University of Alberta

Habitat Selection by Feral Horses in the Alberta Foothills

by

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This thesis is dedicated to all who love the natural world, and work towards managing it for the future.

Abstract

Populations of feral horses have been increasing in the Alberta foothills and pose a concern to the conservation of native grasslands. Sustainable management of feral horses requires information on their habitat use. I utilized spatial data from radio-collared mares to assess seasonal habitat selection for two years beginning November of 2008. Field data were gathered to compare localized habitat use by feral horses, cattle and wild ungulates during summer. Grasslands were consistently selected while conifer forests avoided. Cutblocks were selected only in winter. Feral horse use of vegetation increased within open habitats and decreased with increased human disturbance (i.e. roads, trails and cutlines). Based on pellet surveys, horses use increased with disturbance, was positively related with cattle use, and more likely to occur in open habitat, but decreased with increasingly rugged terrain and greater wild ungulate use. Information provided by this study may necessitate changes to regional range management plans.

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List of Symbols and Abbreviations

-2LL – Negative Two Log Likelihood

ADF – Acid Detergent Fibre

AIC – Akaike Information Criteria

AICc –Akaike Information Criteria adjusted for small sample sizes

$AICc_i$ – Akaike Information Criteria for Initial Model

$AICc_{min}$ – Akaike Information Criteria for Candidate Model

ANS – Avoided, Neutral, Selected

ASRD – Alberta Sustainable Resource Development

AUM – Animal Unit Month

β – Beta Coefficient

BIC – Bayesian Information Criteria

BLM – Bureau of Land Management

^{o}C – Degrees Celsius

cm - Centimetre

CP – Crude Protein

CTI – Steady State Wetness Index

DEM – Digital Elevation Model

DOP – Dilution of Precision

EXP – Exponent

GCS NA 1983 – GCS North American 1983

GIS – Geographic Information System

GPS – Geographic Positioning System

HMA – Herd Management Areas

HMU – Horse Management Unit

ha - Hectare

Hr – Hour

k – Number of Parameters

kg - Kilogram

km - Kilometre

m – Metre

mm – Millimetre

n – Sample Size

N - Nitrogen

NAD 1983 – NAD 1983 UTM Zone 11N

NAD 1983 10TM – NAD 1983 10TM AEP Resource

NW - Northwest

OHV – Off-Highway Vehicle

Proc CORR – Pearson Correlation Statistical Procedure

Proc COUNTREG – Count Regression Statistical Analysis

Proc GENMOD – General Linearized Model Statistical Procedure

Proc GLIMMIX – General Linear Mixed Model Statistical Procedure

Proc LOGTISTIC – Logistic Regression Statistical Procedure

Proc MIXED – Mixed Model Statistical Procedure

R^2- Regression Goodness-of-fit Measure

RMFR – Rocky Mountain Forest Reserve

RMFRA – Rocky Mountain Forest Reserve Association

RMNR – Rocky Mountain Natural Region

RSF – Resource Selection Function

RSPF – Resource Selection Probability Function

SE – Standard Error

SW – Southwest

TRI – Topographic Ruggedness Index

USA – United States of America

UTM – Universal Transverse Mercator

WFR – Wild Free-Roaming

WHOAS – Wild Horses of Alberta Society

ω_i – Model Probability

X – Unknown Variable

ZINB – Zero-Inflated Negative Binomial

ZIP – Zero-Inflated Poisson

1. THE PAST AND PRESENT OF FERAL HORSES ON PUBLIC LANDS

1.1 Introduction

Wild horses (*Equus ferus*) of the Equidae family were historically well-established inhabitants of North America until extirpated from the continent more than 8,000 years ago during the Pleistocene mega-faunal extinction (Lever 1985). However, the domestic horse (*Equus ferus callabus*) was introduced with the exploration of European settlers and the invasion of the Spanish Conquistadors in the 1500s (Singer 2005 and Lever 1985). As domestic horse populations expanded with settlement, these animals were the basis for the large populations of feral, free-ranging horses that currently occupy large areas of the western United States and portions of Canada (Singer 2005, Lever 1985).

Large populations of horses were coined "mustangs" as they consisted of escaped and released horses or their descendents, often with mixed bloodlines (McKnight 1959). These horses were, and often still are, referred to as wild horses, even though they remain of feral origin and are genetically different from the wild horses that once occupied North America. Despite the common misconception, these terms and the existence of these horses seem to create a sense of freedom and wildness of spirit, in turn leading to a strong bond that can often be found between the public and these animals (McKnight 1959). While historically this bond existed in large part due to society's reliance on horses for food, work, and transportation, more recently horses are valued as a source of recreation (Singer 2005). The "wild wild west" was a time when the horse was particularly valuable, and although the need to have a horse for everyday survival is no longer present, there remains a strong intrinsic need by society to see these populations remain and thrive. These strong feelings can make it challenging to manage current feral horse populations by balancing environmental and social concerns (Nimmo and Miller 2007).

In the USA large populations of horses have been reduced to smaller herd sizes through relocation efforts that moved horses into reserves managed by the Bureau of Land Management (BLM) (BLM 2011). Additional, herd management is accomplished through the removal of excess animals via adoption to private owners (BLM 2011). While this may not be the easiest and most economical management method, it allows for the retention and management of horse populations and remains consistent with the strong sentimental values held by the public. Nevertheless, the ongoing management of these horse populations remains problematic due to difficultly associated with finding sufficient adoptive homes (BLM 2011). Moreover, non-management is not considered an option as the maintenance of population numbers and range health is imperative for the longevity of both (BLM 2011).

In Canada the establishment of feral horse populations and associated management has been unique from that in the US, in part because these herds are not descendents of original free-ranging mustang herds. Feral horse populations can be found on Sable Island in Nova Scotia (Plante et al. 2007), in the Bronson Forest of Saskatchewan (Government of Saskatchewan 2009), in the Rocky Mountain Forest Reserve (RMFR) of Alberta (Government of Alberta 2011), and in the Cholcotin and Brittany Triangle of British Columbia (Government of British Columbia 2008). These various herds have unique origins and environments, and thus experience different levels of management according to provincial regulations, with management ranging from minimal or non-existent, to intensive capture programs attempting to maintain horse populations at sustainable numbers.

This study is focused on feral horses in a portion of the RMFR in SW Alberta, a foothill environment where horses have been present since the early 1900s. These populations started small but have continued to grow [Unpublished Alberta Sustainable Resources Development (ASRD) data]. Being a public land base, this area is managed for a variety of uses, including wildlife habitat management, livestock grazing, energy extraction, commercial timber management, and recreational activities, among others (Government of Alberta 2010). As these different activities continue to increase, so does the risk of habitat degradation, which could affect the range health of existing vegetation, as well as the sustainability of several land uses in the region, including livestock grazing, and the conservation of several endemic wild ungulate populations (e.g. elk, moose, and deer), as well as that of feral horses. The limited grasslands and shrublands in the area are of even greater concern as they are already known to be susceptible to ongoing shrub encroachment (Burkinshaw and Bork 2009) and are often vulnerable due to concentrated livestock grazing (Willms et al. 1988).

The stewardship of public lands in Alberta falls under the jurisdiction of ASRD. ASRD is responsible for the effective management of "Alberta's lands, forests, fish and wildlife" for "present and future Albertans" (ASRD 2011). As stewards of the land ASRD works with many different partners and stakeholders to manage the resource and maintain the health of these ecosystems. The added complication created when feral horses occupy these landscapes includes concerns over the impact of horse populations on habitats in the region, and potential conflict created with other land uses, including potential competition with wildlife and livestock for forage resources. Distinct differences exist on the perceived importance and role of horses in these landscapes. There are some who feel that because horses were introduced to the area, these animals should be treated like escaped livestock and removed from the landscape, or at a minimum, their populations managed to minimize conflict with other land uses, including the conservation of existing native plant communities (Tannas, 2010). Others feel that these horses require additional protection, a sentiment fuelled by incidences where feral horses have been illegally killed on public rangeland (CBC News 2009). Advocates for the increased protection of feral horses include the Wild Horses of Alberta Society (WHOAS) (WHOAS 2011).

The current method through which ASRD manages feral horses in Alberta is through Horse Capture Licenses, which are issued at the discretion of the Minister of Lands (ASRD 2011). However, this mechanism has not resulted in a consistent population reduction, as evidenced by increasing horse populations (unpublished ASRD data).

1.2 Study Justification, Purpose and Objectives

The management of any population of large herbivores on public land by ASRD and associated agencies (i.e. Fish and Wildlife Division), depends heavily on a reliable understanding of what habitats these animals require, and how those requirements may vary seasonally throughout the year. In the case of feral horses, limited information is available on what habitats these animals use, including those fundamental factors that may influence the use of specific habitat types (e.g. grasslands, forest, shrubland, etc.) commonly found across the landscape. Moreover, the widespread availability of comprehensive spatial data, including that provided by GPS (geographic positioning system) collars, can markedly increase the ability of researchers to test fundamental questions on habitat selection by animals.

This thesis reports on an original study involving a partnership between the University of Alberta, the Rocky Mountain Forest Reserve Association (RMFRA), and ASRD. It attempts to address questions surrounding habitat selection by horses and potential mechanisms for that selection, in a portion of the Rocky Mountain Forest Reserve, SW of Bragg Creek, Alberta. This research has been designed with the intent of gaining increased scientific knowledge of the specific behaviour and selection patterns of feral horses. This knowledge should assist land managers in understanding the habitat needs of feral hoses, including identifying those habitats likely to receive greater use from these animals. This information in turn, will help ASRD and other land management staff development more sustainable land management practices and policies, with the added benefit of potentially helping to relieve tensions between different stakeholders concerned with the future management of feral horses. Finally, this study will identify additional knowledge gaps related to the biology and grazing ecology of feral horses, and may therefore assist in the development of future research. Specific objectives of this research include to:

1. Identify those habitats that feral horses select, including how that selection may vary seasonally through the year, as well as throughout the day.

2. Quantify differences in key habitat characteristics during the summer, including forage quantity and quality.
3. Determine those spatial landscape features (e.g. distance to water, topography, proximity to cover) and other land uses (e.g. proximity to recreational trails), that may affect habitat use and selection by feral horses, through linkage of these data to both observed GPS telemetry data, and to field plots assessed in midsummer.

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2. LITERATURE REVIEW

2.1. Feral Horses

2.1.1. History

The feral horse (*Equus ferus callabus)* of today is a member of the horse family Equidae, which belongs to the order Perissodactyla (Franzen 2010, Lever 1985, Clabby 1976). These animals are the same species as domestic horses, the ancestors of which were domesticated rather than wild (*Equus ferus callabus*). The domestic horse is related to the extinct Tarpan (*Equus ferus ferus*) (Kavar and Dovč 2008). The only true wild horses believed to be present today are Przewalski's horses (*Equus ferus prezwalskii*) (Lever 1985, Clabby 1976, Simpson 1951). In the 1950's, expeditions to find Przewalski horses were becoming more unsuccessful (Simpson 1951). The last wild Przewalksi horses were seen in the Gobi desert in 1968, and remained only in captivity (Franzen 2010). Re-introduction of the Przewalski's horses has since been undertaken in numerous regions and several projects have been successful (Machteld et al. 1996).

The first interaction between humans and wild horses occurred about 15,000 years ago, and the first signs of domestication were evident approximately 9,000 years later (Goodwin 2007). Wild equids were present in North America until approximately 8,000 years ago when the Pleistocene mega-faunal extinction occurred (Lever 1985). Domestic horses were introduced to the continent in the 1500's and there is some debate over whether they were brought over by the Spanish Conquistadors or the Europeans (Singer 2005, Lever 1985 and McKnight 1959). Regardless of who is responsible, equids were re-introduced to the continent around 1519 and spread widely through war, thievery, escape and release. The spread of domestic horses led to the development of feral or 'escaped', horse herds. The term "mustang" was coined for these horses as they were a mix of many breeds, instead of purebreds (McKnight 1959).

By the 1800's it is estimated that there were millions of feral horses roaming North America. In the late 1800's and early 1900's many horses were captured and sent over for use in the Boer War, used for domestic military purposes, put to use on farms and ranches, or exploited for human and animal consumption (Singer 2005, Lever 1985). As settlement increased and fencing became more popular, the feral horse slowly lost its ability to exploit its preferred habitat (McKnight 1959). By the mid-1900's there were efforts from both American and Canadian agencies to remove feral horses from the landscape (Level 1985). In 1971, *The Wild Free-Roaming (WFR) Horses and Burros Act* was established by the United States Congress and administered by the Bureau of Land Management (BLM) (BLM 2011). Prior to the WFR Act horses and burros were roaming on more than 50 million acres of land, but now reside in Herd Management Areas (HMA) that total approximately 30 million acres (BLM 2011). To maintain appropriate herd numbers the BLM removed excess animals from the range. Some animals are adopted out, while those that are over ten years of age or have been passed over for adoptions three times are available for sale to private owners (BLM 2011).

Herds in Alberta are managed differently than those in the United States as official management occurs under the Horse Capture Regulation in the *Stray Animals Act* (Government of Alberta 2008). This regulation stipulates the number of capture licences that are available in a year, and what equipment must be used to capture the horses (Government of Alberta 2008). Feral horses in SW Alberta are descendents of workhorses released in the early 1900's (Government of Alberta 2011). Despite capture attempts on these horses, not all efforts were successful and this marked the beginning of Alberta's feral horse herds. Since that time three significant herd management units (HMUs) have developed in the eastern slopes of the Rocky Mountain Forest Reserve (RMFR). Minimum population estimates in 2009 from aerial surveys showed that there were approximately 131 animals near Bragg Creek, 98 animals from Highway 1 to the Red Deer River, and 437 animals in the Clearwater River Area (Unpublished ASRD data). Ongoing aerial surveys suggest that populations of feral horses are increasing (Unpublished ASRD data) as minimum population estimates have increased to greater than 1000 feral horses between the three HMUs in 2010.

These large herds are broken down into numerous discrete harems that each consist of one to a few stallions, and numerous mares with foals.

2.1.2. Social Behaviour

Feral horses are gregarious animals that live in four types of familial groups: harem or band groups, multiple male and female groups, bachelor male groups, and maverick females (McCort 1984 and Linklater et al. 1999). Harems are normally defined as one stallion and numerous mares and their foals (McCort 1984). However, they can also be defined as one to few stallions and numerous mares and foals (Linklater et al. 2000, Linklater 2000, Cameron et al. 2003), which would include multiple male and female groups in the definition of a harem. There is large variation in the size of harems with the average ranging between 3.4 to 12.3 horses (McCort 1984). Salter and Hudson (1982) found that the average range for bachelor herds in Alberta was 1-6, while harems varied from 3-17 horses with relatively stable membership. Harems are typically well-adapted to changing environmental conditions including food supply (Goodwin 2007). They are normally stable familial units that vary little without outside interference. In contrast, bachelor male groups are not as stable and the animals within them are likely to change often (McCort 1984), while maverick mares tend to wander extensively (Linklater et al. 1999).

The social structure within harems is important to how horses interact with one another and the social hierarchy within each harem may vary depending on the occupants and the conditions of the surrounding environment (i.e. food scarcity may alter interactions and make the hierarchy more pronounced). Harems with more than one stallion will have a male hierarchy within the herd (Linklater et al. 1999). Higher ranking stallions have greater access to the mares that are present. Harems with multiple stallions are more likely to have a variety of paternities among foals (Cameron et al. 2003). With different paternities there is the possibility that other stallions will try to kill the foals thereby returning mares to estrus sooner. As a result, mares are more likely to be protective of their foals because of aggression from non-paternal stallions (Cameron et al. 2003). The combination of mares protecting their foals and increased aggression from males due to the competition to breed can lead to reduced fitness in mares within multi-stallion herds.

