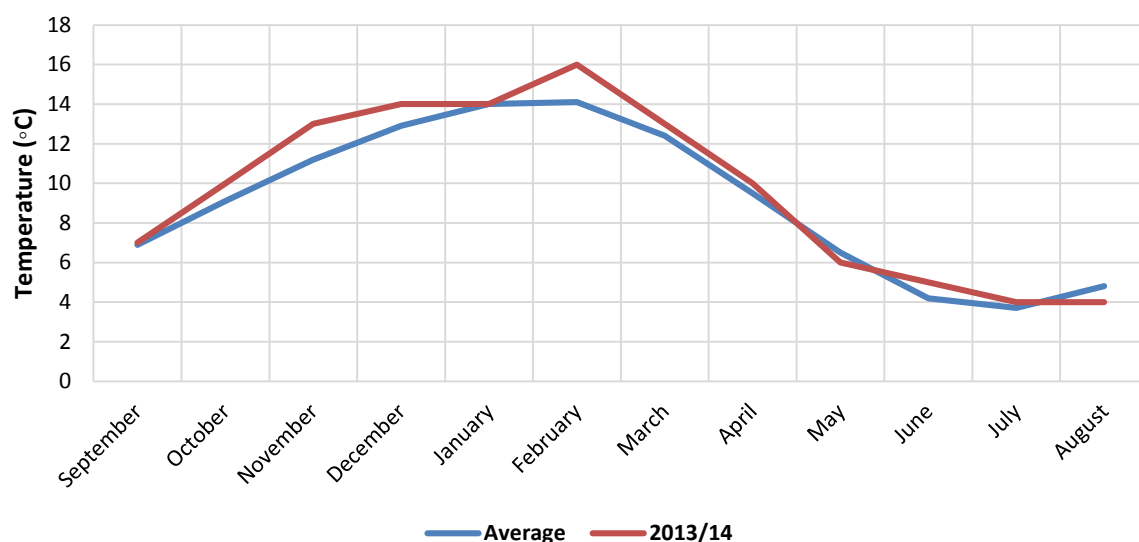


Figure 15: Average daily temperatures in Fiordland compared to actual temperatures during the year of the study. Data sourced from www.wunderground.com.

As can be seen from figure 15 the average daily temperature in FNP was greater both during the study and in the year leading up to the study when compared with the district average. The actual average temperature was lower than the district average in August 2014, the last month of the study period, where the mean daily temperature failed to rise above 4°C between July and August.

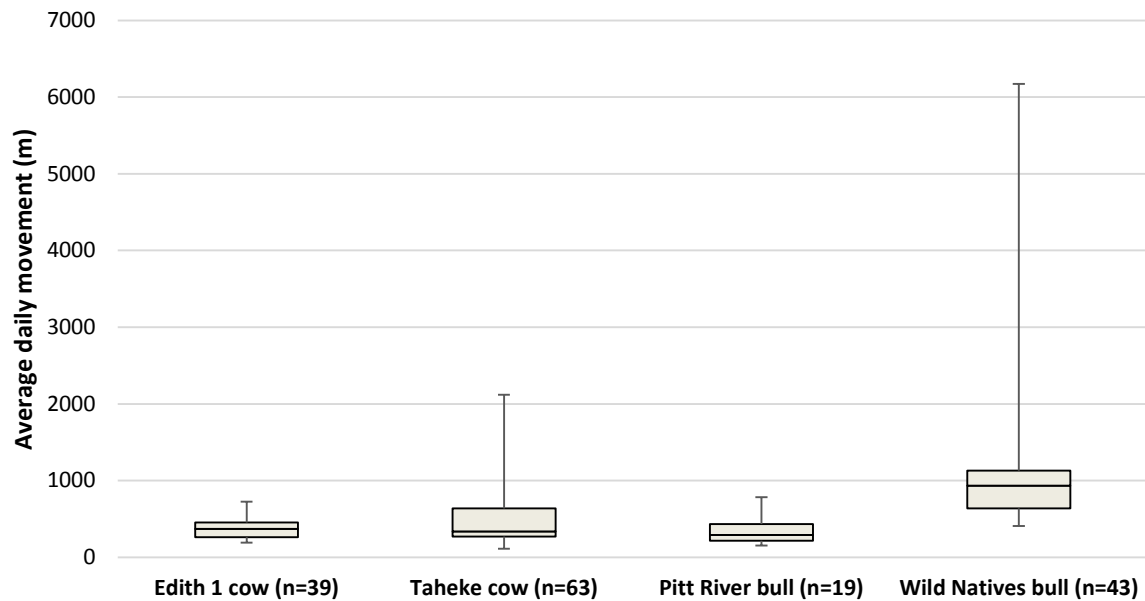


Figure 16: Average distance travelled per day during winter (June, July & August) by four wapiti. Where n is the number of days that provided sufficient fixes for measurement of distance.

It can be seen from Figure 16, that average daily travel varied significantly, both between animals and across the winter. There was an apparent reduction in daily travel from June into July for the Taheke, Pitt River and Wild Natives animals. This was followed by an increase into July which was more apparent for the Wild Natives bull and less so for the Taheke cow and the Pitt River bull. Changes in daily movement were steadier for the Edith cow whose daily travel slowly but consistently increased through the winter months. Monthly changes in average daily travel followed a similar curve to the average daily temperature each month, seen in figure 15. Daily movements were evenly distributed for both the Edith 1 cow and the Pitt River bull which had similar movements of around 200-800 m/day. Movements were more variable and unevenly distributed for the Taheke cow and Wild Natives bull. Average daily travel for these two animals was positively skewed with the cow and the bull reaching 2000+ and 6000+ m respectively at their upper limits. The modal distances of travel suggest that wapiti in Fiordland travel little more than 500 m per day on average during winter.

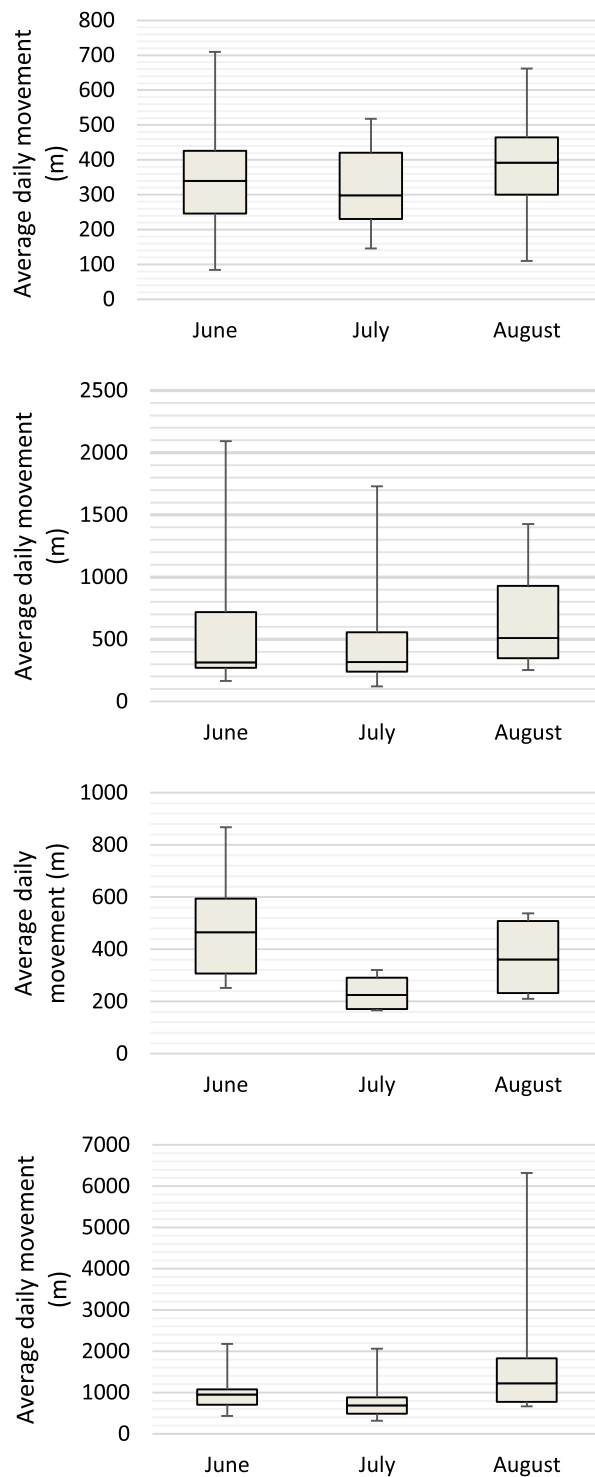


Figure 17: Daily movements of four wapiti in Fiordland National Park during winter (June, July & August). Top = Edith 1 cow, second = Taheke cow, third = Pitt River bull, and bottom = Wild Natives bull.