Harems with only one stallion have a different social structure. The stallion is often the dominant animal within the herd and responsible for mare protection (Linklater et al. 2000, Ganskopp and Vavra 1986). However, there are instances where the stallion may not be the dominant animal within the herd (Houpt and Keiper 1982), and mares may be more aggressive than stallions. Mares are more likely to be dominant in herds where the stallion is a juvenile (Sigurjonsdottir et al. 2003). Mares in single stallion harems are likely to have better animal fitness than those in multi-stallion harems (Cameron et al. 2003) because they do not have to expend as much energy to protect foals and fend off advances from different stallions.

Similarities in social behaviour between different types of familial groups also exist. In both types of harems, single or multi-stallion, the majority of foals leave the group when they approach maturity. These young typically leave voluntarily to join up with another, or to start their own harem (Goodwin 2007, Duncan 1992). This results in lower incidences of inbreeding in resident populations. It also means that as populations continue to grow there is a possibility that the number of different harems will continue to rise.

Harems and bachelor male groups usually have a core home range area that they do not deviate too far from (Linklater et al. 2000, Linklater et al. 1999), but they also do not show much indication of territoriality (Linklater 2000, Ganskopp and Vavra 1986). There is a wide range of home range sizes, from 0.8 – 303 km^2 (McCort 1984). Salter and Hudson (1982) found that home range sizes average 15 km^2 in SW Alberta. Although there is evidence in numerous cases that the home ranges of different harems overlap with little conflict (Linklater at al. 2000, Linklater et al. 1999, Linklater 2000, Ganskopp and Vavra 1986, McCort 1984, Salter and Hudson 1982), when there is a shortage of resources, stallions will actively defend their territory (Goodwin 2007). Where interactions occur between harems it is most likely to be between stallions of the groups (Salter and

Hudson 1982), but the majority of time, the less dominant harem will leave the area and avoid confrontation (Salter and Hudson 1982, Kruger and Flauger 2008).

2.1.3. Grazing Behaviour

Maximization of time spent foraging is important for ungulates so that they do not expend unnecessary energy, and is known as optimal foraging theory (Kie 1999). However, optimal foraging theory is not as appropriate for ungulates as they forage on a landscape where resource availability is heterogeneous (Senft et al. 1987). When differences between landscapes and patches are noticeable, animal movement is not random and ungulates choose patches that provide maximum benefit (WallisDeVries et al. 1999). Senft et al. (1987) suggest that ungulate foraging behaviour and movement should be examined by determining the different scales at which they can make decisions and the hierarchy surrounding these decisions. Choices can be made at the regional scale where the landform is chosen, at the landscape scale where communities or large patches are chosen, and at the community scale where micropatches, feeding stations and ultimately individual plants and plant parts are selected (Senft et al. 1987). At each level the decision can be affected by abiotic and biotic factors (Bailey et al. 1996). The decision can also be affected by temporal aspects as different plant communities will be available at different times of the year. For example, snow depth may impact what areas horses choose to forage based on what forage will be available (Salter and Hudson 1979). In contrast, areas with minimal forage availability such as those under conifer forests remain underutilized (Salter and Hudson 1979). The different decisions made at each level dictate what is available at the succeeding level and therefore, where and on what ungulates are likely to forage.

Grazing behaviour of ungulates is a function of several factors, including forage availability and quality (van Beest et al. 2010), socialization (Kruger and Flauger 2008), predation risk (Kie 1999), as well as morpho-physiological adaptations of the ungulate (Holechek et al. 2004). With respect to the latter factors, ungulates fall into two categories depending on their digestive system:

foregut and hindgut fermentors. Horses are hindgut fermentors characterized by an enlarged caecum that functions as a secondary fermentation chamber (Franzen 2010, Janis 1976). The caecum is vital to horse survival because it allows for the partial digestion of hemi-cellulose, a primary component of vegetation biomass (Doblin et al. 2010). Once complex carbohydrates have been exposed to fermentation in the caecum, it passes through the colon where nutrients have their last chance at absorption (Janis 1976). Hindgut fermentation in horses remains a less efficient system of forage digestion than the foregut fermentation in ruminants such as cattle (Shingu et al. 2010). However, the passage of forage through horses is much quicker than it is in foregut fermentors because ingested material does not spend as long in the rumen awaiting microbial breakdown (Janis 1976). This can be advantageous for horses because it allows them to increase the passage rate of food if required (i.e. when forage quality and associated digestion is low).

Horses are herbivores whose primary food source is the current annual (i.e. vegetative) growth of plants (Janis 1976). Horses typically prefer graminoids (Franzen 2010, Salter and Hudson 1979, Janis 1976), but the preference of individual animals may change depending on the immediate environment and time of year. In Alberta, Salter and Hudson (1979) found that the main components in feral horse diets were grasses, sedges and rushes. They also found that browse, specifically shrubs, were present in greater amounts during spring, while forbs constituted only a very small portion of the diet at all times of the year (Salter and Hudson 1979). This was supported by Irving (2001), who discovered that feral horses preferred disturbed areas dominated by grasses and avoided intact pine sites.

Similar to other large herbivores (Bailey et al. 1996), horses forage across different spatial scales, and selection at each scale affects what is available at the next scale. Harems typically have a home range that they are loyal to (Ganskopp and Vavra 1986, McCort 1984) and as a result, the patch and feeding station available to harems often remain similar each year. Although the home range may change to accommodate changes in resource availability from year to year, it seldom changes dramatically from its original boundaries (McCort 1984). Once the home range is established for each herd, they select their camp areas where they rest when not foraging (Bailey et al. 1996) together with their preferred feeding sites.

As with other ungulates, diet selection by feral horses must address the fundamental trade-off of obtaining sufficient forage of high enough quality to survive (Senft et al. 1987). Factors affecting horse foraging that have received considerable attention are generally related to individual grazed patches and their location. Horses prefer patches that are more productive than others (Edouard et al. 2009, Fleurance et al. 2009, Naujeck et al. 2004), so while they may graze throughout an entire patch site, they concentrate feeding efforts on the more productive portion of the patch. Horses tend to choose swards with greater biomass, but may exhibit no preference based on differences in digestibility (i.e. fibre content) (Fleurance et al. 2009). The location of patches on the landscape is also important to foraging decisions. Horses are more likely to spend time on flat pastures, but are also likely to utilize plateaus and sloping ridgetops when available (Ganskopp and Vavra 1987). Selection of patches that are easily accessible reduces energy expenditure, while patches with greater biomass allow horses to maximize their intake rate. Horses also maximize their intake rate by increasing the number of bites they take, although this strategy will ultimately be limited by the size of the individual animal (Fleurance et al. 2009).

Social interactions also influence where horses forage, and in what order individual animals are allowed to feed. Maternal behaviour impacts where foals are likely to forage, as they mimic the behaviour of mares (Goodwin 2007, Cameron et al. 2003). Herd hierarchy also affects where horses eat, as submissive or lower ranking animals will move out of the area that higher ranking animals prefer to occupy (McCort 1984). Avoidance of dominant animals during foraging (Kruger and Flauger 2008) may lead to reduced fitness in those individuals relegated to lower quality habitats or patches. This effect is exacerbated with multiple horse harems in one area, as subordinate individuals are prevented from moving to new areas in search of favourable foraging locations by adjacent harems. McCort (1984) found that harems that were more submissive or less aggressive generally gave way to those more dominant. This effect could cause entire harems to be in better condition than others given limitations in resources, including forage.

Resources in the home range of a harem may be further limited by seasonal conditions, or by other ungulates utilizing similar resources. In areas where water is limited harems are less likely to stray from water and are more likely to compete with other harems (Stevens 1988). Forage availability is particularly important at the end of the grazing season when biomass is limited (McInnis and Vavra 1987), and during spring prior to green-up when there forage is limited because growth has not yet occurred (Salter and Hudson 1979). If cattle are in the area there is a possibility of competition for resources as they demonstrate similarities in habitat use and dietary choice (Shingu et al.2010, McInnis and Vavra 1987, Salter and Hudson 1980).

Key differences in foraging behaviour exist between horses and cattle at the patch scale because cattle are less selective about what they eat while horses spend more time within preferred patches, as demonstrated by their tendency to take more bites per patch (Shingu et al. 2010). Between cattle, horses and wild ungulates, the former two tend to occupy the same foraging areas as they are the least likely to use steep slopes and rugged terrain (Ganskopp and Vavra 1987). There are however, some similarities in the dietary preferences of horses and elk at all times of the year, as well as between horses and moose in spring and summer (Salter and Hudson 1980). Little dietary overlap occurs between horses and deer because deer prefer browse (Hubbard and Hansen 1976). Although the dietary overlap between horses and wild ungulates is generally small, there is always the possibility that this may increase if habitat is limited and/or foraging conditions are poor. When this occurs the potential for range overuse and risk of resource degradation also increases.

2.2 Global Positioning Systems and Geographic Information Systems

Global positions system (GPS) technology is becoming increasingly popular in wildlife and livestock studies because it allows researchers to study animal movements without unintentionally influencing them. This technology typically consists of radio collars mounted around the neck of animals, and has made it possible to follow animal movements regardless of time of year and weather conditions (Moen et al 1997). When animal location data are collected it can be compiled in a geographic information system (GIS) together with resource maps of the study area, allowing for the collection, manipulation, conversion, analysis, and modelling of animal locations in space and time (Lo and Yeung 2002). Eventually, these data can lead to the development of electivity indices or resource selection functions (RSF) to allow for the determination of habitat selection.

Before habitat selection can be determined the advantages and limitations of GPS collar data must be assessed. Location fix accuracy is one of the primary things that must be considered when using GPS data in a habitat study. Prior to 2000, there was approximately a 40 m error between uncorrected location fixes and the actual collar location due to selective availability, the intentional degradation of satellite signals (Friar et al. 2004, Moen et al. 1997). This discrepancy is no longer an issue because selective availability no longer exists as the United States government no longer intentionally degrades satellite signals (Friar et al. 2004). Even without degradation however, attention still must be directed to other sources of error or interference.

Environmental factors are frequently major impediments restricting the reliability of location fixes or fix rate. Rugged terrain has the potential to create biases in the data because signals from satellites are intercepted or disrupted (Cain et al. 2005), thereby yielding inaccurate locations or reducing the number of fixes collected. D’Eon et al. (2002) found that topography alone was not the cause of poor fixes, but rather that the combination of tree cover coupled with rugged terrain had a large impact on reducing successful fixes. While Moen et al. (1996) found that increased canopy cover decreased the number of fixes, others have concluded that tree height rather than canopy cover is the limiting factor for GPS use (Dussault et al. 1999, Rempel and Rodgers 1997, Rempel et al. 1995). In any case, old growth forest with maximum tree height and canopy closure is likely to be the most difficult habitat within which to get accurate fixes.

It has also been hypothesized that movement by animals wearing GPS collars has the potential to interfere with collar function. This notion has been dispelled however, as numerous studies have shown that orientation and animal movement do not reduce collar effectiveness (D'Eon and Delparte 2005, Moen et al. 1996). Current collars have advanced to the point that they are now used in studies to assess energy budgets in cattle (Ungar et al. 2005), suggesting that they should be reliable for other large animals, including horses.

Dilution of precision (DOP) is another factor that can impact location error. DOP is a measurement of satellite geometry (Langley 1999); in particular how well positioned the satellites are to provide an accurate location. When a two dimensional fix is made it requires three satellites, for a three dimensional fix it requires four satellites: when those satellites are not orientated in an optimal position it can reduce location accuracy (i.e. location fixes obtained while the satellites are arranged in a linear fashion will have a very high DOP). When DOP factors are greater than six, spatial error is estimated to be more than 30 m (D'Eon et al. 2002), and these data are often omitted from the data set for analysis.

Many brands of GPS collars are available to collect spatial data. The Lotek collars being used in this study are designed so that they can collect up to 17,000 geospatial locations, which can be remotely downloaded, thereby allowing collars to remain on animals for more than a single year (Lotek Wireless Inc. 2010). These collars have been shown to be one of the most effective brands in the Canadian Rocky Mountains as they have one of the highest fix rates and do not require correction for habitat bias (Hebblewhite et al. 2006). This is important because it increases the reliability of the collars and suggests they will provide accurate information.

2.3. Resource Selection

Resource selection is the fundamental process whereby an animal chooses one type of resource over another to the point that use is disproportionate to what is available on the landscape (Manly et al. 2002). The act of selecting resources occurs by both people and animals, and is what leads to some areas of a landscape being used more heavily than others. Although resource selection itself is easy to define, it is difficult to quantify ecologically. A popular method to quantify resource selection is through the development of resource selection probability functions (RSPFs) and resource selection functions (RSFs). A RSPF is a function demonstrating the "probabilities of use for resource units of different types" (Manly et al. 2002). The RSPF is most useful when used and unused resources in a study area can all be determined through presence versus absence of the focal organism. If the entire selection cannot be counted however, then it is necessary to develop a RSF. The RSF is the RSPF multiplied by an arbitrary constant to create a standardized function proportional to the probabilities of use (Manly et al. 2002). For this study the focus will be on RSPFs for field site (i.e. presence versus absence) data, and RSFs for telemetry data as not all resource units in the area will be classified as used versus unused, but rather as used versus available.

Resource selection studies are becoming more popular as they allow researchers to start to quantify selection on the landscape. The scale of the landscape chosen is ultimately up to the researcher and must be selected such that the data collected are not taken out of context. Since scale affects actual selection that is measured, habitat selection will vary depending on the type of study that is done including the scale of data interpretation (Boyce 2006). It has been recommended that studies be conducted across multiple scales if possible since they are not independent of one another (Meyer and Thuiler 2006). Moreover, some of the different variables influencing selection may be useable at more than one scale, while others will be scale specific.

The different resource units that can be examined in an RSF are habitats used (i.e. organism present), unused (i.e. organism absent), and available (Manly et al. 2002). These different units were more difficult to examine in the past, but now the utilization of GPS collars and geographic information systems (GIS) allows for relatively easy determination of these units. These different units can be examined at different levels and frequencies, and in different combinations with one another. The most common combinations of resource units are used/unused and presence/available (Boyce et al. 2002). The different units can then be categorized into three different general designs: population level studies that look at the entire study area and all animals involved (design I); individual level studies that examine use for individual animals but consider available resources at the population level (design II); and individual level studies that use specific animals and also consider availability at the individual level (design III) (Manly et al. 2002). The choice of study design and types of resource units to be examined depends upon the study that is being conducted.

The theory of resource selection has been applied to habitat use and selection (D'Eon and Serrouya 2005, Boyce et al. 2003, Boyce and McDonald 1999), conservation planning (Johnson et al. 2004), evaluating predation risk (Hebblewhite et al. 2005), human-wildlife interactions (Hebblewhite and Merrill 2008), and estimating population numbers (Allen et al. 2008). The wide array of different studies demonstrates how useful resource selection functions can be to different types of research and associated resource management. RSFs also provide flexibility because they can accommodate many different types of resource (i.e. biophysical) information, including categorical and continuous variables (Manly et al. 2002, Boyce and McDonald 1999). The implication of this is that virtually all types of resource variables can be studied using RSF methods.

When developing an RSF it is important to consider that not all variables selected may be necessarily appropriate or independent of one another. To reduce the number of variables being examined correlations between different variables should first be examined. Among variables that are strongly correlated the one that is either easiest to measure or most useful for interpretation should be retained while others are removed from the analysis (Boyce et al. 2003, Johnson et al. 2000). After all relevant variables have been selected they are included in different combinations to create different models to try and explain the data.

Models can be developed through different statistical methods, for example, fitting a logistic regression, log-linear modelling, and generalized linear models (Boyce et al. 2002, Manly et al. 2002). Each data set will require a specific type of statistical model that will be determined by the type of data and the study objectives. In all situations however, models are created to identify and assess those variables influencing resource selection. Different combinations can then be analyzed using an information criterion to determine which models are the most appropriate and produce a ranking of models. Models that are most appropriate will contain variables that best fit the data based on explanatory power and parsimony.

Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC) are methods of inference developed by Hirostuga Akaike (Anderson 2008) and Gideon Schwarz (Schwarz 1978) to explain the goodness-of-fit of a model. Akaike developed his criterion based on the work by Simon Kullback and Richard Leibler so that the model closest to reality was chosen (Anderson 2008). BIC is based on the assumption that the real model does exist, and it is one of the competing models (Kuha 2004). Despite the different aims of the Criteria's they are similar because they rank the contrasting models that are developed by how close they are to reality. Rankings for both Criteria's are developed such that increasing model complexity is penalized and the model with the most explanatory power with the fewest variables is chosen (Anderson 2008, Ward 2008), which in turn allows the researcher to ignore variables that are not beneficial. BIC modelling may be better at handling larger sample sizes, such as those generated in GPS collars studies, because as sample sizes increases it places more emphasis on simple models than AIC (Raftery 1995). AIC and BIC modelling have been used in many different studies and are being paired with RSFs (Boyce 2006, Boyce et al. 2002). The combination of RSF's with the selection Criteria's allows for selection of the most appropriate model to explain geospatial data, including animal behaviour.

2.4. Study Area

2.4.1. General Area

The feral horse study is located in the McLean Creek Recreational Area, near Bragg Creek, Alberta. This area is located in the Rocky Mountain Natural Region (RMNR) of Alberta (Figure A.1, Appendix A). The RMNR is 49, 070km^2 or approximately 7.4% of the province (Natural Regions Committee 2006). This area consists of steep to mildly rolling hills with an elevation range of 825m to 3600m (Natural Regions Committee 2006). The bedrock sediments in the Region are from the Palaeozoic and Mesozoic ages in the Alpine and Subalpine Natural Subregions, and the Cretaceous and Tertiary ages in the Montane Natural Subregion (Natural Regions Committee 2006).

The Bragg Creek area is located in the Montane Natural Subregion. The elevation range is 825m to 1850m (Natural Regions Committee 2006). The Montane Natural Subregion comprises 0.9% of the province of Alberta, but has a large variety of plant communities (ASRD 2005). Bedrock sediments in the area belong to the Brazeau, Blackstone, Cardium and Wapiabi formations (Sheelar and Veauvy 1977). They are largely mudstone and sandstone. The wide range of elevations and topographic positions on the landscape results in this area having a high number of different soil types. Soil groups found in the area include Dark Gray Chernozems (most often under upland grasslands), Gray and Dark Gray Luvisols and Brunisols under forests or grasslands, and Gleysols and Organics in lowlands (Sheelar and Veauvy 1977). Gray and Dark Gray Luvisols are the dominant soils in the entire area.

The wide variation in soils is representative of a variety of vegetation. The dominant community types include: grasslands (native and modified), forests (conifer, mixedwood and deciduous), conifer cutblocks, and riparian shrublands (ASRD 2005). While the areas of each habitat vary widely, conifer forests occupy the majority of the region (Rhemtulla et al. 2002). Areas occupied by the different habitat types are approximately as follows; conifer forests at 69%, conifer cutblocks at 13%, mixedwood forest at 9%, riparian shrublands at 4%, and lastly grasslands at 4% (Table A.1. Appendix A). The remaining 1% is water.

Dominance of conifer forests may lead to forage shortages for herbivores in the area, as conifer forest is not regarded as primary range for cattle and horses, and typically has limited herbage in the understory. Herbage production of plant communities varies widely, and is generally ranked as follows: grasslands > shrublands > conifer cutblocks > forests (ASRD 2005).

Climate in the area is highly seasonal, with daily average temperatures at the Elbow Ranger Station ranging from -9^{o}C in January to 12^{o}C in July and August (Environment Canada 2010). Precipitation is lowest in December (~ 20 mm) and greatest in June (~ 104 mm), with the majority falling as rainfall during summer (Environment Canada 2010). Mean annual precipitation for the region is 644 mm (Environment Canada 2010).

2.4.2. Rocky Mountain Forest Reserve

The study area is located within the Rocky Mountain Forest Reserve (RMFR), an area of land set aside by legislation in 1910 to protect the water quality in the region (Government of Alberta 2010). In 1964, the *Forests Reserves Act* formally re-established the area as a place for conservation of vegetation and water quality under the control of the province of Alberta (Government of Alberta 2010, Province of Alberta 2004). The RMFR is within the Green Zone (publically managed) area of the province and is not only a place of conservation; it is also home to a host of different land use activities. These activities include wildlife habitat management, livestock grazing, energy extraction, commercial timber management, and recreational activities (Government of Alberta 2010). The ongoing utilization of the region by a wide variety of users is leading to fragmentation of many plant communities and increased risk of range degradation. This degradation is especially detrimental to grasslands in the area as they are already limited in area due to shrub encroachment (Burkinshaw and Bork 2009), which has led to decreases in forage productivity. Additionally, native *F. campestris* grasslands in the region are known to be susceptible to disturbance and overgrazing (Willms et al. 1985), resulting in changes in species composition.

The RMFR contains many different wild animal populations, including wolves (Hebblewhite et al. 2005), bears (Mowat et al. 2005), moose (Salter and Hudson 1980), elk (Allen et al. 2008), deer (Salter and Hudson 1980) and bighorn sheep (Brown et al. 2010). There are also feral horses and domesticated cattle throughout much of the region. With the numerous species found there are many different interactions that may occur, in turn affecting the habitat of all ungulates. Lack of available forage may present problems, especially in spring and fall when forage can be scarce.

One of the primary activities occurring in the study area is cattle grazing. The RMFR is divided into numerous grazing allotments, three of which encompass the study area. These areas receive cattle use [~2300 animal unit months (AUMs)] by around 1600 cattle, from approximately June 15th until October 15th of each year. To ensure the sustainability of livestock grazing in the RMFR, forest grazing permit holders have developed the Rocky Mountain Forest Range Association (RMFRA). The goal of the RMFRA is to work towards the sustainable management of grazing lands within the RMFR (Unpublished ASRD Data). The RMFRA was formed in 1998 and provides support for the ongoing conservation and management of range resources throughout the area (Unpublished ASRD Data).

Another major activity occurring in the study area is recreational activities, including off-highway vehicle (OHV) use. The McLean Creek Recreational Area is a 202 km^2 area that has been designated for OHV use with specific trails and routes for different types of OHVs (ASRD 2010). Designating this area for OHVs is an attempt to consolidate the impact of OHVs in one area rather than spreading them across the entire RMFR. Within the OHV area there are numerous other activities permitted; such as random camping (tents and trailers), hiking, horseback riding, cross-country skiing, and hunting and fishing (ASRD 2010). All these activities can lead to daily interaction between wild animals, feral horses, cattle and humans.

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3. SPATIO-TEMPORAL VARIATION IN HABITAT SELECTION BY FERAL HORSES IN THE ALBERTA FOOTHILLS

3.1. Introduction

The foothills region of Alberta is a publically managed, multi-use area that is important to public and private sectors. Common activities in the region include: natural resource extraction, commercial timber management, cattle grazing, wildlife management, and recreational use (Government of Alberta 2010). Many of these activities occur at lower elevations in the landscape, which are typically those areas with relatively uncommon grassland and shrubland habitats. As land use intensifies within the region there is increasing concern for the health of these habitats, particularly grasslands and shrublands that are small in area, susceptible to ongoing shrub encroachment (Burkinshaw and Bork 2009), and vulnerable to degradation due to concentrated livestock grazing (Willms et al. 1988) and disturbance (Alberta Sustainable Resources Development (ASRD) 2009). Conservation of these habitats depends on the availability of reliable information regarding their use and associated risk of degradation under various disturbances.

Relative habitat use of different ungulates in the area needs to be determined to maintain sustainable management. Cattle grazing is limited to the summer period (mid June to mid October), but feral horse populations rely on these habitats throughout the year. Habitat selection by feral horses is not well understood, as the last study conducted in the area (i.e. within 100 km) was done 30 years ago, and was limited to direct observational data (Salter and Hudson 1979, 1982). Further work near Hinton, Alberta, approximately 350 km northwest of Bragg Creek, was conducted by Irving (2001) on the impacts of feral horses on forest regeneration. This work was also limited to observations conducted at a localized scale. With the development of global positioning system (GPS) and geographic information system (GIS) technology, it is possible to examine spatial and temporal variation in habitat selection by horses at a much finer scale and over longer time periods.

Free-ranging feral horses have been present in the Alberta foothills since the early 1900’s (Government of Alberta 2011). Initial populations of feral horses originated from unwanted and released or escaped work animals that later evaded capture attempts in the 1920's. Feral horse populations in this region have been increasing since then (Unpublished ASRD data) and are supplemented by released or escaped individuals, as evidenced by the recent presence of feral horses with brands (personal observation, Tisa Girard). There are three major concentrations of feral horses in the eastern slopes of the Rocky Mountain Foothills. According to aerial estimates completed in 2009, there were at least 700 feral horses in different horse management units (HMUs) with the minimum population estimate increasing to 1000 in 2010. Approximately 131 of these horses were located in the HMU west of Bragg Creek. Each HMU consists of smaller familial groups called harems that are typically comprised of one stallion with multiple mares and foals (McCort 1984; Linklater et al. 1999). In Alberta, harems consist of 3-17 animals (Salter and Hudson 1982).

Habitat selection and utilization by herbivores may be influenced by many different factors (Senft et al. 1987). In the Alberta foothills, the abundance and composition of vegetation may have a large impact on those habitats horses select as they prefer herbaceous instead of woody browse as forage (Salter and Hudson 1979). Additionally, horses are known to prefer areas with greater biomass availability (Fleurance et al. 2009). Horses have previously been found to avoid sites with intact conifer forest and instead prefer disturbed areas (Irving 2001), such as roads and cutlines, where grass production is greater. Although water availability may impact horse selection in areas were water is limited (Stevens 1988), Salter and Hudson (1979) found water had no influence on horse use in the foothills of Alberta.

Landscape terrain is also likely to influence habitat selection, as horses are more likely to occupy areas with flat pastures or gently sloping ridgetops (Ganskopp and Vavra 1987). The accessibility of an area also plays a key role in regulating animal movement as it minimizes unnecessary energy expenditure (Senft et al. 1987). In areas with rugged topography or dense vegetation, the presence of roads and trails can increase accessibility, thereby increasing selection of those habitats in close proximity to these corridors. Alternatively, increased human presence (i.e. motor vehicles, recreational vehicles, hikers, etc.) may decrease animal selection of these habitats, particularly by wildlife (Laliberte and Ripple 2004). However, the net impact of these corridors on feral horses remains unknown. Finally, previous exposure to habitats by horses is also likely to influence future habitat selection of younger animals, with harems remaining loyal to a home range once established, and frequently following examples set by older animals (Launchbaugh and Howery 2005, Bailey et al. 1996, McCort 1984).

The eastern slopes of the Rocky Mountains contain high variation in the availability of habitats for free-ranging feral horses, with marked additional changes in resource availability over time (Hebblewhite 2005). Given the importance of grasslands to the conservation of biodiversity in the region, a greater understanding is needed of habitat selection and use by herbivores, including free-ranging feral horses. The objective of this study was to use global positioning system (GPS) technology to quantify habitat selection by feral horses across the landscape in a portion of the RMFR, including variation in habitat selection over time. Moreover, this study evaluates potential mechanisms influencing spatio-temporal variation in habitat selection by feral horses, including the role of habitat type, water availability and topography, habitat accessibility and human disturbance, as well as thermal characteristics.

3.2 Materials and Methods

3.2.1. Study Area

Feral horses examined in this study were from the HMU west of Bragg Creek, situated in the McLean Creek Recreational Area of Alberta, approximately 50 km SW of Calgary (Figure A.1, Appendix A). This area is located within the RMFR on the eastern slopes of the Rocky Mountains, and is important for supporting various land use activities in the region.

Landscapes in the study area fall within the Rocky Mountain Natural Region, more specifically the Montane and Subalpine Natural Subregions, with elevations ranging from 825m to 3600m (Natural Regions Committee 2006). Bedrock sediments in the area are mudstone and sandstone (Sheelar and Veauvy

1977), and produce a wide range of soil types depending on elevation and topography. Soil groups in the area include Dark Gray Chernozems under upland grasslands, Gray and Dark Gray Luvisols and Brunisols under forests, and Gleysols and Organics in lowlands (Sheelar and Veauvy 1977). Luvisols are the dominant soils in the area.

Vegetation is diverse across the region, and consists of a mosaic of relatively sparse grasslands [both native and modified (i.e. those altered to grazing-tolerant introduced plant species)] and riparian shrublands situated predominantly along valley bottoms, and uplands comprised of mixedwood forests, extensive conifer forests, and widely distributed conifer cutblocks (Figure A.2, Appendix A) (ASRD 2005). While areas of each habitat vary widely across the landscape, conifer forests occupy the majority of the region (Table A.1, Appendix A) (Rhemtulla et al. 2002). Areas occupied by the different habitat types are approximately as follows; conifer forests at 69%, conifer cutblocks at 13%, mixedwood forest at 4%, shrublands at 9%, and lastly grasslands at 4%. The remaining 1% is water. Herbage production of plant communities also varies widely, but is generally ranked as follows: grasslands > shrublands > conifer cutblocks > mixedwood forests > conifer forests (ASRD 2005).

Climate of the area is distinctly seasonal, with daily average temperatures at the nearby Elbow Ranger Station ranging from -9^{o}C in January to 12^{o}C in July and August (Environment Canada 2010). Annual precipitation for the region is 644 mm, with the majority falling as rain during summer (Environment Canada 2010): June (104 mm) and December (20 mm) are the wettest and driest months, respectively. Annual precipitation for both years of the study remained close to normal, at 624 mm (2009) and 633 mm (2010), although seasonal patterns of precipitation were not similar (Figure B.1, Appendix B). In 2009 precipitation was limited early in the growing season with a peak late in the growing season (Figure B.1, Appendix B). During 2010, the precipitation pattern was similar to normal, with the exception that peak rainfall occurred a few months later than usual (Figure B.1, Appendix B).

3.2.2. Geospatial Data Acquisition

The feral horses of focus for this study are a part of the HMU west of Bragg Creek herd, with an estimated 131 animals distributed among 11 harems. Five randomly selected mares from different harems were fitted with GPS collars in October of 2008. Only mares were collared because stallions are known to fight and could damage collars. Mares are also more likely to stay with the same herd longer than stallions, with the latter often fighting to maintain their position, and therefore at risk of being displaced. All collared horses were healthy, ranged in age from three to seven years, and were representative of the majority of horses. Collars were applied to horses through aerial netting and/or tranquilizer darting by Bighorn Helicopters Ltd. staff under the supervision of a certified, practicing veterinarian on 28 October, 2008.

Over the course of the study, authorized (i.e. permitted) feral horse extractions resulted in the lead stallion of one of the collared mares being removed in February of 2009. Consequently, this harem disbanded and the collared mare joined with another harem already containing a collared mare for the balance of the study. Thus, these 2 individuals were treated as 1 individual after that time in the analysis.

Lotek 7000 series GPS collars were used. Collars were programmed to record GPS locations every hour for a two year period from 28 October, 2008 through 8 October, 2010 for one mare, and through 25 October, 2010 for the remaining three mares. Remote downloads of geospatial data were conducted every three to four months. One collar dropped off early in June 2010, while the rest were removed in October 2010. For every positional fix of the animal, collars recorded the date and time, location (elevation, latitude, longitude), dilution of precision, ambient temperature, number of satellites used to obtain the fix, viability of the fix, and the type of fix (2D or 3D) (Lotek Wireless Inc. 2011). Collars weighed approximately 1.25 kg and did not appear to interfere with routine horse behaviour.