Figure 17 shows that daily distance travelled was variable between animals and within months. It can be seen that daily travel by the Edith cow and Pitt River bull was evenly distributed each month of the study period whilst movements of the Taheke cow and Wild Natives bull were more unevenly

distributed within each month. It can be seen in general that there was a slight decrease in daily movement from June into July with an increase in activity from July into August.

4.3 Home range size

Table 11: Home ranges and core areas expressed using MCPs and 95% and 50% KDEs during the months of winter for six wapiti. Where n = number of GPS fixes contributing to home range analysis.

Animal	n	Home range (ha)		
		100% MCP	95% KDE	50% KDE
Edith 1	294	62.8	90.7	28.1
Edith 2	203	43.9	57.6	17.3
Taheke	331	266.0	365.7	38.3
Pitt River	237	122.4	130.2	17.5
Saints Creek	182	218.2	257.9	35.4
Wild Natives	304	733.1	1385.6	375.2

From Table 11, it can be seen that 95% KDEs consistently estimated larger home ranges than 100% MCPs. 95% KDEs were on average 37.8% larger than 100% MCPs (range: 6.4-89%). Average 100% MCP home range size was 241.1 ha (range: 43.9-733.1 ha). Average 95% kernel home range was 381.3 ha (range: 57.6–1385.6 ha). Average 50% kernel core area was 85.3 ha (range: 17.3-375.2 ha). Home range size was variable for all three measurements carried out, however, 50% KDE core area showed the least amount of variability with the exception of the Wild Natives bull.

4.4 Habitat Selection

It can be seen from Table 12 (Page 49) that the proportions of different habitat types within home ranges were variable, also refer to Plates 9-14. Indigenous forest made up a large proportion of individual home ranges at an overall average of 48.8% (SE $\pm$ 12%). Tall tussock grassland also made up a large proportion of home ranges at an overall average of 37.7% (SE $\pm$ 10%) of total areas. Subalpine shrub land was also present at an average of 7.3% (SE $\pm$ 6%) but was less prominent than indigenous forest or subalpine shrub land.

There was also a high level of variation in electivity values between animals. Even sympatric animals, such as the two Edith cows or the Taheke cow and Wild Natives bull, showed contrasting electivity of the same habitat types. Some habitat types were completely avoided such as landslides, lakes and sub alpine herb fields whilst others were highly preferred, such as sub alpine shrub land. Alpine herb fields were noticeably avoided as they contributed to an average of only 2.1% (SE $\pm$ 1%) of each home range. Even when present within a home range alpine herb fields were either avoided ($E \approx -1$) or not selected for ($E \approx 0$). It can be seen that indigenous hardwood forests were selected for by only one animal, Saints creek bull, however, this habitat type was only present in the Saints creek

area. It can be seen that more treacherous habitat types such as lakes and landslides were completely avoided once satellite imagery was used to correct location data.

Table 12: Habitat selection by six wapiti in Fiordland during winter (June, July, August), based on the proportion of habitat used in relation to proportion of habitat available. Where E = 1 shows complete preference, E = 0 shows no preference, and E = -1 shows complete avoidance.

Edith 1	% of total fixes	% of home range	Ivlev's electivity index (E)	Edith 2	% of total fixes	% of home range	Ivlev's electivity index (E)
Alpine Grass/Herbfield	-	-	-	Alpine Grass/Herbfield	-	-	-
Indigenous Forest	53.6%	58.3%	-0.042	Indigenous Forest	89.6%	76.8%	0.077
Lake or Pond	-	-	-	Lake or Pond	-	-	-
Sub Alpine Shrubland	14.3%	11.0%	0.130	Sub Alpine Shrubland	6.4%	6.9%	-0.038
Tall Tussock Grassland	32.1%	30.7%	0.022	Tall Tussock Grassland	4.0%	16.2%	-0.604
Landslide	-	-	-	Landslide	-	-	-
Broadleaved Indigenous Hardwoods	-	-	-	Broadleaved Indigenous Hardwoods	-	-	-
Taheke	% of total fixes	% of home range	Ivlev's electivity index (E)	Saints Creek	% of total fixes	% of home range	Ivlev's electivity index (E)
Alpine Grass/Herbfield	0.6%	2.8%	-0.647	Alpine Grass/Herbfield	1%	0.9%	0.081
Indigenous Forest	23.8%	44.6%	-0.304	Indigenous Forest	64%	47.0%	0.153
Lake or Pond	0.0%	4.2%	-1.000	Lake or Pond	-	-	-
Sub Alpine Shrubland	1.2%	3.8%	-0.520	Sub Alpine Shrubland	3%	7.7%	-0.437
Tall Tussock Grassland	74.4%	44.6%	0.250	Tall Tussock Grassland	24%	26.6%	-0.051
Landslide	-	-	-	Landslide	-	-	-
Broadleaved Indigenous Hardwoods	-	-	-	Broadleaved Indigenous Hardwoods	7%	18.0%	-0.439
Pitt River	% of total fixes	% of home range	Ivlev's electivity index (E)	Wild Natives	% of total fixes	% of home range	Ivlev's electivity index (E)
Alpine Grass/Herbfield	0.0%	2.2%	-1.000	Alpine Grass/Herbfield	4.6%	6.9%	-0.200
Indigenous Forest	14.0%	31.4%	-0.383	Indigenous Forest	25.8%	34.4%	-0.143
Lake or Pond	-	-	-	Lake or Pond	0.0%	2.3%	-1.000
Sub Alpine Shrubland	36.2%	8.2%	0.631	Sub Alpine Shrubland	23.5%	6.4%	0.572
Tall Tussock Grassland	49.8%	58.3%	-0.079	Tall Tussock Grassland	46.0%	49.9%	-0.041
Landslide	-	-	-	Landslide	0.0%	0.1%	-1.000
Broadleaved Indigenous Hardwoods	-	-	-	Broadleaved Indigenous Hardwoods	-	-	-

Table 13: Fix success rate of six GPS collared wapiti scheduled for five fixes per day (fix interval = 6 hours) during winter. Where habitat is the predominant habitat within each 95% KDE, TTG = tall tussock grassland and IF = indigenous forest.

Animal	Potential Successful Fixes*	Successful Fix Attempts	Fix Success Rate	Habitat
Edith	324	239	73.8%	IF
Edith 2	324	150	46.3%	IF
Taheke	324	281	86.7%	TTG/IF
Saints Creek	368	182	49.5%	IF
Pitt River	368	237	64.4%	TTG
Wild Natives	368	304	82.6%	TTG

*Potential fixes based on number of days with fix interval programmed at six hours.

Table 13 shows that the fix success rates were variable between animals. On average fix attempt success rate was low with a mean of 67.2%. There were no observable trends in fix attempt success rate between sexes, with similar values being produced. There is a visible correlation between fix success rate and habitat type with higher success rates in TTG, open, than IF, closed canopy. The highest fix attempt success rates were produced by the Taheke cow and Wild Natives bull, 86.7% and 82.6% respectively, these animals also shared similar TTG home ranges.

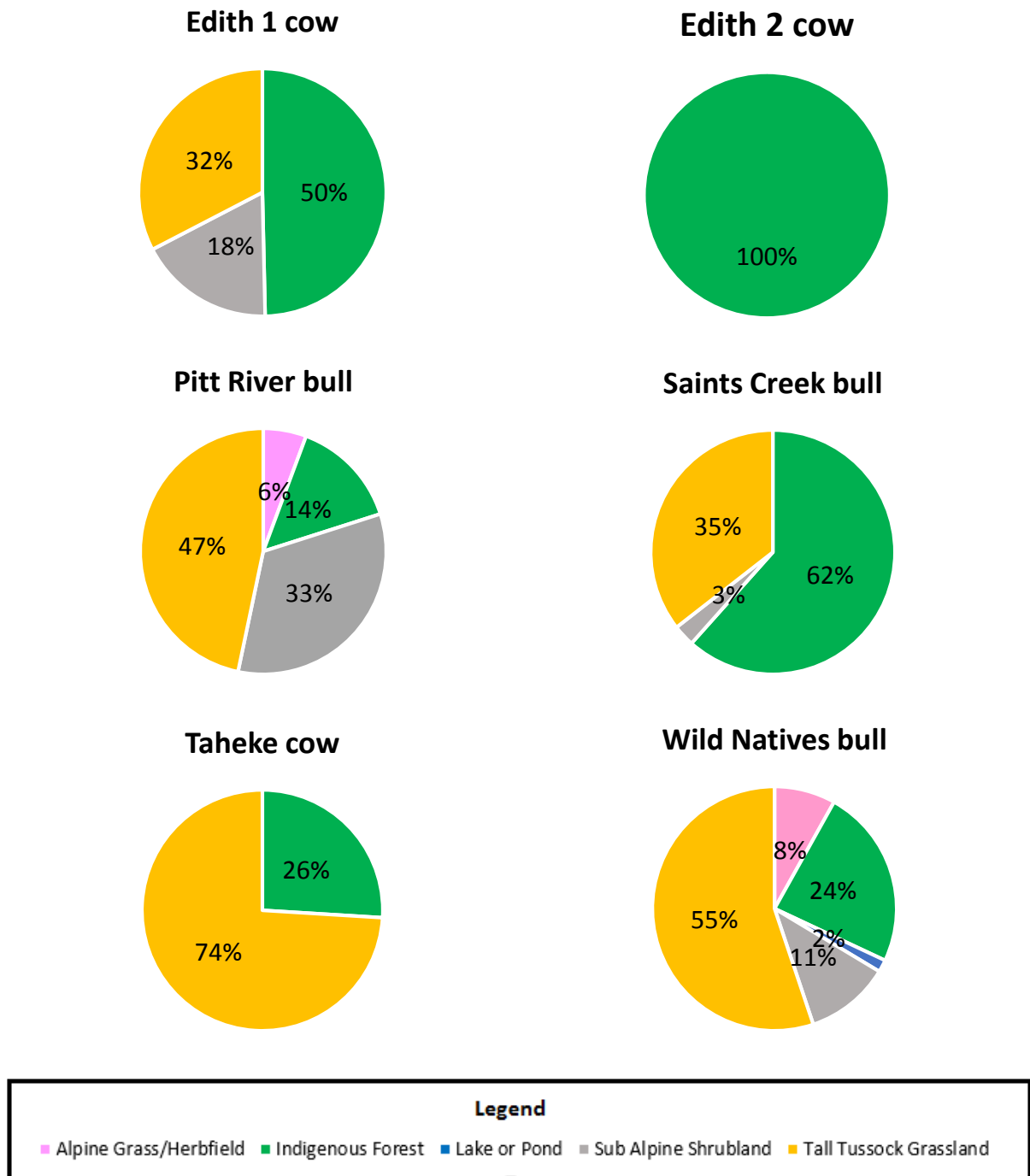


Figure 18: Composition of habitat (%) within each 50% KDE core area of six wapiti during winter (June, July, August) in Fiordland National Park.

It can be seen in Figure 18, that 50% core areas varied in habitat composition between animals. Indigenous forest was an important habitat type that occurred within the core area of all animals at an average of $46 \pm 13\%$ SE of total composition. Tall tussock grassland was also an important habitat type which occurred in the core area of all but one animal at an average of $49 \pm 8\%$ SE of total core area composition. Other habitat types were also present within core areas including sub-alpine shrub land, alpine grass/herb field and ponds although these were less significant and varied between animals.

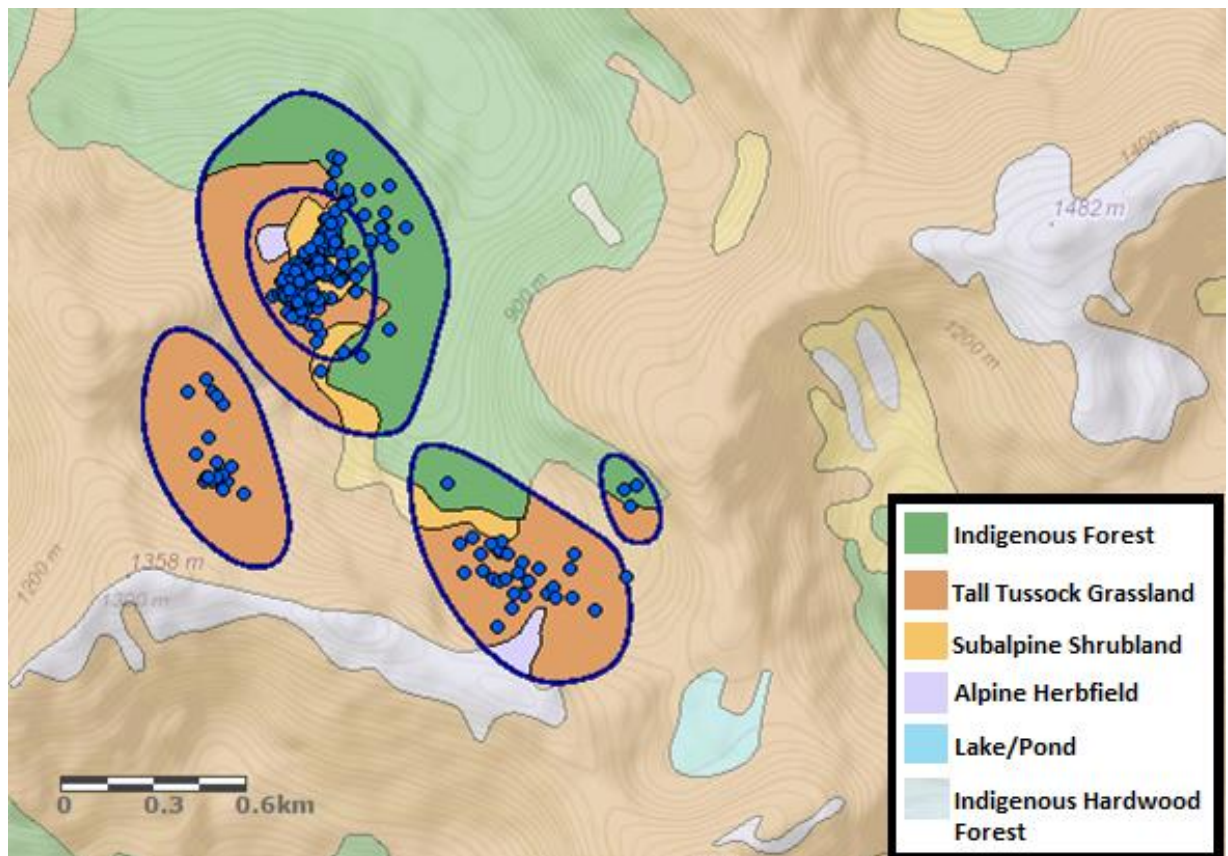


Plate 9: 95% and 50% KDEs for the Pitt River bull.

It can be seen in Plate 9, above, that the Pitt River bull concentrated much of its movement in one area within its home range. Many of these locations seem to occur at or near the forest/field/scrub boundaries. These fixes and the KDEs are also primarily located on north/north easterly facing slopes. This animal often approached the saddle, seen at bottom middle of image, but never crossed.