3.2.3. Data Preparation

Downloaded data on feral horse locations were entered into a geographic information system (GIS) using ArcGIS 9.3 (ESRI 2009), and converted to Universal Transverse Mercator (UTM) format. Horse data were gathered in the GCS North American 1983 (GCS NA 1983) system, and projected in the NAD 1983 UTM Zone 11N (NAD 1983) in ArcMap 9.3.1. Data were then examined in ArcMap 9.3.1 (ESRI 2009). Datasets were initially screened for errors caused by high dilution of precision (DOP) or incorrect fixes. Uncut conifer forests are the habitats most likely to experience incorrect fixes and poor satellite reception due to tree height (Dussault et al. 1999, Rempel and Rodgers 1997, Rempel et al. 1995). Although it may create a slight bias against conifer forests, points with a DOP greater than 6.0 (approximately 9.6% over two years of data) were removed from the dataset because they were considered inaccurate (D'Eon et al. 2002). Collars were initially turned on in Pincher Creek, Alberta, so those points and others that were obvious incorrect fixes (i.e. well outside the study area), as determined through visual assessment, were also removed.

Spatial data files describing different landscape features of the area were provided by ASRD. Data in the GIS included shapefiles of: locations of roads, Kananaskis Country recreational trails, cutlines, known water sources (i.e. rivers, streams and ponds), vegetation types, and a digital elevation model. Roads, trails, cutlines, and water source shapefiles were in GCS NA 1983 geographic coordinate system and projected as straight line data in the NAD 1983 10TM AEP Resource (NAD 1983 10TM) coordinate system. Habitat (i.e. vegetation) type shapefiles were gathered in the same geographic coordinate system, while being projected as polygon data in the NAD 1983 system. The digital elevation model (DEM) used a raster dataset with 25 m resolution in the same coordinate system as the habitat shapefiles.

Spatial data in the GIS were initially used to create different variables for the study area (Table 3.1). Habitat shapefiles were grouped into five categories: uncut conifer forest, conifer cutblocks, lowland grasslands, mixedwood forests, and riparian shrublands. Forest categories were also combined to provide a "forest" variable in addition to the two different forest types. The "spatial join" function in ArcMap 9.3.1 was used to determine which habitat type's individual horse observations fell within. The "near" function in ArcMap 9.3.1 was used to generate distances between data points and the different landscape features and cover variables.

The DEM was also used to generate additional topographic and solar radiation variables. A topographic ruggedness index (TRI) was generated using the DEM and an ArcScript created by Riley et al. (1999) to assess changes in elevation between adjacent grid cells. Solar radiation exposure of the area was calculated for diffuse and global solar radiation. Radiation values were calculated using an ArcScript originally created by Kumar et al. (1997), for 21 March, the first day of spring.

3.2.4. Resource Selection Analysis

Resource selection functions (RSFs) can be used to quantify how animals select specific areas of the landscape, and can be performed using a comparison of used vs. unused variables, or used vs. available variables (Manly et al. 2002). The current study was considered a type III design (Manly et al. 2002) to investigate resource selection for used vs. available variables. Horse use data were taken directly from GPS collar positional fixes, while available habitat data were generated from random points within each individual's home range.

3.2.4.1. Developing Home Ranges

Home ranges are the areas where animals perform the majority of their normal activity, and although there may be slight forays outside of the home range, these are representative of the area where the animal spends the majority of their time (Burt 1943). In this investigation, home ranges were created for each collared horse to determine the habitat and landscape features available to each animal. Initially, separate home ranges were developed for the different years and seasons of study, but as they showed little variation from one another, a single home range for each horse was developed for the entire study (i.e. two yr) period. Home ranges from different horses were also visually assessed for independence, and considered independent as home ranges typically followed watershed boundaries regardless of neighbouring harems, with some animals demonstrating overlap in home range and others very little, suggesting collared horses and their associated harems neither avoided nor preferred other harems.

As the study area is not a homogenous landscape it is important that established home ranges account for differences in availability of habitat types, variation in distances to different landscape features, and differences in topography. Kernel home range analysis is a "non-parametric statistical method for estimating probability densities from a set of points" (Rodgers and Kie 2010). For this study kernel home ranges were created using the Home Range Tools developed by Rodgers et al. (2007) in ArcMap 9.3.1 (ESRI 2009). As recommended by Blundell et al. (2001), fixed kernel distributions with the reference bandwidth were used to develop home ranges with 50%, 90%, and 95% use polygons. The 95% kernel home ranges were used to account for the majority of horse activities, as the smaller 50% home range may have resulted in the examination of resting areas only. Due to the short time lag (1 hr) between successive data points, spatial autocorrelation was present in the data. Work done by de Solla et al. (1999) found that an increased number of data points improved spatial accuracy and precision. As the removal of data points to reduce spatial autocorrelation would have decreased the robustness of home ranges, the entire corrected data sets were used for kernel home range development.

After home ranges were developed, random points were generated at a density of a single point per hectare over the entire range. This procedure provided an even distribution of resource availability assessment for each horse. Random points were used to determine the amount of habitat (vegetation types) available to each horse. Each random point was also assessed for the same landscape features that horse location data points were, thereby allowing for comparison of used and available spatial data.

3.2.4.2. Habitat Electivity Analysis

Ivlev's Electivity Index (Ivlev 1961) (see Equation 1) was initially used to determine horse selection for each habitat.

Electivity for habitat 'x' = (% horse data points in habitat 'x' - % random points in habitat 'x') / (% horse data points in habitat 'x' + % random points in habitat 'x') [1]

Horse use data were then compared with the available data to determine if specific habitats were selected or avoided (i.e. differed from random). Electivity's with confidence intervals greater than zero indicated a selection for that habitat, while those less than zero indicated avoidance (Ivlev 1961). Electivity's were calculated for each horse and examined for year, season and time of day effects to determine if they could be treated as random during further analysis. Differences in electivity among habitat types were examined using Proc MIXED in SAS 9.2 with the residual maximum likelihood method, using individual horse as a random effect (Gillies et al. 2006). The initial electivity analysis was used to determine the spatial [Avoided, Neutral or Selected (ANS)] division of data (see Section 3.2.5.2) for subsequent assessment of RSFs.

3.2.4.3. Developing Resource Selection Functions (RSFs)

Separate RSFs were developed for winter, spring, summer, and fall, as preliminary analysis showed there were marked differences in habitat electivity between seasons, but not between years. Seasonal cut-offs were established from combinations of expected changes in plant growth and associated forage availability based on known changes in plant phenology, snow cover, etc. Using these criteria, the winter season was set from 1 November to 31 March, and accounted for the majority of time when snow was on the ground (Figure B.2, Appendix B). Spring use was from 1 April to 15 May, accounting for the transitional period from dormancy through initial green-up of vegetation. Summer went from 16 May to 15 September, accounting for the primary growing season and time of greatest plant production and forage availability. Lastly, fall went from 16 September to 31 October, coincident with rapid plant senescence before snow fall alters forage accessibility. Although preliminary analysis was also done comparing horse activity between day and night, no diurnal patterns of horse use were evident. Thus, no further analysis was done addressing this particular notion.

Horse and random data points with all their associated habitat and landscape variables were combined in Microsoft Excel (2007) to create a dataset for each animal. Used data points were set to “1” while those available were set to “0”. Variables used for resource selection were those described in Section 3.2.3 (Table 3.1). All variables were initially examined for redundancy using Pearson’s correlations with Proc CORR in SAS 9.2. For variables correlated at $|r| > 0.7$ across all horses, redundant variables were removed so that there was only one representing the group: however, variables were retained when at least one horse did not show correlation prior to data combination. The diffuse solar radiation and elevation x ruggedness variables were correlated with ruggedness. Ruggedness was kept because it was considered representative of many different environmental variables. Similarly, the distance to water x elevation variable was correlated with distance to water, with the latter retained because it was considered easier to measure and interpret (see Section 3.4).

Variables were divided into various themes representing different *a-priori* hypothesized requirements of feral horses in the region. The different themes and variables included were:

1. Null model with no additional variables. [Additional analyses were run using the ANS as a surrogate null model to determine if habitat effects were dominating the models (see Appendix C). Since the ANS was not overwhelming the models, it was not used as the null reference.]
2. Habitat model with the five different categories condensed into ANS according to the previously described electivity analysis (see Section 3.2.6).
3. Water and Topography, including
    a. Distance to water
    b. Ruggedness
    c. Ruggedness x distance to water
    d. Water distance + ruggedness

e. Water distance + ruggedness + water x ruggedness

4. Disturbance, including

   a. Distance to roads and trails

   b. Distance to cutlines

   c. Distance to roads and trails + distance to cutlines

5. Thermal, including

   a. Distance to all forest (conifer or mixedwood)

   b. Distance to conifer forest

   c. Distance to mixedwood forest

   d. Solar radiation

   e. Distance to conifer forest + distance to mixedwood forest

   f. Distance to conifer forest + solar radiation

   g. Distance to mixedwood forest + solar radiation

   h. Distance to forest + solar radiation

   i. Distance to mixedwood forest + distance to conifer forest + solar radiation

To determine which variables were most representative of each theme the -2 log likelihood (-2LL) was obtained using Laplace Approximation with horses as a random effect in Proc GLIMMIX in SAS 9.2 (Gillies et al. 2006). Akaike Information Criteria (AIC) and Bayesian Information Criteria (BIC) were initially used to rank models, but the large sample sizes overwhelmed the AIC and BIC so a different method was required. The -2LL was used to generate a pseudo R^2 (goodness-of-fit) for each model to compare the percentage of deviance explained by all models in comparison to the null (Cameron and Windmeijer 1997, Windmeijer 1995) (see Equation [2]).

McFadden's pseudo R^2 = 1 – (log likelihood candidate model / log likelihood null model) [2]

The model within each theme that best explained deviance in horse use was chosen. Usually, this was the model with the greatest actual percent of deviance explained, with the condition that increasing the number of variables by one had to produce an increase of at least 1% in the deviance explained. The exception was if none of the models had an explanatory power greater than one, in which case the best model was still chosen to move forward to represent that theme in the final model testing to prevent the possibility of missing compounding effects. The process of model selection was completed separately for each season. Finally, additional models were created treating ANS (i.e. habitat selection) as a null model following the same process outlined above.

Once the representative model for each theme was chosen they were combined in an additive fashion, and again run through Proc GLIMMIX using the Laplace Approximation, to determine the final model accounting for horse use patterns. The first model used only the theme with the greatest explanatory value from the previous stage. Themes were then added and tested in a descending fashion, but were only carried forward to the next step where they gave a 1% increase in pseudo R^2. This was done for each season to generate the final themes and variables to be included in the RSF for feral horses across the study area.

Final RSFs (Manly et al. 2002) were developed to describe the relationships between horses and the different landscape characteristics (see Equation [3]).

$$\text{RSF} = \exp(\beta_1 x_1 + \ldots + \beta_p x_p) \qquad [3]$$

The beta (β) coefficient was obtained from the Proc GLIMMIX (SAS Institute 2007) output used to obtain the -2LL. As a last step, the RSF was combined in ArcGIS (ESRI 2009) with the spatially mapped environmental data to create habitat suitability maps for feral horses throughout the study area.

3.3. Results

3.3.1. Kernel Home Range and Electivity

Kernel home range analysis indicated that the horses fitted with GPS collars occupied markedly different areas, both in size and spatial location (Table 3.2; Figure 3.1). The entire area of kernels also dictated the number of random points used in the subsequent RSF analysis. The 95% kernel home ranges of horses in this study ranged from 12.4 km^2 to 90.8 km^2 in size. Random points were generated at a rate of 100 per km^2; resulting in 5640 random points for

Horse 1, 1240 points for Horse 2, 9080 points for Horse 3, and 3470 random points for Horse 4.

Patterns of horse electivity between habitats varied markedly across individual seasons (Table 3.3). During the winter, conifer cutblocks and grasslands were both selected ($p<0.05$); while mixedwood forests and riparian shrublands remained neutral (i.e. not significantly different from zero) ($p<0.05$) (Table 3.3). In contrast, conifer forests were avoided during winter ($p<0.05$). In spring, lowland grasslands, mixedwood forests and riparian shrublands were all preferred, although lowland grasslands were the most preferred ($p<0.05$). Cutblocks were neither selected nor avoided during spring, and conifer forests were again avoided. In summer, lowland grasslands and riparian shrublands were again selected, with grasslands the most selected ($p<0.05$). Neither conifer cutblocks nor mixedwood forest differed significantly from zero at that time. Although conifer forest was avoided in summer, it remained marginally different ($p<0.06$) from mixedwood forest. Finally, lowland grassland was selected in the fall, but remained similar to conifer cutblocks, and differed marginally from mixedwood forests ($p<0.09$). Horses exhibited neither selection nor avoidance of conifer cutblocks, mixedwood forests and riparian shrublands during fall.

Electivity varied seasonally for each habitat type (Table 3.3). Grasslands were consistently selected in every season (Table 3.3), though electivity for these areas during fall remained lower than at other times ($p<0.05$). Riparian shrublands were selected in spring and summer, but experienced neutral selection in winter and fall ($p<0.05$). Conifer forests were consistently avoided in all seasons ($p<0.05$), but were particularly strongly avoided by horses in spring. While conifer cutblocks were selected in winter ($p<0.05$), these areas were neither selected nor avoided in all other seasons (i.e. spring, summer, and fall). Finally, mixedwood forests were selected in spring only ($p<0.05$), with no selection or avoidance for this habitat in all other seasons.

3.3.2. Resource Selection

Comparison of the initial *a-priori* models within individual themes indicated that the same variables or variable combinations explained the majority of deviance in observed horse distribution across the study area during winter, spring and summer (Tables 3.4-3.7), and were therefore carried forward to the final analysis. The ANS model represented the habitat theme and was carried forward to the final models by default as it was the only variable in the theme. The ruggedness variable was consistently carried forward from the water and topography theme. As the model with "water x ruggedness" appeared favourable for the spring season, the relationship between distance to water and ruggedness was examined in more detail. However, those results were counterintuitive, suggesting that all sources of water (i.e. pooled water due to rain) may not have been marked in the GIS, which in turn, could account for the unexpected relationship within water x ruggedness (Figure 3.2). Within the disturbance theme, roads and trails were the most important factor, although disturbance explained less than 1% deviation in habitat use during winter and summer. The model that explained the most deviance in the thermal theme was distance to both forest types (mixedwood and conifer) separately, in combination with solar radiation: this model also explained more deviation in horse distribution than all other leading models from any other theme.

When leading preliminary models from all themes were compared the explanatory power of themes was generally as follows, in descending order: thermal > habitat > water and topography > disturbance, a ranking that remained consistent across all seasons. Moreover, the variables chosen to represent each theme remained similar across spring, summer and winter seasons. Variables that moved forward to the final assessment included: ANS from the habitat theme; ruggedness and water in the topography theme; roads and trails in the disturbance theme; and distance to mixedwood and conifer forest (separately) together with solar radiation from the thermal theme. The fall analysis was similar to the other seasons as the variables chosen from the habitat, water and topography, and thermal themes remained the same. The exception in the fall was within the disturbance theme, where the model with roads and trails in combination with cutlines, explained more deviance than just roads and trails (Table 3.7). Moreover, for each season, the final theme models remained the same (i.e. exhibited similar patterns) regardless of whether the actual null model or surrogate null (ANS) was used (Tables 1-4, Appendix C).