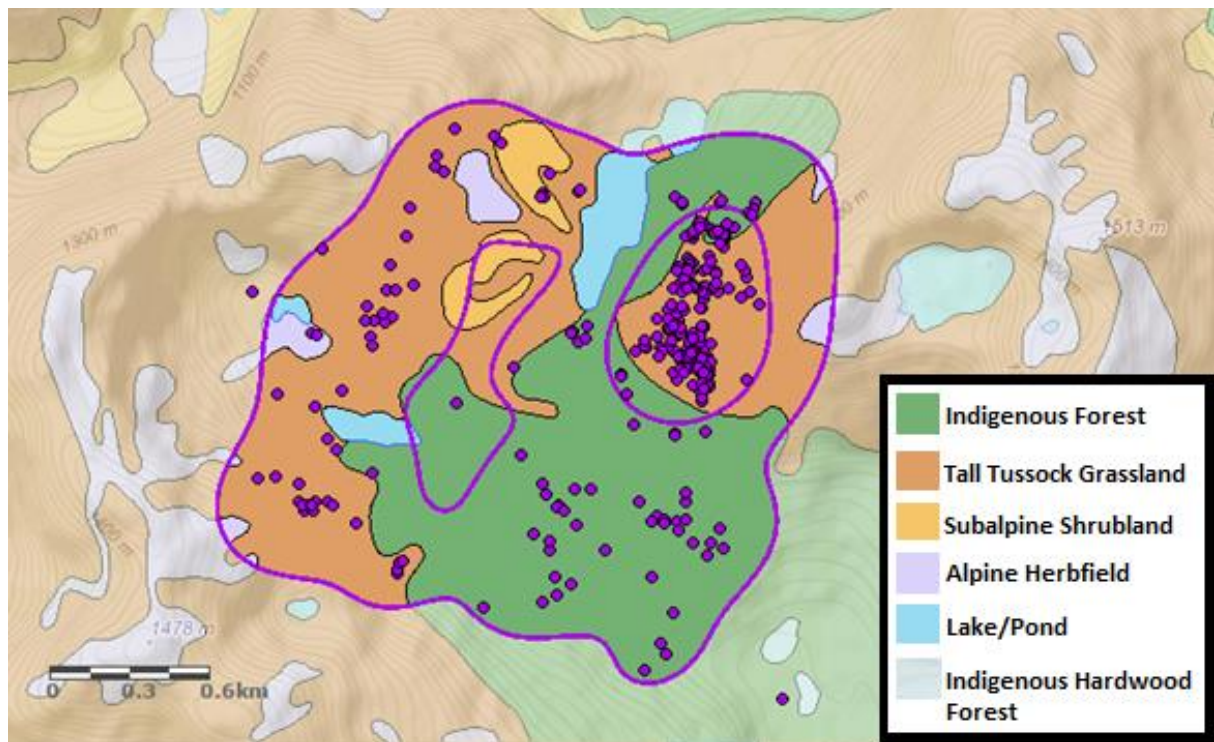


Plate 10: 95% and 50% KDEs for the Taheke cow

It can be seen in Plate 10, above, that the Taheke cow concentrated much of its movement in one area within its home range. A notable portion of the locations occurred deep within indigenous forest, sometimes 600+ m from the forest edge. Most of the locations for this animal seem to be protected from southerly and westerly winds, either by forest or topography or both.

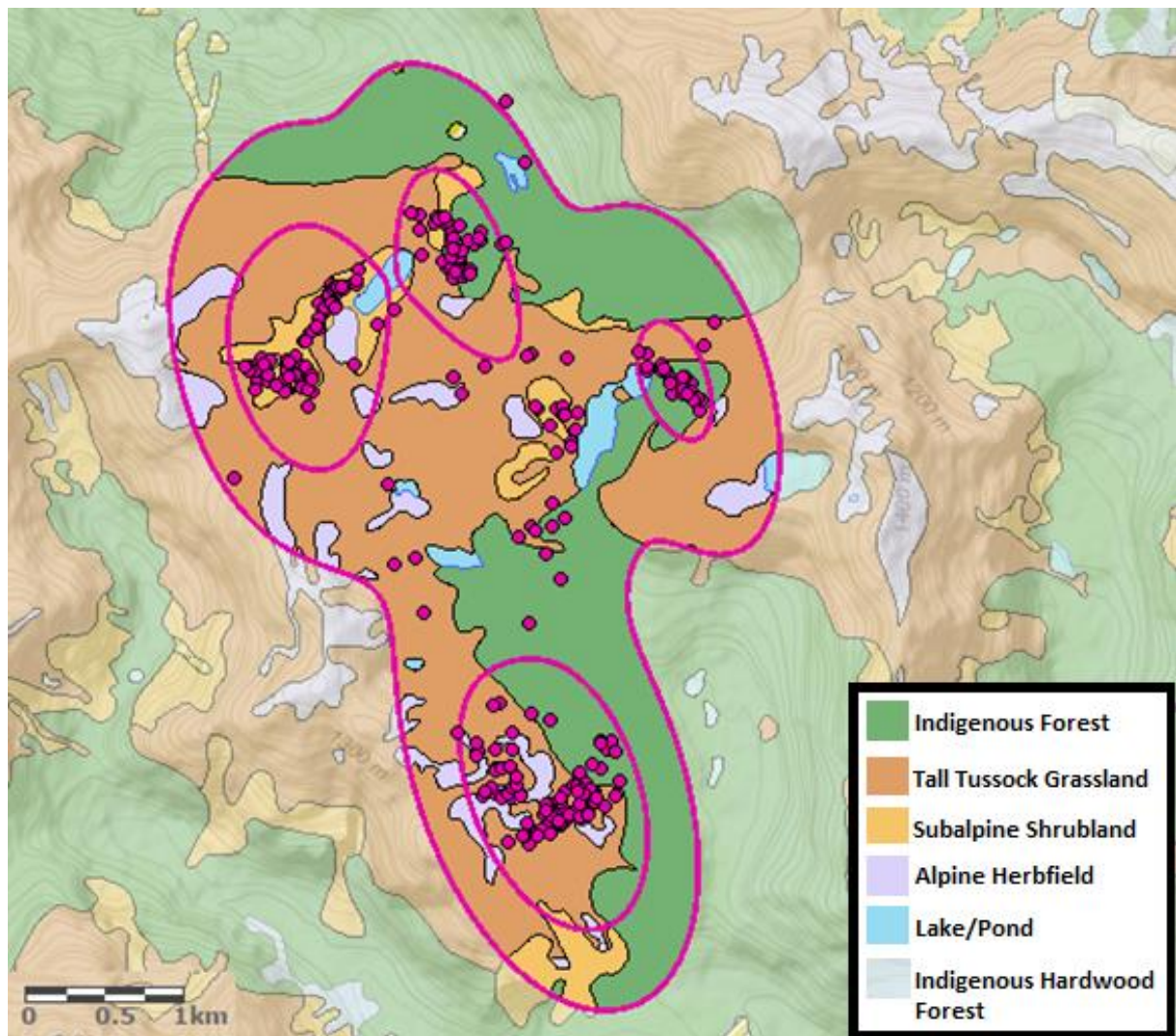


Plate 11: 95% and 50% KDEs for the Wild Natives bull.

It can be seen in Plate 11, above, that the Wild Natives bull had four core areas where fixes were densely distributed. The home range of this animal is large when compared to the other study animals and as a result locations are more sparsely dispersed. Many of these locations occur at or near boundaries between habitat types. Many locations also occurred within subalpine shrub land which, is a transitional habitat type between forest and tussock. This animal also seems to spend more time at a greater distance from the forest compared to the other animals.



Plate 12: 95% and 50% KDEs for the Edith 1 cow.

It can be seen in Plate 12, above, that the Edith 1 cow concentrated much of its movement in a small area resulting in both small 50% and 95% KDEs. A large proportion of the 50% KDE visibly encompasses subalpine shrub land. This home range appears to face north-west with topographical protection from westerly and southerly winds.