In the final analysis (i.e. model combination) of winter horse data, the model that explained the most deviance, while adhering to the rule of a minimum one percent increase in horse distribution per variable added, was the “thermal plus habitat” model at 21.3% (Table 3.8). Other variables included in the final winter model were distance to each of conifer and mixedwood forests (i.e. uncombined), solar radiation, and ANS. In the final spring analysis, the leading model was the “thermal plus habitat plus disturbance model”, explaining 31.5% of deviation in horse distribution (Table 3.9). Other variables included in the spring model were distance to separate conifer and mixedwood forests, solar radiation, ANS, and distance to roads and trails. During final analysis of the summer horse distribution data, the leading model was the “thermal plus habitat model”, explaining only 17.2% of horse distribution (Table 3.10), and which included variables such as distance to conifer and mixedwood forest, solar radiation and ANS. In the final analysis of the fall data, the most appropriate model was the “thermal plus habitat plus disturbance” combination, explaining a relatively low amount of variance at 13.3% (Table 3.11). This model had more component variables compared to the other final seasonal models, and included distance to separate conifer and mixedwood forest, solar radiation, ANS, distance to roads and trails, as well as distance to cutlines.

For all seasons, a similar type of relationship, although with different strengths, was evident by the effect of the thermal and habitat variables. As distance to conifer and mixedwood forests increased and as solar radiation increased, β estimates revealed an increased probability of horse selection in the landscape (Tables 3.12-3.15). Increasing horse presence in selected habitats and decreasing selection in avoided habitats was a consistent theme across all models (Tables 3.12-3.15). For the spring and fall models that included the disturbance theme (Tables 3.9, 3.11), the probability of horse selection increased as distance to roads/trails and cutlines increased (Tables 3.13, 3.15).

The final RSFs created for each season determined the likelihood of feral horse presence across the entire study area. The RSFs (see Equations [4-7]) in turn, were used to generate habitat suitability maps for each season (Figure 3.3).

$$RSF_{winter} = \exp(0.380*\text{conifer distance} + 0.076*\text{mixedwood distance} + 0.200 \times 10^{-3}*\text{solar radiation} + 0.580*\text{ selected} - 1.140*\text{avoided}) \quad [4]$$

$$RSF_{spring} = \exp(0.250*\text{conifer distance} + 0.088*\text{mixedwood distance} + 0.340 *\text{solar radiation} + 0.980*\text{ selected} + 0.067*\text{ distance to roads/trails} - 0.620*\text{avoided}) \quad [5]$$

$$RSF_{summer} = \exp(0.560*\text{conifer distance} + 0.077*\text{mixedwood distance} + 0.140 \times 10^{-3}*\text{solar radiation} + 1.030*\text{ selected} - 0.310*\text{avoided}) \quad [6]$$

$$RSF_{fall} = \exp(0.450*\text{conifer distance} + 0.074*\text{mixedwood distance} + 0.120 \times 10^{-3}*\text{solar radiation} + 0.850*\text{selected} + 0.031*\text{distance to roads/trails} + 0.110*\text{distance to cutlines} - 0.560*\text{avoided}) \quad [7]$$

Habitat suitability maps were scaled into seven categories using a quantile binning method that differed between seasons (Table 3.16). Habitat suitability maps (Figure 3.3) demonstrated that approximately 14% of the landscape was highly selected; ~42% of the landscape was strongly avoided; while the remaining 42% fell in the middle.

3.4 Discussion

3.4.1. Home Ranges of Feral Horses

Previous work has shown that feral horse home ranges can vary considerably in size (McCort 1984), findings supported by the home ranges of collared horses in this study. The relatively stable home range sizes for each horse across seasons however, suggests that these animals have territories they are loyal to, similar to the findings of Ganskopp and Vavra (1986). The average home range of horses examined here was approximately 50 km^2, which is 35 km^2 larger than that found by Salter and Hudson (1982). The larger home ranges found in the current study could arise because of a difference in resource availability or exposure to disturbances between study areas. Methodology (i.e. use of GPS collars) may also influence the difference in home range sizes. For example, the current study area may have lower forage availability due to the proliferation of conifer forests, as well as high exposure to disturbances (particularly recreational activity) associated with the McLean Creek Recreational Land Use Area, an explanation that would also account for the marked breadth in home range sizes among animals. Additionally, the ability of GPS collars to continuously track horse movement throughout the year would effectively maximize home range sizes. In contrast, Salter and Hudson (1982) relied on first-hand observational data to establish horse home ranges, which under a limited sampling period and intensity, could greatly underestimate home range size.

As feral horses are gregarious animals (McCort 1984), it is likely that the home ranges mapped in the current study are representative of entire harems rather than individual animals. Although some harems appeared to be using their selected habitat at a much higher intensity than others based on their home ranges (i.e. Horse 3, which has a very small home range), intensity of use will also depend on the size of the harem and the proportion of useable habitat within each home range. While efforts were made to obtain harem population size and demographic information for each collared horse, repeated attempts to gather this information failed in the field. Small home ranges may also stem from highly concentrated resources coupled with a low abundance of competing ungulates. Notably, the home range of Horse 3 contained the greatest relative proportion of grasslands and riparian shrublands (i.e. primary range). Moreover, Horse 3 was in the most isolated (and least accessible) region of the study area, which may lead to a reduction in human disturbance, as well as reduced cattle access to the area.

In contrast, those harems situated closer to increased human activity (i.e. near the McLean Creek Campground) had larger horse home ranges. Larger home ranges under increased disturbance could be an attempt by horses to spread out in order to avoid interaction with humans (Laliberta and Ripple 2004), a finding supported by the RSF models from spring and fall when disturbances were more important (Tables 3.13, 3.15). However, the large home range size of the horse nearest the campground may also have occurred because resources could be more limited in this higher traffic area. This area has the lowest proportion of grasslands and shrublands of all home ranges, potentially resulting in faster depletion of forage resources. Moreover, forage availability may combine with disturbance to influence home range size, and could explain why disturbance had no impact on horse use of these individuals during summer, when forage quantity and quality are generally at a peak, thereby allowing these animals to occupy more isolated areas with less exposure to disturbance.

3.4.2. Seasonal Habitat Selection by Horses

Distinct seasonal trends emerged within the factors relating to horse distribution across the landscape. During summer, horses exhibited a strong selection for grasslands and riparian shrublands. Both of these habitats have favourable herbage production (ASRD 2005) as well as the type of plant species that horses prefer (i.e. grasses and sedges) according to their diet composition (Salter and Hudson 1979). Preferred species during summer and commonly found in grasslands and shrublands of the region include: *Deschampsia caespitosa*, *Festuca sp.*, *Poa sp. Carex sp.* and *Phleum pratense* (Appendix D). Although depletion of forage could arise at this time of year given that cattle are in the area and have very similar diets to horses (McInnis and Vavra 1987), this is unlikely given the rapid growth and biomass increases commonly observed, with maximum production values for grasslands approaching 3600 kg/ha in the region (ASRD 2005), or up to 4000 kg/ha according to field data.

During fall, horses exhibited indifference to most habitats, although there was still a decided selection for grasslands and avoidance of conifer forests. Grasslands were selected at a lower level, however, than during any other season (Table 3.3). The latter may be due to progressive depletion of available forage (i.e. leading to reduced rates of forage intake per bite) in selected habitats at the end of the summer growing season by the combined grazing pressure from feral horses, wild ungulates and domestic cattle. Reduction in available forage is unlikely to be an issue for cattle because they are removed from the area in early fall. However, reduction of forage availability in selected habitats (i.e. grasslands and shrublands) from the previous season may force horses during mid to late fall into habitats they normally would not occupy, particularly given that horses are known to prefer high biomass areas (Fleurance et al. 2009).

Increased selection by horses for cutblocks during winter in the current study is contradictory to Irving (2001) who found horses selected disturbed areas (e.g. roadsides, pipelines, and other developed lands) over pine cutblocks. The aforementioned study was conducted in areas 350 km NW of the current study and in a different Natural Region (i.e. the Upper Foothills). The increase in horse use of cutblocks found here during winter may take place because horses are widening their search for remaining forage at that time of year (Salter and Hudson 1979). Depletion of forage within primary ranges (i.e. grassland and riparian shrubland) during summer and fall, in part due to cattle grazing, may cause horses to move into cutblocks in search of available forage, as shown by a change from a neutral electivity to a positive electivity. Work done by Kauffman (2011) in SW Alberta found that, similar to feral horses in the current study, cattle avoided conifer cutblocks during summer, in part due to an aversion to the obstructive influence of abundant slash within this habitat. As a result, forage in cutblocks is less likely to be as depleted as other habitats (grasslands and riparian shrublands) heading into fall and winter. Finally, as cutblocks are raised above the valley bottom, the former may also be less susceptible to cold air drainage during winter (Henson 1952), and therefore have more favourable thermal conditions compared to primary ranges situated directly in valley bottoms. Ambient temperature recordings from the GPS collars support this theory as the average temperature during January was 4^{o}C higher in cutblocks than in grasslands.

Increased selection for shrublands during spring coincides with the increased presence of shrubs in the spring diets of horses (based on fecal assessment) observed by Salter and Hudson (1979). Increased use of shrublands may arise because of a greater ability by horses to access these areas as snow melts, coupled with taller shrub biomass representing some of the only forage available after winter and prior to spring green up of herbaceous vegetation. This is also supported by the observation that the greatest aversion to conifer forests was evident at this time, with three of the five habitats (mixedwood, riparian shrubland, grassland) selected by horses to a greater extent during spring than in any other season. Overall, these findings suggest feral horses may be adapting seasonally to utilize what forage is most available within their primary habitats.

3.4.3. Mechanisms Regulating Habitat Use by Horses

Habitat use by feral horses differed according to season, but there were some common trends evident throughout the analysis. For all seasons the thermal and habitat themes were components of the final model. Within the thermal theme the variables selected remained the same and indicated that feral horses select open areas away from conifer and mixedwood forests. Although forests may be used for temperature regulation by providing shade in summer and relief from wind and cold in winter (Musterud and Østbye 1999), our results indicated that horses were not utilizing forest cover as expected. There are several potential explanations for this. First, the thermal cover theme in the final RSF analysis indicated that sun exposure may not have been high enough for horses to seek cover in summer, and relatively cool temperatures in this mountainous environment may limit the need for horses to seek shade. Moreover, the combination of increasing selection with greater distance from forested areas as well as solar radiation, suggests horses may be maximizing exposure to sun, which could be a particular advantage in winter to aid with thermoregulation of body temperature. Similar observations have been made with cattle in Montana (Keren and Olson 2007). Forests also have the disadvantage in that they provide relatively low amounts of forage for ungulates (see Chapter 4), and could therefore dissuade horses from using them, at least during foraging periods. Finally, an alternative explanation for the unexpected influence of forests on horse use patterns may be that this habitat is associated with a greater risk of predation. Horses are thought to be susceptible to predation in this region, particularly from cougars (*Puma concolor*) (Knopff 2010), and avoidance of forests may be an adaptive strategy to minimize this exposure.

Aversion by horses to features such as roads, trails and cutlines in this study may be because of the large amount of human activity on and near these features (Laliberte and Ripple 2004). Roads and trails are traveled extensively by recreationalists, including hikers, cyclists, dirt bikers, OHV riders, snowmobilers, and even horseback riders. While this aversion was expected to be more prevalent in summer than fall or spring, the opposite pattern was observed. The analysis of associated field data (Chapter 4) showed a similar pattern with horses even selecting areas closer to roads, trails and cutlines during the summer. During the transitional seasons horses may be avoiding linear features due to a reduction in concealment cover. Areas adjacent to trails are where the majority of deciduous woody species (shrubs and trees) are found, and spring and fall would coincide with periods prior to leaf-out and after leaf-fall, respectively. Although we hypothesized that horses could be using linear features as movement corridors, this did not occur the majority of time. Horses could also be avoiding linear features because they can attract predators (Whittington et al. 2005). Caution should be exercised in interpreting horse use patterns during the short, transitional spring and fall seasons, as a smaller sample size of animal observations within these 1.5 month long interval could lead to less reliable RSF models, and more variability may be expected in horse use within these seasons from year to year.

Water and topography consistently played little role in regulating horse use of this landscape, regardless of season. The lack of a water effect corroborates with Salter and Hudson (1979), who concluded water was not a limiting factor for horse use in the Alberta foothills. Water remained relatively abundant throughout the study area in the form of creeks and ponds, and likely ensured a consistent supply at all times. The finding that ruggedness was not a factor influencing habitat selection suggests that significant changes in topography (i.e. elevation, slope and aspect) do not pose the same limitation for horses as these conditions do for cattle (Kauffman 2011). Moreover, the limited interaction between water and ruggedness observed here (Figure 3.2) suggests horses selected areas far from known water sources and with greater ruggedness. This observation is counterintuitive and could reflect the incompleteness of mapped water sources, as more rugged topography normally has a greater abundance of localized water sources (i.e. puddles and ponds) following routine water redistribution in these landscapes.

Across all observed relationships between horse use and landscape features, none of the models explained a large amount of variance in horse distribution (13.3% to 31.5%). The large range and low explanatory power in RSF values may indicate that there are many factors not being captured in the explanation of horse habitat selection. The greatest variance explained was by the spring model, which remained unexpected because this period is one of the shorter and more variable seasons. However, rapidly changing conditions at that time of year (i.e. coincident with snowmelt and initiation of growth) may also lead to more predictable behaviour by horses as they attempt to maximize survival and recovery following a cold, snowy winter. The least variation in horse presence explained was by the fall model, and is perhaps consistent with the notion that this transitional season may bring widely varying conditions depending on the previous summer's growth coupled with potential variability in the onset of vegetation dormancy and senescence.

3.5. Management Implications

Overall, seasonal habitat selection maps suggest there are small areas of the landscape selected by horses that primarily include grassland and shrubland areas. Habitat selection by feral horses was mainly influenced by distance to forests, sun exposure and habitat type in this study. Although horses are using neutral and avoided areas of the landscape, selected habitats are likely to have more concentrated use by feral horses. The problem of concentrated use may be exacerbated by human disturbance in the area as horses avoid roads and trails. If levels of recreational activity are not monitored and increase markedly in the future, the risk of degradation to grassland and shrubland areas may increase, particularly if grasslands decline in area under ongoing shrub encroachment (Burkinshaw and Bork 2009). Alternatively, the feral horses may become less fearful of recreational users, and start to pose a safety risk (i.e. vehicle collisions).

Monitoring and registration programs to track users in the McLean Creek Recreational Area would be a potential strategy to determine how patterns of land use are changing.

The identity of selected habitats changed slightly throughout the seasons (i.e. increased selection of cutblocks in winter). Increased selection of cutblocks in winter could be problematic and lead to heightened land use conflicts between forestry and feral horses. It is unknown whether increased horse use of regenerating cutblocks could increase damage to tree seedlings. Similarly, it is unknown whether horse reliance on cutblocks is influenced by existing levels of grazing from horses, cattle or their combination, within primary ranges (grasslands and shrublands). A comparison of different buffer zones within and around cutblocks revealed that horses were not using the edges of cutblocks any different than the cutblock cores. Further research is needed to determine the impact and mechanisms regulating seasonal feral horse grazing in cutblocks.

Given that habitat selection maps were based on the RSFs there is considerable variation that has not yet been explained (68-86%) in horse use across this landscape. Increasing the number of horses examined could also improve the explanation of horse selection as the number of individuals examined here (n=4) is a relatively small sample size. In depth analysis of the vegetation data (e.g. forage biomass and quality) may contribute to the explanatory power of horse distribution (see Chapter 4). Examining the presence or absence of predators in the area could also be beneficial.