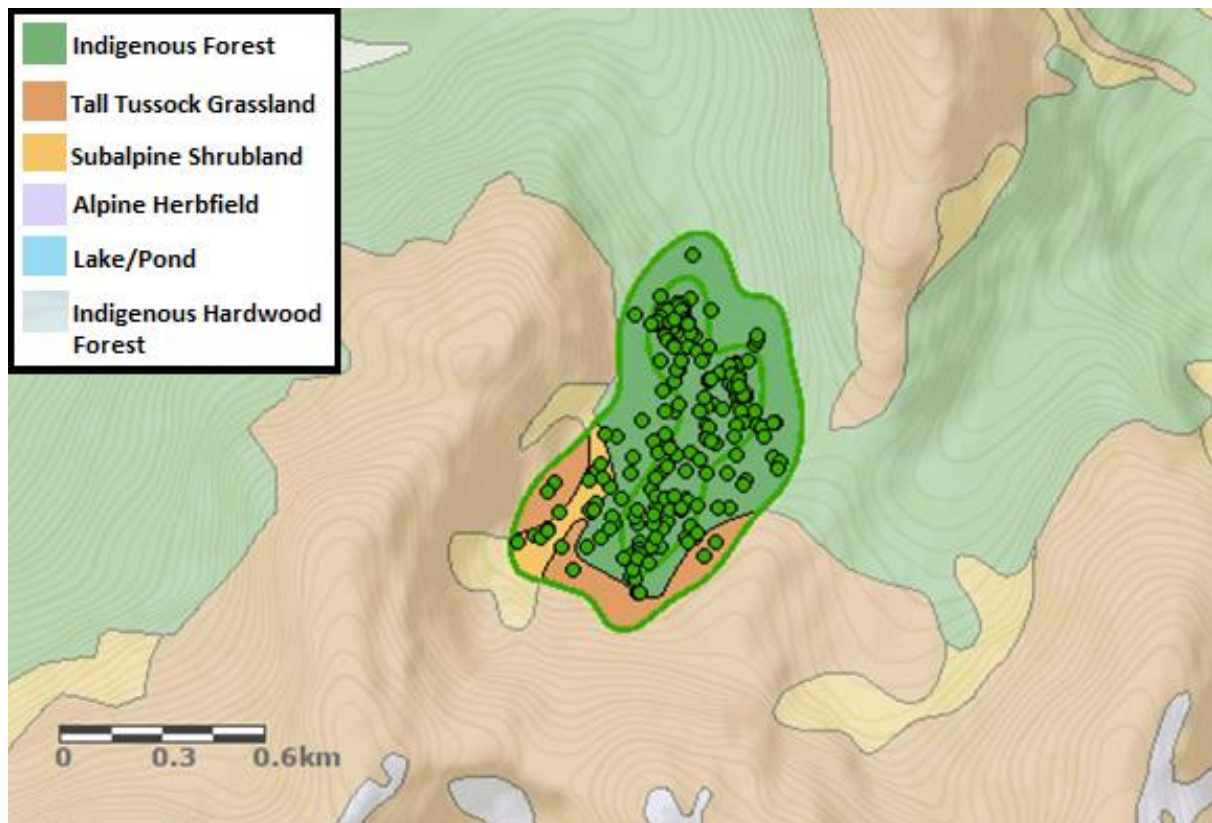


Plate 13: 95% and 50% KDEs for the Edith 2 cow.

It can be seen in Plate 13, above, that the Edith 2 cow concentrated its movements even more densely than the Edith 1 cow at the same site and subsequently had a smaller home range. These locations are also on north-east facing slopes with protection from westerly and southerly winds.

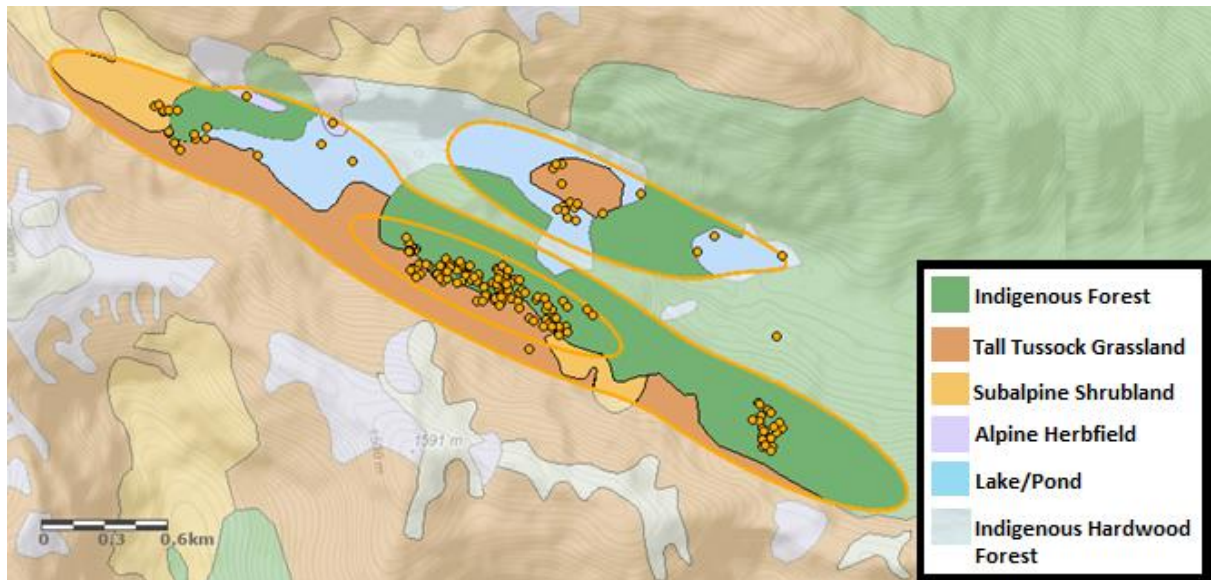


Plate 14: 95% and 50% KDEs for the Saints Creek bull.

It can be seen in Plate 14, above, that the Saints Creek bull had a very linear home range, preferring north-east facing slopes along one side of the valley. The 50% KDE was centred roughly in the middle of this area where a majority of the locations occurred in a dense linear manner. The locations occurring along this line were also consistent with the indigenous forest/tall tussock grassland ecotone which, stretches almost the length of the valley.

Chapter 5

Discussion

5.1 Summary

This discussion firstly addresses the results obtained during this study and then attempts to explain factors that may have driven these observations. This information has then been used, along with identified limitations, to formulate suggestions for FWF in their future studies of wapiti movements in Fiordland.

5.2 Discussion of results

5.2.1 Daily movement

Average daily movement was variable both within months and between animals. There was a general trend suggesting wapiti travel little more than 500 m on most days during winter. Some days, possibly where patches of high forage density were found, movement was only around 200 m per day or less. On a small proportion of days, however, animals would travel large distances, sometimes multiple kilometres (as much as 6 km/day). There was no significant difference in movement between males and females as one individual of each sex travelled a comparable distance to a member of the opposite sex. The results suggest that daily movement was partially driven by temperature as the average daily movement followed a similar trend as the average daily temperature experienced each month. However, this may have just occurred by random chance as only four of the six animals were analysed for daily movements, due to data deficiency. Furthermore, because the data was subsampled to standardise analyses (see methodology) and the days where travel was measured may not be a true representation of the movement each month or for the course of winter. Temperatures in Fiordland are at their lowest in winter (c. 4°C) reaching an annual minimum in July (c. 3°C) before rising in August (c. 5°C) as day length increases toward spring. It could be speculated that because plant growth would be limited during the entire period of this study, due to cold temperatures, that a general increase in movement would occur due to a gradual reduction in forage biomass. This would be a result of a depletive browsing effect where plant growth did not supplement forage availability but continual browsing by deer would result in a decrease in the total forage biomass at browsed sites (Wickstrom *et al.*, 1984).

When compared to other studies, daily movements of wapiti in Fiordland during winter were similar to those of other elk in Yellowstone National Park, North America, during early summer but almost ten times less than those in late spring (Craighead *et al.*, 1973), and around 3.5-10 times less

than red deer in Southern Queensland, Australia, during winter (Amos *et al.*, 2014). This is likely due to inconsistency of fix intervals (FI) between this and other studies. Other studies have used FIs of c. one hour in an attempt to buffer the effect of tortuous routes travelled by cervids which are not easily measured in straight-line distance (Frair *et al.*, 2005). As previously mentioned, in order to maximise battery life, GPS collars had long intervals (6 hours) between fix attempts. Long FIs (≥ 6 hours) have been suggested as being too long for accurate analysis of fine-scale movements such as daily travel (Pepin *et al.*, 2004). Mills *et al.*, (2006) stated that when movement paths are tortuous, the use of long FIs will increasingly underestimate actual movement distance. There is also a possibility that the low deer density (c.1/100 ha), resulting from previous aerial control, has meant that competition for forage is less of an issue. Forage availability is density dependant, therefore, a reduction in deer numbers would cause an increase in forage availability, thus limiting competition and decreasing movement. Red deer densities studied by Carranza *et al.*, (1991), in Spain, were between 0.5-1 deer/ha, c. 100 times the density of wapiti in Fiordland, and daily movements were subsequently ten times greater than wapiti in Fiordland. This would mean that wapiti in Fiordland would have to travel less, even during a period of reduced forage production.