The first step in developing a better understanding of the impact feral horses have on vegetation in the McLean Creek area and their associated rangeland sustainability is to quantify horse use across the landscape. Using the RSFs generated in this study could enable habitat managers to map out additional regions suitable for horse occupation and establish seasonal carrying capacity based on changes in horse use patterns throughout the year. In particular, winter has the lowest area of selected habitat and could therefore be used to establish year-long carrying capacities for feral horses. If the carrying capacity is calculated based on these areas, the amount of degradation seen on them should decline. Moreover, the strong similarity in habitat use between cattle and horses (Appendix F) indicates cattle must be considered when calculating carrying capacity of either or both herbivores.

Table 3.1. Description of variables developed in ArcGIS 9.3 used in the assessment of feral horse resource selection. Variables include spatial and habitat type data.

Variable	**Description**
Distance to roads and trails	Distance from horse or random data points to the nearest road or trail. Measured in 100m increments.
Distance to water	Distance from horse or random data points to the nearest source of water. Measured in 100m increments.
Distance to cutlines	Distance from horses or random data points to the nearest cutline. Measured in 100m increments.
Distance to mixedwood forest	Distance from horses or random data points to the nearest mixedwood forest. Measured in 100m increments.
Distance to conifer forest	Distance from horses or random data points to the nearest conifer forest. Measured in 100m increments.
Distance to any forest	Distance forest or random data points to the nearest forest habitat type. Measured in 100m increments.
Terrain ruggedness index (TRI)	Ranking of changes in the terrain. Increasing values indicate increasing roughness.
Diffuse solar radiation	Measure of scattered wavelengths on March 21.
Global radiation	Measure of shortwave + diffuse radiation.
Conifer forest	Habitat type, presence indicated by a 1, absence by a 0.
Conifer cutblock	Habitat type, presence indicated by a 1, absence by a 0.
Lowland grassland	Habitat type, presence indicated by a 1, absence by a 0.
Mixedwood forest	Habitat type, presence indicated by a 1, absence by a 0.
Riparian shrubland	Habitat type, presence indicated by a 1, absence by a 0.
Distance to water x terrain ruggedness	Combination of distance to water and ruggedness.
Distance to water x elevation	Combination of distance to water and elevation.
Terrain ruggedness x elevation	Combination of elevation and ruggedness.

Table 3.2. Kernel home range areas for different utilization levels by feral horses in the Alberta foothills, from October 2008 to September 2010.

	Area (km^2)		
Horse	**50% Utilization**	**90% Utilization**	**95% Utilization**
1	6.3	28.3	56.4
2	0.6	5.0	12.4
3	9.8	44.7	90.9
4	2.2	15.9	34.7

Table 3.3. Mean electivity for various habitats by feral horses in the Rocky Mountain Forest Reserve of Alberta from October 2008 through October 2010.

Habitat	**Winter**	**Spring**	**Summer**	**Fall**
Conifer	-0.444* AB[1] c[2]	-0.618* B c	-0.300* A c	-0.19* A b
Cutblock	0.328* A[3] a	-0.102 B b[4]	0.046 AB b	0.073 AB ab
Grassland	0.506* A a	0.718* A a	0.602* A a	0.226* B a[5]
Mixedwood	-0.053 A b	0.190* A b	0.013 A bc[6]	-0.046 A ab
Shrubland	-0.005 A b	0.195* A b	0.192* A b	-0.096 A[7] b

Pooled standard error ± 0.15 across all treatments.
* Electivity's differ from zero p<0.05.
[1] Seasonal means within a row with different uppercase letters differ, p<0.05.
[2] Habitat means within a column with different lowercase letters differ, p<0.05.
[3] Electivity for the cutblock during winter differs from the cutblock during summer at p<0.08.
[4] Electivity for the cutblock during spring differs from the mixedwood and shrubland in spring at p<0.07.
[5] Electivity for the grassland during fall differs from the mixedwood during fall at p<0.09.
[6] Electivity for the mixedwood during summer differs from the conifer during summer at p<0.06.
[7] Electivity for the shrubland during fall differs from the shrubland during spring and summer at p<0.08.

Table 3.4. Summary results depicting comparative model strength linking feral horse observations from GPS telemetry data collected during winter (1 November – 31 March) 2009 and 2010, and various landscape attributes. Bolded and italicized components indicate leading model in a theme, and which were carried forward into the final assessment.

Theme	Component (Winter Analysis)	k*	R^{2**}
Null			
		1	0.00
Habitat			
	ANP	***3***	***11.19***
Water and Topography			
	Water Distance	2	0.01
	Ruggedness	***2***	***3.55***
	Ruggedness x Water Distance	2	0.68
	Water Distance + Ruggedness	3	3.57
	Water Distance + Ruggedness + Water x Ruggedness	4	3.92
Disturbance			
	Roads and Trails	***2***	***0.25***
	Cutlines	2	0.01
	Roads and Trails + Cutlines	3	0.29
Thermal			
	Forest Distance	2	5.90
	Conifer Distance	2	3.12
	Mixedwood Distance	2	7.01
	Solar Radiation	2	3.31
	Conifer + Mixedwood Distance	3	11.77
	Conifer Distance + Solar Radiation	3	6.30
	Mixedwood Distance + Solar Radiation	3	9.89
	Forest Distance + Solar Radiation	3	9.04
	Mixedwood + Conifer Distance + Solar Radiation	***4***	***14.44***

* Indicates the number of parameters used.
** McFadden's pseudo R^2 goodness of fit measure.

Table 3.5. Summary results depicting comparative model strength linking feral horse observations from GPS telemetry data collected during spring (1 April – 15 May) 2009 and 2010, and various landscape attributes. Bolded and italicized components indicate leading model in a theme, and which were carried forward into the final assessment.

Theme	Component (Spring Analysis)	k*	R^{2**}
Null			
		1	0.00
Habitat			
	ANP	***3***	***17.18***
Water and Topography			
	Water Distance	2	0.69
	Ruggedness	***2***	***1.35***
	Ruggedness x Water Distance	2	1.22
	Water Distance + Ruggedness	3	2.06
	Water Distance + Ruggedness + Water x Ruggedness	4	2.15
Disturbance			
	Roads and Trails	***2***	***1.12***
	Cutlines	2	0.33
	Roads and Trails + Cutlines	3	1.27
Thermal			
	Forest Distance	2	6.31
	Conifer Distance	2	3.52
	Mixedwood Distance	2	7.25
	Solar Radiation	2	6.87
	Conifer + Mixedwood Distance	3	12.92
	Conifer Distance + Solar Radiation	3	10.70
	Mixedwood Distance + Solar Radiation	3	13.24
	Forest Distance + Solar Radiation	3	13.49
	Mixedwood + Conifer Distance + Solar Radiation	***4***	***19.30***

* Indicates the number of parameters used.
** McFadden's pseudo R^2 goodness of fit measure.

Table 3.6. Summary results depicting comparative model strength linking feral horse observations from GPS telemetry data collected during summer (16 May – 15 September) 2009 and 2010, and various landscape attributes. Bolded and italicized components indicate leading model in a theme, and which were carried forward into the final assessment.

Theme	Component (Summer Analysis)	k*	R^{2**}
Null			
		1	0.00
Habitat			
	ANP	***3***	***7.92***
Water and Topography			
	Water Distance	2	0.00
	Ruggedness	***2***	***3.45***
	Ruggedness x Water Distance	2	0.89
	Water Distance + Ruggedness	3	3.45
	Water Distance + Ruggedness + Water x Ruggedness	4	3.69
Disturbance			
	Roads and Trails	***2***	***0.91***
	Cutlines	2	0.08
	Roads and Trails + Cutlines	3	0.94
Thermal			
	Forest Distance	2	3.84
	Conifer Distance	2	2.10
	Mixedwood Distance	2	7.83
	Solar Radiation	2	2.05
	Conifer + Mixedwood Distance	3	11.94
	Conifer Distance + Solar Radiation	3	4.03
	Mixedwood Distance + Solar Radiation	3	9.67
	Forest Distance + Solar Radiation	3	5.79
	Mixedwood + Conifer Distance + Solar Radiation	***4***	***13.62***

* Indicates the number of parameters used.
** McFadden's pseudo R^2 goodness of fit measure.

Table 3.7. Summary results depicting comparative model strength linking feral horse observations from GPS telemetry data collected during fall (16 September – 31 October) 2009 and 2010, and various landscape attributes. Bolded and italicized components indicate leading model in a theme, and which were carried forward into the final assessment.

Theme	Component (Fall Analysis)	k*	R^{2**}
Null			
		1	0.00
Habitat			
	ANP	***3***	**3.19**
Water and Topography			
	Water Distance	2	0.03
	Ruggedness	***2***	**1.77**
	Ruggedness x Water Distance	2	0.18
	Water Distance + Ruggedness	3	1.79
	Water Distance + Ruggedness + Water x Ruggedness	4	2.35
Disturbance			
	Roads and Trails	2	0.42
	Cutlines	2	0.88
	Roads and Trails + Cutlines	***3***	***1.18***
Thermal			
	Forest Distance	2	1.67
	Conifer Distance	2	1.16
	Mixedwood Distance	2	6.41
	Solar Radiation	2	1.36
	Conifer + Mixedwood Distance	3	8.94
	Conifer Distance + Solar Radiation	3	2.49
	Mixedwood Distance + Solar Radiation	3	7.53
	Forest Distance + Solar Radiation	3	2.99
	Mixedwood + Conifer Distance + Solar Radiation	***4***	***10.03***

* Indicates the number of parameters used.
** McFadden's pseudo R^2 goodness of fit measure.

Table 3.8. Final summary results depicting comparative model strength of combined themes of feral horse observations from GPS telemetry data collected during winter (1 November – 31 March) 2009 and 2010, and various landscape attributes. Bolded and italicized model indicates final model selection.

Theme	***Component (Final Winter Analysis)***	***k****	***R^2****
Null			
		1	0.00
Thermal			
	Conifer + Mixedwood Distance + Solar Radiation	4	14.44
Thermal + Habitat			
	Conifer + Mixedwood Distance + Solar Radiation + ANP	***6***	***21.25***
Thermal + Habitat + Water & Access			
	Conifer + Mixedwood Distance + Solar Radiation + ANP + Ruggedness	8	22.02
Thermal + Habitat + Disturbance			
	Conifer + Mixedwood Distance + Solar Radiation + ANP + Distance to Roads/Trails	8	21.74
Thermal + Habitat + Water & Access + Disturbance			
	Conifer + Mixedwood Distance + Solar Radiation + ANP + Ruggedness + Distance to Roads/Trails	9	22.70

* Indicates the number of parameters used.
** McFadden's pseudo R^2 goodness of fit measure.

Table 3.9. Final summary results depicting comparative model strength of combined themes of feral horse observations from GPS telemetry data collected during spring (1 April – 15 May) 2009 and 2010, and various landscape attributes. Bolded and italicized model indicates final model selection.

Theme	***Component (Final Spring Analysis)***	***k****	***R^2****
Null			
		1	0.00
Thermal			
	Conifer + Mixedwood Distance + Solar Radiation	4	19.30
Thermal + Habitat			
	Conifer + Mixedwood Distance + Solar Radiation +ANP	6	30.28
Thermal + Habitat + Water & Access			
	Conifer + Mixedwood Distance + Solar Radiation + ANP + Ruggedness	8	30.29
Thermal + Habitat + Disturbance			
	Conifer + Mixedwood Distance + Solar Radiation + ANP + Distance to Roads/Trails	***8***	***31.48***
Thermal + Habitat + Water & Access + Disturbance			
	Conifer + Mixedwood Distance + Solar Radiation + ANP + Ruggedness + Distance to Roads/Trails	9	31.56

* Indicates the number of parameters used.
** McFadden's pseudo R^2 goodness of fit measure.

Table 3.10. Final summary results depicting comparative model strength of combined themes of feral horse observations from GPS telemetry data collected during summer (16 May – 15 September) 2009 and 2010, and various landscape attributes. Bolded and italicized model indicates final model selection.

Theme	***Component (Final Summer Analysis)***	***k****	***R^2*****
Null			
		1	0.00
Thermal			
	Conifer + Mixedwood Distance + Solar Radiation	4	13.62
Thermal + Habitat			
	Conifer + Mixedwood Distance + Solar Radiation + ANP	***6***	***17.15***
Thermal + Habitat + Water & Access			
	Conifer + Mixedwood Distance + Solar Radiation + ANP + Ruggedness	8	17.61
Thermal + Habitat + Disturbance			
	Conifer + Mixedwood Distance + Solar Radiation + ANP + Distance to Roads/Trails	8	17.76
Thermal + Habitat + Water & Access + Disturbance			
	Conifer + Mixedwood Distance + Solar Radiation + ANP + Ruggedness + Distance to Roads/Trails	9	18.45

* Indicates the number of parameters used.
** McFadden's pseudo R^2 goodness of fit measure.

Table 3.11. Final summary results depicting comparative model strength of combined themes of feral horse observations from GPS telemetry data collected during fall (16 September – 31 October) 2009 and 2010, and various landscape attributes. Bolded and italicized model indicates final model selection.

Theme	***Component (Final Fall Analysis)***	***k****	***R^2****
Null		1	0.00
Thermal	Conifer + Mixedwood Distance + Solar Radiation	4	10.03
Thermal + Habitat	Conifer + Mixedwood Distance + Solar Radiation + ANP	6	11.47
Thermal + Habitat + Water & Access	Conifer + Mixedwood Distance + Solar Radiation + ANP + Ruggedness	8	11.79
Thermal + Habitat + Disturbance	***Conifer + Mixedwood Distance + Solar Radiation + ANP + Distance to Roads/Trails + Cutlines****	***8***	***13.26***
Thermal + Habitat + Water & Access + Disturbance	Conifer + Mixedwood Distance + Solar Radiation + ANP + Ruggedness + Distance to Roads/Trails + Cutlines	9	14.12

* Indicates the number of parameters used.
** McFadden's pseudo R^2 goodness of fit measure.

Table 3.12. Ranked influence of different variables in the leading RSF model for feral horses in the Alberta foothills in winter (1 November – 31 March) 2009 and 2010.

Variable	β[1]	SE[2]	*P* value
Distance to conifer forest	0.380	0.001	$<0.100 \times 10^{-3}$
Distance to mixedwood forest	0.076	0.021	$<0.100 \times 10^{-3}$
Solar radiation	0.200×10^{-3}	0.000	$<0.100 \times 10^{-3}$
Preferred Habitat	0.580	0.031	$<0.100 \times 10^{-3}$
Avoided Habitat	-1.140	0.033	$<0.100 \times 10^{-3}$

[1] Beta coefficient.
[2] Standard error.

Table 3.13. Ranked influence of different variables in the leading RSF model for feral horses in the Alberta foothills in spring (1 April – 15 May) 2009 and 2010.

Variable	β[1]	SE[2]	*P* value
Distance to conifer forest	0.250	0.002	$<0.100 \times 10^{-3}$
Distance to mixedwood forest	0.088	0.032	$<0.100 \times 10^{-3}$
Solar radiation	0.340×10^{-3}	0.000	$<0.100 \times 10^{-3}$
Preferred Habitat	0.980	0.045	$<0.100 \times 10^{-3}$
Avoided Habitat	-0.62	0.054	$<0.100 \times 10^{-3}$
Distance to roads and trails	0.067	0.004	$<0.100 \times 10^{-3}$

[1] Beta coefficient.
[2] Standard error.

Table 3.14. Ranked influence of different variables in the leading RSF model for feral horses in the Alberta foothills in summer (16 May – 15 September) 2009 and 2010.