It was determined that FIs should be reduced from six to three hours, allowing for eight fixes per day, to increase accuracy. The increasing of fix rates may also improve fix attempt success rates and ultimately the functional lifespan of devices. Mills *et al.*, (2006) found that FIs of intermediate length (e.g. 1.5 hours) had the highest efficiency as they balanced time required for location acquisition with the number of daily location attempts. Intermediate length FIs also provided reliable transmitter operational lifespans of ~ 1.75 years as GPS units could utilise ephemeris data from the previous fix, thus reducing the time spent acquiring telemetry at each location. Results of Cain *et al.*, (2005) suggest that an increase in fix rate, from every six to every three hours, may improve fix success rates by 5%. However, they did not take other factors into account, such as the interaction between fix interval and canopy closure. Therefore, it may be possible that by increasing fix rates, the fix attempt success rate will increase, by greater than 5% in this study, as a result of ephemeris data reducing fix attempt periods and buffering the effects of canopy closure.

5.2.2 Home range size

Home ranges estimated using 95% KDEs were larger than those estimated using 100% MCPs. This was not an expected result as KDEs tend to produce smaller and more accurate home ranges by excluding the areas in which locations did not occur (Seaman 1996, Hemson 2005, Benhamou & Cornelis 2010). The possible cause of this is the estimation of home range using an incorrect model. By selecting 95% KDEs the effect of areas surrounding each location becomes greater. This creates a systematic increase in the polygon created and the estimation of greater home ranges, when compared with KDEs of finer

scale. Home range estimation of deer has been shown to have better accuracy if 80% KDEs are used instead of 95% or 100% KDEs (Amos *et al.*, 2014), accordingly any future analysis will use 80% KDEs.

The extent of daily travel generally corresponded with home range size. The Wild Natives bull then Taheke cow had the greatest average movements each month and subsequently had larger home ranges. Daily travel is a key parameter of home range size (Mills *et al.*, 2006). If daily travel increased, as a result of reduced forage biomass during winter, so too will home range size. Home ranges of wapiti in this study were smaller than in previous studies of annual home ranges (Craighead *et al.*, 1973, Moeller 2010, Starr 2013) and even winter ranges (McCorquodale 2003, Anderson *et al.*, 2005) of elk in North America. Home ranges of our wapiti were also smaller than red deer in Australia (Amos *et al.*, 2014), but similar in size to that of red deer in Spain (Carranza *et al.*, 1991) and the Swiss Alps (Bocci *et al.*, 2010). It is difficult to compare home range areas among different studies since the results will vary based on the method of estimation used, as well as the influence of sample sizes on the results (Moeller 2010).

The Wild Natives bull had a larger home range than any of the other study animals which was more comparable in size to home ranges of other elk in North America (McCorquodale 2003, Moeller 2010). It could be suggested that this animal, being of stronger wapiti phenotype and larger size compared to the other two bulls, may express more wapiti-like behaviour with regards to ranging. Scaling of body mass to range use is well documented and would suggest the greater size of this animal would mean it had a greater energy requirement and have to travel further to find more food. This may therefore be apparent as a requirement for greater feed intakes and the observably larger home range (refer to Plate 11 and Table 11). The home range of this bull did, however, contain a large proportion of tall tussock grassland (TTG). Tussock grassland would have a lower plant diversity and production than the forest/field interface, based on the previous findings of Winn (1976). Furthermore, when grazing pasture deer have been shown to reject patches, regardless of forage quality, if a threshold biomass is not available (Foccardi *et al.*, 1996). Wickstrom *et al.*, (1984) also found that elk were reluctant to expend feeding effort in grass swards of low biomass, regardless of digestibility. This would mean that animals spending a greater proportion of time grazing open areas rather than foraging near the forest edge, such as the Wild Natives bull, would likely travel more to find patches meeting the forage biomass threshold. Furthermore, it was notable that animals sharing the same ranges had similar home range size when compared with animals at different sites. This supports the theory that ranging behaviour is forage driven as similar home ranges will provide similar forage availability and thus a different requirement to travel to find patches meeting the forage biomass threshold.

As seen in Plate 11 the 95% KDE for the Wild Natives bull encompasses peaks and ridgelines, where actual fixes did not occur. Although not statistically significant, as this study did not measure utilisation of slope or elevation, this brings into light the importance of selecting appropriate models

for the measurement of home range. It is important to note that although KDEs are attributed as being more accurate than MCPs they do not take into account natural barriers such as wide bodies of water and cliffs (Cecilia Latham, Landcare Research pers. comm.) which are a key part of the landscape in Fiordland. If inappropriate models or smoothing parameters are selected then biased estimation of home ranges and habitat selection is likely to occur (Seaman 1996, Nilsen *et al.*, 2007). Although larger and possibly more biased the 95% KDE seems to better reflect the shape of the wapiti home ranges and the density at which locations occurred within them, see Appendix 2. In this instance the 100% MCP may be superior to the 95% KDE as overestimation of home range is less noticeable.

5.2.3 Habitat Selection – 95% KDEs

Electivity values varied between animals showing the heterogeneity of different sites. Sub-alpine shrub land (SAS) was the habitat most strongly selected for by any animal (Pitt River bull $E=0.631$, Wild Natives bull $E=0.572$). This may reflect the importance of this habitat type as a source of food. The second most selected habitat was TTG (Taheke cow $E=0.250$, Edith 1 cow $E=0.130$). No general trend could be found in the preference for any habitat type as habitats that were highly selected for by some animals were highly avoided by others. It is important to note, however, that selection analyses based on the proportion of use in relation to the proportion of availability, such as Ivlev's electivity index, are limited (Johnson 1980). This would especially be the case in this study with long FIs resulting in fixes representing only a small proportion of the actual areas occupied. It may therefore be more beneficial to rely on the proportion of each habitat within the 50% core areas, see Figure 18, as these are the areas that animals spend a high amount of their time.

Alpine herb fields were a habitat type that were generally avoided ($E \approx -1$) or did not occur within the 95% KDE of most animals. This habitat type is described as areas of vegetation above the tree line, dominated by low growing and mat-forming herbs and grasses (LCDB v.4). The bare ground component in this land cover type is typically very high, and areas are usually associated with gravel and rock. This habitat type may be important within the lives of Fiordland wapiti as herbs are often highly nutritious (10+ MJME/kg DM, Bliss 1962) and have health benefits associated with beneficial minerals and secondary plant compounds (Ramirez-Restrepo & Barry 2005). This habitat type is, however, located at higher elevations which means winter grazing may be limited by reduced forage availability under snow cover and the animal's desire to expose themselves to unnecessary travel through the deeper snow. Snow depth has been reported to change the use of open and forested areas (Martinka *et al.*, 1974). This may result in wapiti selecting for habitats such as indigenous forest (IF) and tall tussock grassland (TTG) at lower altitudes. Other habitat features, such as landslides and ponds, were completely avoided ($E = -1$) which is probably due to the risk associated with moving through these habitat types. Wapiti have been shown to swim across ponds and lakes to access forage

sites and secret salt licks, but do so only occasionally as swimming is energy expensive (Toweill & Thomas 2002).

It can be seen that some land cover classes were not present in the home ranges of certain animals or were not selected for. Habitat use is a characteristic of its availability within the landscape (Hobbs & Hanley 1990). For example, indigenous hardwood forest (IHF) was not present in the valleys of any animal, apart from the Saints Creek bull, therefore, it could not be selected for by most animals even though it may represent an important part of the habitat for animals in the Saints Creek area. The Saints Creek bull did however, show an avoidance ($E = -0.439$) of IHF habitat suggesting that this habitat type was not an important part of the animal's home range.

From visual observation of Plates 9-14, it can be seen that fixes occurred predominantly on north-facing slopes or in the middle of large flat areas. This is likely a response to forage availability as cold winter temperature would mean that sunny exposed areas would be warmer. This aspect would also receive the greatest levels of photosynthetically active radiation (PAR), when compared to south-facing slopes, thus increasing plant growth (Taiz & Zeiger 2010). Ager *et al.*, (1983) showed that elk in the northern hemisphere remained on sunny south-facing aspects during the winter in order to maximise available temperatures whilst preferring shaded north facing aspects during the summer to avoid excessive temperatures. Without actual statistical analysis, preference for this aspect cannot be evaluated.

5.2.4 Habitat selection – 50% KDEs

The size of the 50% KDEs correlated with that of the 95% KDEs which is likely as the two are a product of similar parametric functions. There may be some level of bias in core areas as there was a notably low fix attempt success rate, on average, during this study. Increases in location error due to rugged terrain may represent a systematic bias in location data (Blackie 2009). For animals in heterogenous environments, such as Fiordland National Park, location error may result in misclassification of habitat use and limit the viability of statistical tests and lead to bias in conclusions (Cain *et al.*, 2005). Missing location data can result in under sampling of some areas compared to others. As animals are likely to bed in IF, due to the hiding cover it provides, there may be a reduced fix attempt success rate when animals are bedding which would represent a significant amount of each animal's time.

From observation of the 50% KDEs, it can be seen that IF was an important habitat type within core areas as it was present at a significant level for all animals. This is likely due to the importance of forest for providing bedding sites for animals. It has been shown that elk prefer bedding sites with hiding cover to reduce the chance of detection by predators during times of vulnerability. Although no natural predators of wapiti, apart from humans, are present in New Zealand the innate behaviour to avoid predators is likely to drive some habitat choice.

Another important habitat type within core areas was TTG which was notably present in the core areas of all but one animal. This highlights the importance of not only TTG as a habitat choice, but also the importance of the forest/field interface. With a high proportion of both forest and open habitat within the core area of animals there will undoubtedly be a significant area where the two habitat types meet in an ecotone. Wapiti browsing these areas would benefit from both high levels of forage biomass and immediate access to hiding cover. There is a general decline in habitat use by wapiti with increasing distance from the forest edge (Coop 1971, Winn 1976). This is supported by the findings of Leckenby (1984) who observed that at least 80% of elk use in summer forage areas in the Blue Mountains, Oregon, occurred within 300 m of the forest/field border.

Sub-alpine shrub land also occurred within most 50% core areas, to a lesser extent, which would provide animals with further forage options. The class is transitional between IF at lower altitudes and TTG, alpine herb fields, and alpine gravel and rock above 1200 - 1300m (LCDB v.4). Plant communities in this habitat are more stable than lowland scrub types with composition and height strongly influenced by rainfall and exposure. Typical species present include *Hebe*, *Olearia*, *Dracophyllum* and *Cassinia* with canopy height ranging from 0.3 – 4 m. Wapiti may therefore select SAS for its ecotonal qualities of high forage production and proximity to hiding areas, also mentioned in the paragraph above.

5.2.5 General Conclusions

In conclusion, it can be seen that daily travel and home range size varied between individual wapiti during winter. It is likely that ranging behaviour was driven by forage availability. Reduced forage production coupled with depletive grazing by deer, may have resulted in increased movements by individuals attempting to find patches of sufficient forage biomass, in late winter. Indigenous forest and tall tussock grassland made up large proportions of the available habitat and were subsequently reflected as large proportions of the habitat utilised and within the 50% core areas. It is likely that the forest/field interface may provide optimal forage options with high plant diversity and production coupled with proximity to hiding cover.

It was hypothesised that wapiti in Fiordland would have reduced ranging, both in movements and total area used, when compared to elk in North America. This hypothesis is supported by the cross-comparison of findings from this experiment with those of experiments carried out elsewhere. The home ranges of wapiti in this study were smaller than elk studied in North America and more comparable to red deer studied in Western Europe with similarly mild winters.

It was also hypothesised that wapiti in Fiordland would exhibit similar habitat preferences to previously observed preferences for forest/field border habitats. This hypothesis is supported by the findings of this experiment. The wapiti in this experiment showed a strong preference for ecotonal habitat as many locations were concentrated along the IF/TTG boundary. Most core areas were also

located on the forest edge. Some individuals also showed a preference for subalpine shrub land which is a transitional habitat between IF and TTG.

5.3 Limitations of study and future research

5.3.1 Fix attempt success rates

Fix attempt success was generally greater for animals whose fixes occurred predominantly in TTG and other open areas rather than IF. This is because the closed canopy of IF limits the availability of open sky, reducing the ease of acquiring a fix (Mills *et al.*, 2006). There have also been reports of interactions between long FI (≥ 6 hours) and low levels of open sky resulting in increasingly low fix attempt success rates (Cain *et al.*, 2005). The low average fix attempt success rates of this study may have limited the accuracy of data. Low fix success rates have been shown to cause misrepresentation of true values in sampling, leading to systematic bias in analyses and erroneous conclusions (D'Eon *et al.*, 2002). It may, therefore, be beneficial to increase the fix rate, not only to reduce the coarseness of results, but to increase the success rate of fix attempts which, will further increase number of locations retrieved.

5.3.2 Fix Rate

As the data for this project was supplied by FWF, parameters such as daily number of fixes and fix interval (FI) were predetermined. Fix intervals were set at six hours allowing for five fixes every 24 hours. The more a home range deviates from a smooth unimodal distribution, the larger sample size it will require for accurate estimates (Seaman 1996). It was determined that we had a sufficient number of fixes to calculate an accurate home range size as a minimum of 150 locations are suggested for this analysis (Mills *et al.*, 2006) and all our animals had at least 150 if not 200-300+ locations. Fix rates of six hours have been suggested as being too low for other detailed spatial analyses such as daily movement or habitat selection. Long FIs have also been found to reduce fix attempt success rates, by increasing the time taken to record a fix, which may cause systematic bias within the data. It is possible to carry out location studies with long intervals (>6 hours), however, the researcher must acknowledge the coarseness of the data being analysed (Cecilia Latham, Landcare Research pers. comm.). It was therefore concluded that fix interval should be reduced to three hours allowing for eight locations within a 24 hour period. This would allow future studies to measure movements at a finer spatial scale and allow for measurements of habitat preference and activity during different times of the day.

5.3.3 Study Length

The short period of time associated with carrying out an honours project coupled with collaring of bulls late in the year meant that location data could only be measured for a short period (three months), in order to ensure data standardisation between animals. This meant that seasonal differences in movement and ranging could not be identified, however, measurement within the three months of winter allowed for measurement of movements over a discrete time. Results from this study showed a correlation between temperature, a key driver of forage production, and average daily movement. Studies elsewhere have shown a significant difference in daily travel (Craighead *et al.*, 1973, Carranza *et al.*, 1991, Ager *et al.*, 2003, Amos *et al.*, 2014), home range size (Carranza *et al.*, 1991, Bocci *et al.*, 2010, Amos *et al.*, 2014) and habitat preference (Zhang *et al.*, 2013) between seasons. Accordingly, it would be beneficial to measure the average daily travel during other times of the year to assess the annual trend of movements.

5.3.4 Sample Size

This study was limited by the relatively low sample size of only six individuals and this means we must be cautious when making inferences with regard to how the actual population will utilise home range. Given the differences in daily movement, home range size and habitat selection exhibited by these animals alone, we cannot expect to have sampled the full range of movements and habitat use exhibited by this population. A similar study to this was that of Poole & Park (2001) who GPS collared six female red deer hinds, fixes occurred four times per day with a fix interval of six hours. This study and others like it recognised the limitations of their results as small sample sizes could not give a fair representation of the total population. Other location studies have been carried out on North American elk using low sample sizes, as collaring studies are expensive, due to both equipment costs and labour intensiveness of retrieving radio-telemetry data. Cleveland *et al.*, (2012) also used a small sample size (n=9) to measure the movement response of elk to hunting pressure by humans. This study however, had an elk herd of >300 individuals which rarely split into more than three groups, and groups were never observed without a GPS-collared elk. As mentioned in Latham *et al.*, (2014), at least 30 animals are needed to estimate resource selection of a population and 20-30 (or more) are needed to make statistical summaries of home range size. It would therefore be beneficial for future studies conducted by the FWF in having more collared animals.