Variable	β[1]	SE[2]	*P* value
Distance to conifer forest	0.560	0.001	$<0.100 \times 10^{-3}$
Distance to mixedwood forest	0.077	0.022	$<0.100 \times 10^{-3}$
Solar radiation	0.140×10^{-3}	0.000	$<0.100 \times 10^{-3}$
Preferred Habitat	1.030	0.035	$<0.100 \times 10^{-3}$
Avoided Habitat	-0.310	0.031	$<0.100 \times 10^{-3}$

[1] Beta coefficient.
[2] Standard error.

Table 3.15. Ranked influence of different variables in the leading RSF model for feral horses in the Alberta foothills in fall (16 September – 31 October) 2009 and 2010.

Variable	**β[1]**	**SE[2]**	***P* value**
Distance to conifer forest	0.450	0.031	$<0.100 \times 10^{-3}$
Distance to mixedwood forest	0.074	0.002	$<0.100 \times 10^{-3}$
Solar radiation	$<0.110 \times 10^{-3}$	0.00	$<0.100 \times 10^{-3}$
Preferred Habitat	0.850	0.066	$<0.100 \times 10^{-3}$
Avoided Habitat	-0.560	0.430	$<0.100 \times 10^{-3}$
Distance to roads and trails	0.031	0.0033	$<0.100 \times 10^{-3}$
Distance to cutlines	0.110	0.006	$<0.100 \times 10^{-3}$

[1] Beta coefficient.
[2] Standard error.

Table 3.16. Quantile categories for habitat suitability maps for all fours seasons of habitat selection by feral horses in the Alberta foothills.

Quantile	**Spring**	**Summer**	**Fall**	**Winter**
1	<7.4	<6.5	<7.5	<131.6
2	7.5-10.5	6.6-9.8	7.6-11.8	131.7-252.9
3	10.6-14.7	9.9-14.4	11.9-19.1	253.0-452.6
4	14.8-21.6	14.5-22.1	19.2-32.9	452.7-834.2
5	21.7-35.9	22.2-37.4	33.0-58.0	834.3-1593.1
6	40.0-71.9	37.5-75.8	58.1-118.4	1593.2-4042.5
7	72.0-493434.4	75.9-114462.2	118.5-155351.1	4042.6-3076520.3

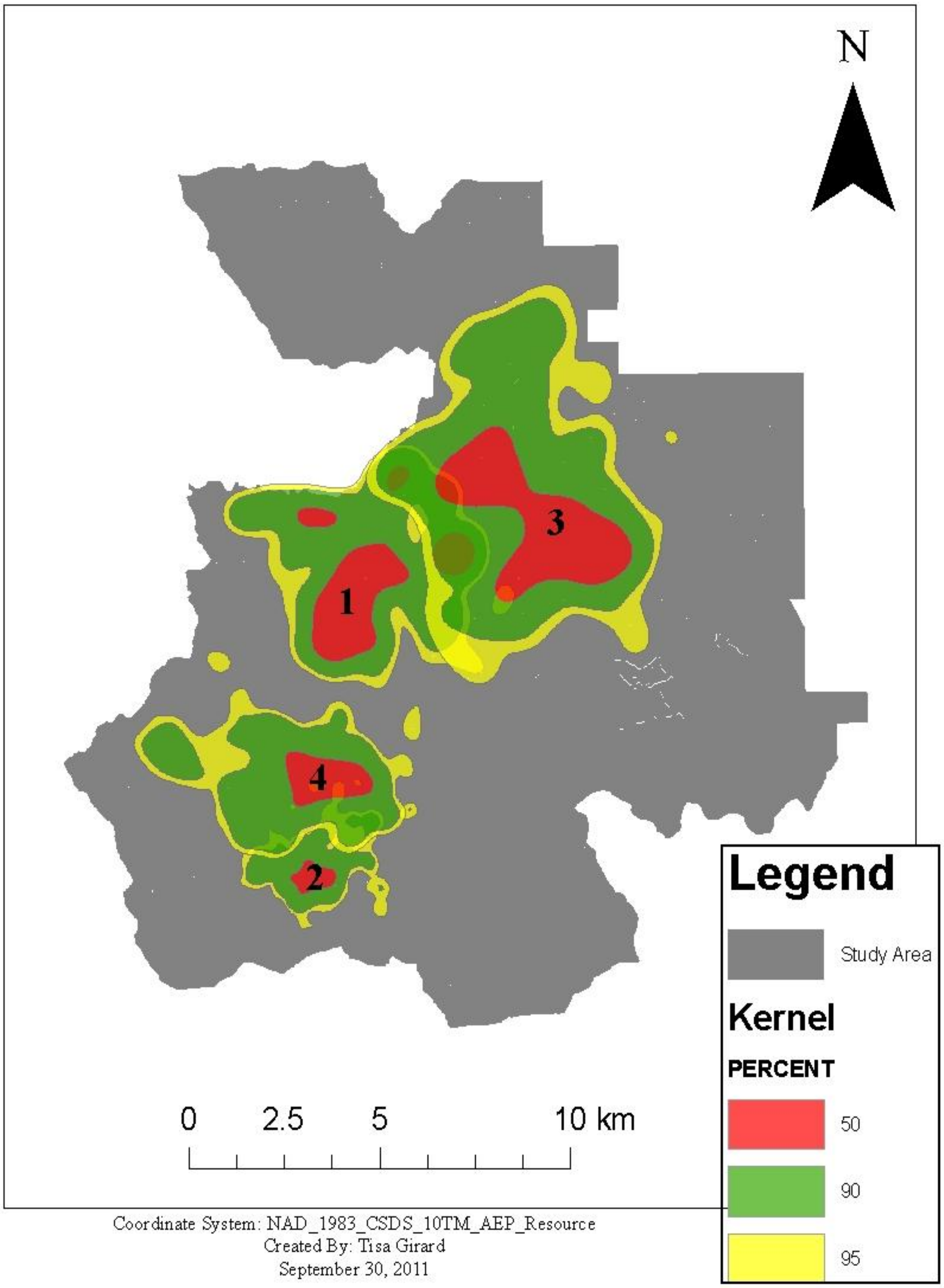

Figure 3.1. Kernel home range areas of each of four feral horses (1-4) in a portion of the Rocky Mountain Forest Reserve of Alberta over two years, October 2008 to October 2010.

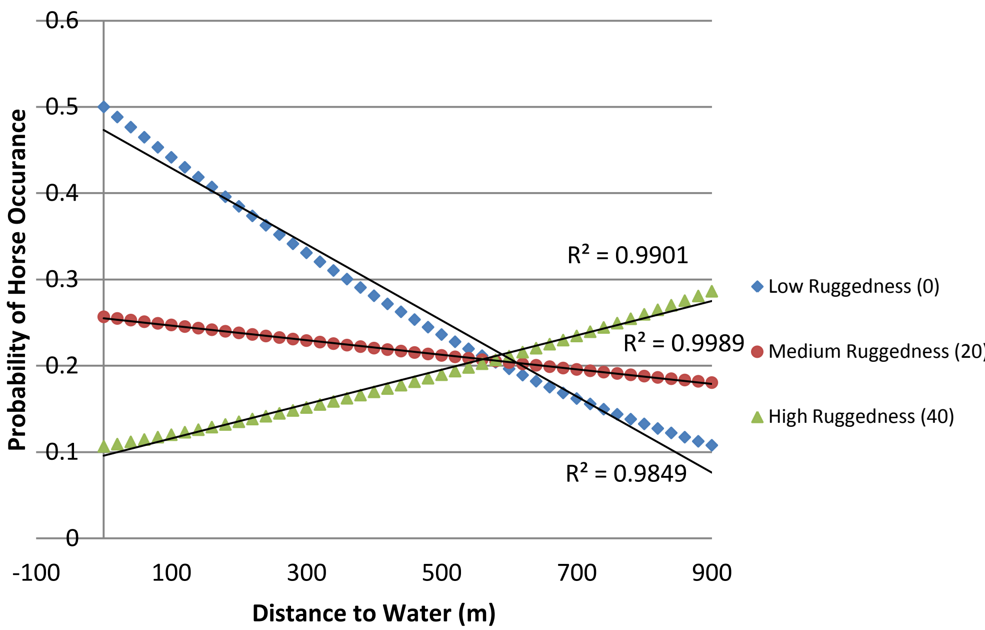

Figure 3.2. Probability of horse occurrence based on the relationship between ruggedness and distance to water in the spring (1 April to 15 May) for both study years (2009 and 2010).

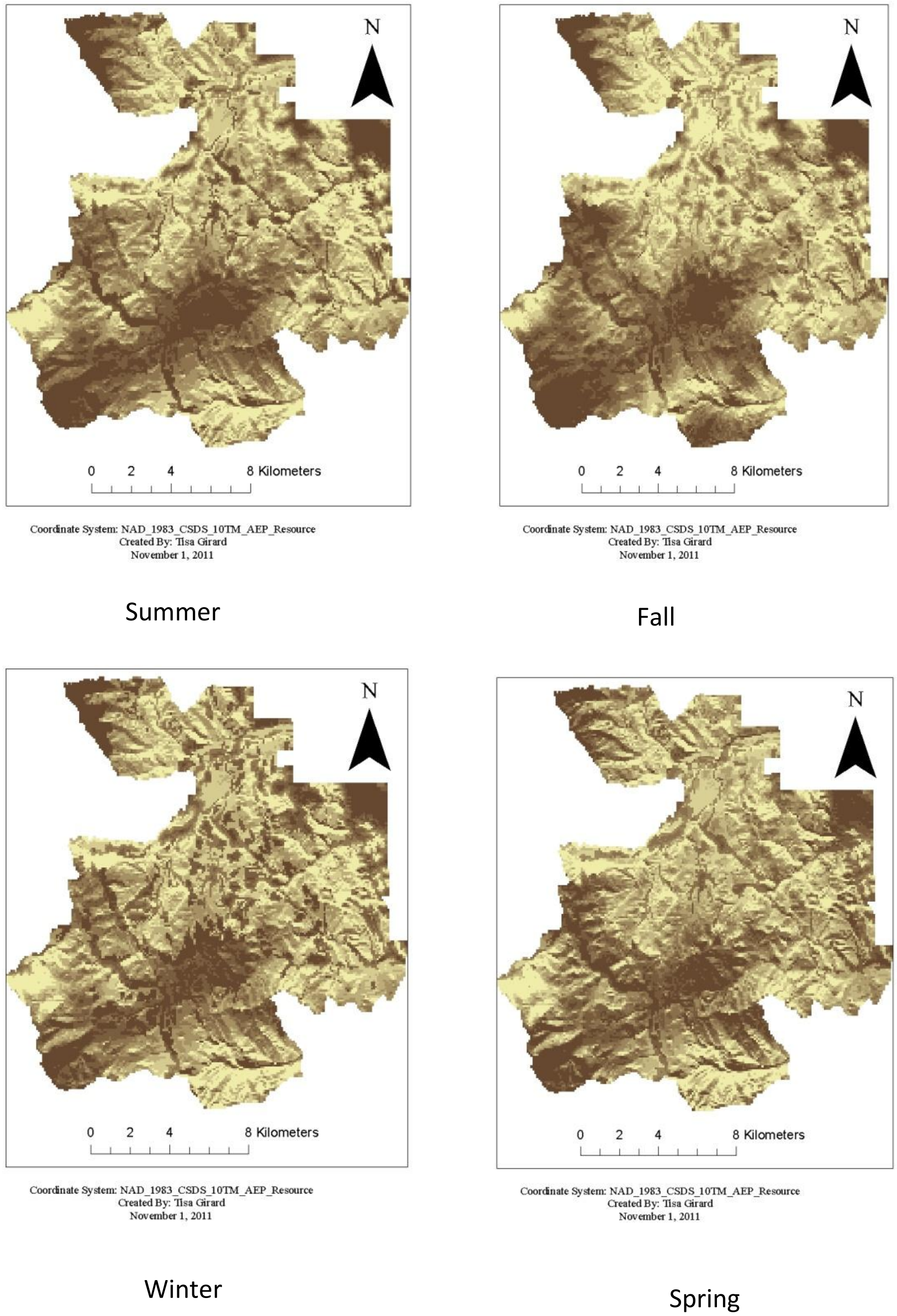

Figure 3.3. Habitat suitability maps for feral horses in the McLean Creek area of SW Alberta, based on RSF developed for the region. RSFs values range from low (light color) to high (dark color).

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4. LINKING SUMMER HABITAT USE BY FERAL HORSES IN THE ALBERTA FOOTHILLS TO LANDSCAPE PROPERTIES USING FIELD PLOTS

4.1. Introduction

Feral horses have been present in Alberta since the early 1900's (Government of Alberta 2011) when surplus workhorses were released into the wild. Since then, populations of horses have grown within three herd management units (HMUs) along the eastern slopes of the Rocky Mountains. Concerns over feral horses in these areas are increasing as there is evidence of growing horse populations (Unpublished Alberta Sustainable Resources Development (ASRD) data) through natural reproduction, together with supplementation from released or escaped horses (evidenced by horses with brands, Tisa Girard, personal observation). Increasing horse activity in this region may increase the possibility of ecosystem degradation, particularly where grasslands and other traditional primary rangelands are vulnerable to shrub encroachment (Burkinshaw and Bork 2009) and concentrated livestock grazing (Willms et al. 1998).

The Rocky Mountain foothills region is home to the Rocky Mountain Forest Reserve (RMFR), a publically managed area designated for multiple uses. Year-round activities within the region include forestry, wildlife habitat management, energy extraction, and recreation (Government of Alberta 2010). Resident wildlife populations include wolves, bears, moose, elk, deer and bighorn sheep. There are also cattle present in this particular portion of the RMFR during the summer from June 15th to October 15th under permitted grazing. Since wildlife, feral horses and cattle can occupy the same landscape during the summer growing season, management of these populations and the associated rangeland resources they rely on depends on a sound understanding of habitat use patterns by each class of herbivore. Managing large herbivores within the region is a year-long effort, but is especially important during summer when habitat overlap is likely to be greatest (Salter and Hudson 1980). Cattle and feral horses also demonstrate distinct habitat overlap, as unlike wild ungulates, they both avoid steep slopes and rugged terrain (Ganskopp and Vavra 1987), congregating instead within valley bottoms.

Dietary overlap is also a possibility during summer months. The main dietary preference of horses in the region is for graminoids, but they also utilize forbs when present, as well as shrubs when necessary (Salter and Hudson 1979). Feral horses and elk exhibit some overlap of diets year round, with additional overlap between horses and moose during spring and summer (Salter and Hudson 1980). There is little overlap between horses and deer at any time of year because deer prefer browse (Hubbard and Hansen 1976) and horses use browse only when necessary. The largest dietary overlap is likely between horses and cattle during summer (Shingu et al. 2010, Salter and Hudson 1980), as both prefer graminoids.

Due to the increased possibility of habitat overlap during summer, it is necessary to develop a better understanding of which areas feral horses are utilizing. Horses may use specific areas of the landscape because of herd socialization (Kruger and Flauger 2008), changes in forage availability and quality (van Beest et al. 2010), and physiological adaptations (Holechek et al. 2004), for example extremes in topography and other landscape features. Socialization plays an important role in regulating horse behaviour, with the gregarious herding nature of horses leading to concentrated activity by these animals. Physiological characteristics are also important as they determine the nutritional needs of individual animals. Horses are typically grazers and their adaptation as a hindgut fermentor means they can ingest a large amount of low quality forage when there is little high quality forage available (Janis 1976). Hence, horses tend to make foraging decisions based on biomass over quality (Fleurance et al. 2009).

Although the diet of horses may be a contributing factor to habitat selection during summer, it is also important to consider other landscape features such as topography, elevation, solar radiation, distance to water and human activity. Investigating habitat selection by horses in relation to these factors is especially important in the RMFR given the high landscape diversity of the region. The objective of this study was to link use data from field plots measuring presence or absence of feral horses, to assess the fundamental role of landscape and habitat characteristics capable of contributing to the behaviour of feral horses, specifically habitat selection. A secondary objective was to compare this selection with that of cattle and wild ungulates during the same period. Data were used to develop resource selection probability functions (RSPFs) for the summer period in this region of the RMFR.