5.3.5 Coarseness of LCDB Data

It is also important to note the coarseness of the Landcover data. Without direct assessment we cannot tell where the small patches of differing habitats exist within each land cover class. This may be especially apparent within the class IF which, has been noted within the Landcover database v. 4, as being a very broad class with no categorisation of sub-classes within IF having yet been undertaken. This is important as small habitat patches may be important for elk where they spend a large proportion of their time (Cecilia Latham, Landcare Research pers. comm.). Coarseness of data may result in misrepresentation of fine-scale habitat preference and bias within results. One GPS fix from the Wild Natives bull was recorded in the Landcover class “pond or lake”, as seen in Appendix 1. This single fix may not be statistically significant, but highlights the significance of water features within elk habitats. Aquatic plants have been shown to be an important part of elk diets in North America (Ager *et al.*, 1983), particularly in winter when snow cover limits the grazing of terrestrial plants (Craighead *et al.*, 1973). The overlaying of both LCDB data and satellite imagery, however, suggests that this fix did not occur within a water feature and was more likely located in TTG and this fix was reclassified as for analysis purposes. This shows the importance of evaluating mapping and location data with operators that are familiar with the study site, which can be used to recognise flaws within Landcover data and the appropriateness of models (Cecilia Latham, Landcare Research pers. comm.).

5.3.6 Additional Habitat Parameters

There was a wide range of electivity values between animals which, may represent the heterogeneity between sites and also show that habitat preference is too complex to be defined by a broad scale term such as land cover classes alone. Habitat preference is a result of multiple parameters (Ager *et al.*, 1983) and is unlikely to be explained solely by vegetation classes. It would, therefore, be beneficial for future studies to take other habitat parameters into account such as elevation, slope, aspect, and distance to hiding cover and water features. Furthermore, snow depth has been identified as one of the key factors limiting habitat use by cervids (Parker *et al.*, 1984, Telfer & Kelsall 1984). It may also be beneficial to carry out some form of direct survey of snow depths and tracking to identify the snow depths which wapiti are using during winter. Due to insufficient data from surveys, models of snow depth could not be created. It may also be too great of a risk to carry out direct snow depth assessments as Fiordland National Park has a high avalanche risk during winter (Ron Peacock pers. comm.).

5.3.7 Location Schedule Synchrony

Fixes between individual animals occurred at different times (around one hour apart) between cows and bulls. This prevented any analysis of interactions between some individuals, e.g. the Taheke cow and Wild Natives bull. Fix attempts should be scheduled for consistent times between animals in order to improve standardisation in sampling. Fix attempts should also be scheduled to the 24 hour clock, New Zealand Standard Time (NZST), to facilitate data analysis.

5.3.8 Selection for Wapiti Type

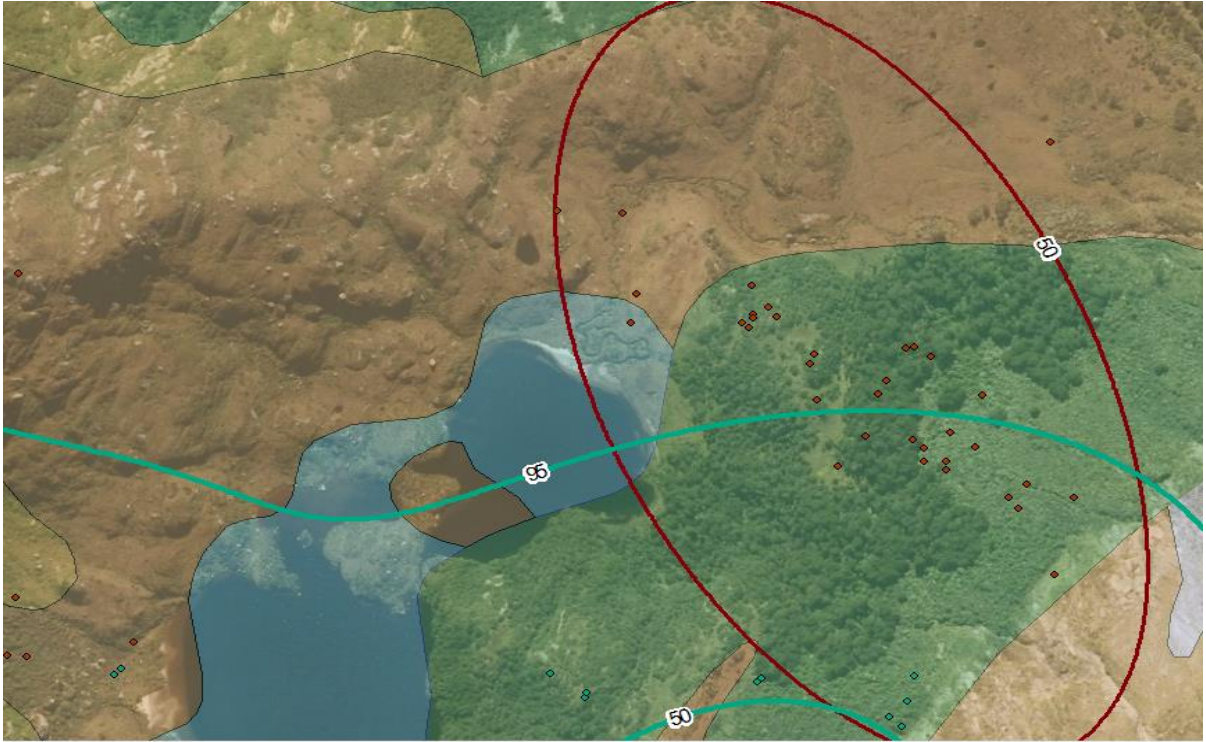
Future animals collared in this trial should be selected during observation from the helicopter for strong wapiti-type characteristics. If information gathered from this project is to be used in the inference of how wapiti-type animals behave, with regard to movements and ranging, then it is important that the animals within the trial are at least of a more wapiti-like phenotype than animals such as the Pitt River and Saints Creek bulls. This would be especially important for the comparison of ranging behaviour of the Fiordland herd with pure-bred wild elk in North America. The selection of animals based on wapiti phenotypes will also prevent animals having to be removed from the trial prematurely, before the next breeding season, as will occur for the Pitt River and Saints Creek bulls. Premature removal will not only limit the contribution of animals to the study but, also limit the replication across seasons by the same animal.

5.4 Overall conclusion

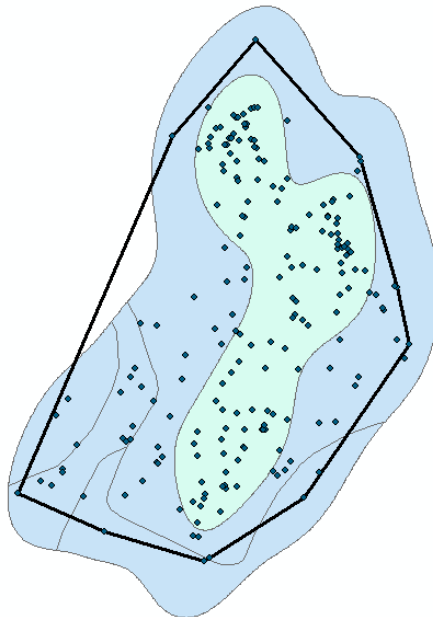
In conclusion this project successfully measured home ranges of wapiti in Fiordland for the first time ever. This will provide us with valuable information towards understanding how wapiti utilise their home range in Fiordland which, may be used in future management strategies of this population. Collared animals will continue to send out data, providing even more information for future studies. By increasing replication, both through animal numbers and measurement over a longer period, results will become more statistically reliable. The increasing of fix rates will also allow for finer temporal scale analysis of data and thus allow for more accurate results on a spatial scale.

Appendix

Appendix 1: GPS locations shown on Landcover classes and satellite imagery. The GPS point nearest the centre of the image is positioned in the lake, on the LCDB class, whilst satellite imagery shows it be positioned in open tussock country.



Appendix 2: 100% MCP, 95% KDE and 50% KDE for the Edith 2 cow. Note that although the KDE is larger than the MCP, the shape of the KDE seems more representative of the shape of the home range with regard to the density of locations.



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