4.2. MATERIALS AND METHODS

4.2.1. STUDY AREA

Field plots were located in the McLean Creek Recreational Area of Alberta, approximately 50 km SW of Calgary (Figure A.1, Appendix A). This area is inhabited by feral horses in the HMU west of Bragg Creek. Field data were collected in areas known to be habituated by collared horses (see Chapter 3 for geospatial analysis of GPS data). This area is located within the Rocky Mountain Forest Reserve (RMFR) on the eastern slopes of the Rocky Mountains, and is an important area for multiple uses (forestry, livestock grazing, wildlife production, recreation, and energy extraction). Cattle grazing in the region is managed through the development of Range Management plans administered by ASRD, and which are approved in conjunction with other land uses including wildlife management and commercial forestry.

Landscapes in the study area are within the Rocky Mountain Natural Region (RMNR), more specifically the Montane and Subalpine Natural Subregions, with elevations ranging from 825m to 3600m (Natural Regions Committee 2006). Bedrock sediments in the area are mudstone and sandstone (Sheelar and Veauvy 1977), and produce a wide range of soil types depending on elevation and topography. Soil groups in the area include Dark Gray Chernozems under upland grasslands, Gray and Dark Gray Luvisols and Brunisols under forests and grasslands, and Gleysols and Organics in lowlands (Sheelar and Veauvy 1977). Luvisols are the dominant soils in the area.

Vegetation is diverse across the region, and consists of a mosaic of sparse grasslands (both native and modified through the invasion of aggressive agronomic species) and shrublands situated predominantly along valley bottoms. Uplands are comprised of mixedwood forests, extensive conifer forests, and widely distributed cutblocks (Figure A.2, Appendix A) (ASRD 2005). While the areas of each habitat vary widely across the landscape (Table A.1. Appendix A), conifer forests occupy the majority of the region (Rhemtulla et al. 2002). Herbage production of plant communities also varies considerably, and is generally ranked as follows: grasslands > shrublands > conifer cutblocks > mixedwood forests > conifer forests (ASRD 2005).

Climate of the area is highly seasonal, with daily average temperatures at the nearby Elbow Ranger Station ranging from -9^{o}C in January to 12^{o}C in July and August (Environment 2010). Average daily summer temperatures range between 10^{o}C to 12^{o}C, with average maximums reaching 22^{o}C and average minimums dropping to 2^{o}C (Environment Canada, 2010). Annual precipitation for the region is 644 mm, with the majority falling as rain during summer (Environment Canada 2010): June (104 mm) and December (20 mm) are the wettest and driest months, respectively. Annual precipitation for both years of the study remained relatively close to normal, at 624 mm (2009) and 633 mm (2010), but within-season patterns were quite dissimilar (Figure B.1, Appendix B). In 2009 early season precipitation was limited with a peak late in the growing season. In 2010, the precipitation pattern was more normal, with the exception that peak rainfall occurred a few months later.

4.2.2. Field Data Collection

Field data were collected in the summer of both 2009 and 2010. During 2009, data were collected from August 5th to August 11th at 57 plots (i.e. sites), each 1 ha (100 m x 100 m) in size. In 2010, data were collected from July 10th through July 24th at the 57 plots from the year before, plus an additional 41 plots for a total of 98 plots. Since only a portion of plots were double sampled the field data were assessed separately between years. Sampling plots were distributed throughout the study area and across the known home ranges of at least 4 different harems (see Chapter 3) on a stratified random basis according to watershed and habitat type. The habitat types considered were based on dominant vegetation types in the area, and included conifer forest, conifer cutblock, lowland grassland, mixedwood forest, and riparian shrubland (Figure B.2, Appendix B). Plots were approximately evenly distributed among the different vegetation types, with each plot placed in a unique polygon according to aerial photos in a GIS. In 2009, 12 to 13 plots were sampled in each habitat, with the exception of mixedwood forests where only 8 plots were sampled due to the limited presence of this habitat type. In 2010, 16 to 27 plots were sampled in each habitat, again with the exception of mixedwood forests (n = 9 plots). Final plot locations were randomly selected within each vegetation polygon.

Once established, the geographic position of the center of all field plots was identified using a GPS. Plots were then assessed for forage availability using ocular estimates of biomass. Average standing biomass of herbage (i.e. grasses and forbs combined) and the mean proportion (i.e. %) utilization of current year's growth was estimated (to the nearest 100 kg/ha) for the plot area. The three most common plant species in the plot were also identified. Horse occupancy was assessed through pellet counts along a 4x100m belted transect, centered on the plot. Only fresh and partially decomposed pellet groups were recorded in order to ensure that they represented relatively recent (e.g. < 8 month old) activity. Occupancy of other herbivores, such as cattle and wild ungulates (elk, moose, and deer), was also recorded for each transect.

During each year, a subset of plots were destructively sampled for current annual herbage and shrub biomass: during 2009 and 2010 respectively, a total of 30 and 55 plots were sampled, with a minimum of 2 plots per habitat type when the habitat was available (i.e. the exception being mixedwood forest), within the home range of each horse used in the parallel spatial analysis (Chapter 3). Within plots directly sampled for biomass, vegetation within a randomly placed 50 x 50 cm (0.25m^2 area) quadrat was sampled using manual clipping. All current annual grass, grasslike and forb biomass was harvested to approximately 2cm height, and current annual growth removed from all shrubs and trees (less than 2 m tall) rooted in the quadrat. Standing dead litter, although limited, was removed from the quadrat through finger-combing prior to harvest and not included in the analysis. All samples were dried for a minimum of 48 hours at 45^{o}C to constant mass, weighed and converted to kg/ha for analysis.

Crude protein and digestibility were measured separately for grasses and forbs. Dried samples were ground to 1-mm using a Thomas® Scientific (Swedesboro, NJ, USA) Wiley Mill, then analyzed for crude protein concentration using a LECO® (St. Joseph, MI, USA) TruSpec FP-428 analyzer. Analysis using a LECO® machine is more efficient than the former Kjeldahl determination and involves three phases: purge, burn, and analysis (Daun and DeClercq 1994). This method was developed by Dumas (1831) and converts nitrogen (N) within the samples into N_2, which can then be measured through thermal conductivity. Crude protein values are derived by multiplying N values by 6.25 (as an average conversion ratio).

Digestibility was determined using acid detergent fibre (ADF) analysis, which quantifies the proportion of the sample consisting of relatively non-digestible cellulose and lignin. Small ground samples are placed into filter bags, sealed and placed in the Ankom^{200} Fibre Analyzer (Ankom Technology) with acetyl-trimethylammonium and sulphuric acid in solution (Ankom Technology 2011). Bags are heated and agitated for an hour, removed, rinsed in acetone, dried and reweighed to determine remaining cellulose and lignin. Greater %ADF levels are indicative of lower digestibility.

4.2.3. Landscape Characterization of Plots

Landscape attributes were assessed for each plot using spatial data files provided by ASRD in ArcGIS 9.3 (ESRI 2009). Data in the GIS included the shapefiles of: locations of roads, Kananaskis Country trails, cutlines, water sources, vegetation types, and a digital elevation model. Roads, trails, cutlines, and water source shapefiles were in GCS NA 1983 geographic coordinate system and projected as straight line data in the NAD 1983 10TM AEP Resource (NAD 1983 10TM) coordinate system. These data were used to determine the distance from plot centers to roads and trails, cutlines, and water. Habitat (vegetation) type shapefiles were gathered in the same geographic coordinate system, while being projected as polygon data in the NAD 1983 based system. Conifer and mixedwood forest habitat types were combined to create an aggregate forest cover class variable, with minimum distance to cover determined for all plots not in forested habitats.

The DEM was used to generate additional topographic and solar radiation variables. A ruggedness index (TRI) was generated using the DEM and an ArcScript created by Riley et al. (1999) to assess changes in elevation between adjacent grid cells. Global solar radiation exposure (short wave + diffuse) of each plot was calculated. Radiation values were calculated using an ArcScript originally created by Kumar et al. (1997), for 21 March, the first day of spring.

4.2.4. Statistical Analysis

All variables were initially tested for redundancy using Proc CORR in SAS 9.2. For variables correlated at $|r|>0.7$, one variable was removed so that there was only one representing the group, with preference in retained variables given to those representative of others and easy to interpret. Distance to mixedwood forest was correlated with ruggedness, with ruggedness retained because of its relevance over the entire study area while mixedwood forests were limited on the landscape. As expected, distance to conifer was also correlated with distance to all forests. The latter (distance to all forests) variable was kept because it took into account the distance to both forest types (mixedwood and conifer). Finally, the water x ruggedness variable was correlated with distance to water. Distance to water was kept because of its ease to quantify and interpret, and because analysis in Chapter 3 indicated that the water x ruggedness relationship may have been confounded by an incomplete mapping of water.

Initial correlation of estimates of standing current annual biomass with actual biomass harvested from field plots, stratified by each of the five habitat types, indicated a reasonable fit (see Appendix E) in each of 2009 and 2010 ($p<0.05$). These findings support the notion that ocular estimations were able to differentiate among areas containing varied forage availability. In order for biomass values to adequately reflect pre-grazing conditions, we used estimates of forage use to model (i.e. back transform) available standing biomass in the absence of herbivory (see Equation 1 below):

Available Biomass = [Estimated biomass (kg/ha) / Estimated use (%)] x 100] [1]

For example, a plot containing an estimated 1000 kg/ha and 50% use at the time of sampling was projected to contain 2000 kg/ha in the absence of large animal herbivory. The relationship between ocular estimates of forage removal and the pellet count densities of horses and cattle (#/400 m^2) within each plot, both individually and combined, were assessed using Proc CORR in SAS. Correlations were considered significant at $p<0.05$.

Variation in actual biomass (from clips), estimated biomass, biomass utilization, and total available standing biomass (i.e. after back transformation) among the five habitat types and two years of sampling were assessed using Proc MIXED in SAS. Forage quality (CP and ADF concentration) of grass and forb components were assessed similarly, with all variables initially tested for normality (Shapiro-Wilks test) and equality of variances (Levenes test). All biomass and ADF values underwent a natural log transformation while crude protein concentrations were found to be normal. Habitat type and year were fixed in the analysis, with plot random. Responses with significant effects were compared using an adjusted Tukey test, based on a $p<0.05$. All analyses used LSmeans. Ungulate pellet densities and utilization estimates between habitat types were also assessed using Prox MIXED in SAS.

The approximate amount of utilization by each ungulate group was assessed by determining the relationship between pellet counts, specific habitat characteristics and estimated biomass utilization levels. The relationship was initially assessed through Pearson correlations (Proc CORR, SAS 9.2). Biomass levels, nitrogen concentrations, and ADF concentrations were evaluated to determine whether they correlated directly with the fecal counts for each species, and which provided an indirect assessment of animal presence, and presumably, forage use.

4.2.4.1. Resource Selection Probability Functions

Resource selection probability functions (RSPFs) can be used to quantify how animals select specific areas of the landscape, and can be performed using a comparison of used vs. unused variables, or used vs. available variables (Manly et al. 2002). The current study was considered a type I design (Manly et al. 2002) intended to investigate resource selection for used vs. unused variables. Occupancy of feral horses, cattle, and wild ungulates was assessed with pellet counts along a 4x100m belted transect.

Forage quantity and quality (CP and ADF) data, together with various landscape attributes (distance to water, distance to roads and trails, distance to cutlines, ruggedness, and global radiation), were then used to develop resource selection functions for feral horses. The primary response variable during analysis was the pellet count density of each animal group (horses or cattle). Although each group was analyzed separately, abundance of the other was used as an index of competition during analysis.

A number of competing models were used to test those factors considered important for altering animal use, and included *a-priori* hypotheses regarding the preference of these animals. Specifically, use by each group was hypothesized to increase with 1) greater forage availability and quality, 2) reduced distance to water, 3) decreased ruggedness, 4) decreased radiation, and decreased distance to shade in forest (i.e. assuming horses strive to avoid summer heat), 5) decreased distance to cutlines (i.e. ready travel routes) but increased distance from roads and trails (to avoid disturbance from recreationalists), and 6) decreased abundance of the other herbivores.

Variables were divided into various themes representing different *a-priori* hypothesized requirements of feral horses in the region. The different themes and variables included were:

1. Forage characteristics
    a. Current annual biomass
    b. Crude protein
    c. ADF (indirect measure of digestibility)

Given that crude protein and digestibility values were only gathered for a subset of plots, a preliminary analysis was conducted to determine if forage quality characteristics had a significant impact. As they did not affect the final model outcome, they were not included in the remainder of the analysis.

2. Water and Topography, including
   a. Distance to water
   b. Ruggedness
   c. Water distance x ruggedness
3. Disturbance, including
   a. Distance to roads and trails
   b. Distance to cutlines
   c. Distance to roads and trails + distance to cutlines
4. Thermal, including
   a. Distance to all forest (conifer or mixedwood)
   b. Solar radiation
   c. Distance to forest + solar radiation
5. Competition
   a. Cattle (or feral horses for the cattle models)
   b. Wild ungulates

Modelling was conducted separately for 2009 and 2010 because field sampling was cut short in the first year yielding a limited data set. As a result, the number of plots available for analysis in 2010 provided a more robust data set.

Pellet count data were initially tested for over-dispersion due to the abundance of zeros (Vaudor et al. 2011), by determining the ratio of variance to mean pellet counts. Values greater than one indicate dispersion, and were further tested using Proc COUNTREG in SAS 9.2. Since the horse data were over-dispersed, -2 log likelihoods (-2LL) were determined through zero-inflated negative binomial (ZINB) regression and zero-inflated poisson (ZIP) regression (Vaudor et al. 2011, Nielsen et al. 2005, Barry and Welsh 2002), using Proc COUNTREG and Proc GENMOD in SAS 9.2. Resulting over-dispersion (alpha) estimates that differed from zero indicated that the zero-inflated models were better than their non-zero counterparts (SAS Institute Inc. 2011). Zero-inflated count models divide the data into an always zero group (zeromodel) and a not always zero group (Nielsen et al. 2005).

First, the zeromodel had to be determined. The -2LL for the zero-model was obtained using logistic regression in Proc LOGISTIC in SAS 9.2. Akaike Information Criteria (AIC), corrected for small sample sizes (AIC_c), was used to rank models within the initial themes (See Equation [2]).

$$AIC_c = -2LL + 2k\ (\text{\# of parameters}) + 2k\ (k+1) / (n\ (\text{sample size}) - k - 1) \qquad [2]$$

Models were compared against one another within themes; with the lowest AIC_c score subtracted from the other AIC_c scores to provide the ΔAIC_c (see Equation [3]).

$$\Delta AIC_c = AIC_{ci} - AIC_{c\ min} \qquad [3]$$

Within each theme, the model with the lowest AIC_c was moved forward to the final analysis where all leading variables from the various themes were combined in an additive fashion (i.e. added sequentially in descending order according to their -2LL). Once the AIC_c analysis was complete, the final model with the lowest ΔAIC_c was considered the best zeromodel.

Second, the ZIP or ZINB model had to be determined. The best zero-model was brought forward into the ZINB and ZIP model analysis. The same themes were tested, and ranked using AIC_c. Different variables were combined in an additive fashion for the final analysis to determine the best overall model. Final model selection was based on the lowest ΔAIC_c, which in turn was considered to be the best model explaining horse presence. Model probabilities (ω_i) were calculated to quantify the probability of each model being the best model among all models tested (See Equation [4]).

$$\omega_i = \exp(-0.5\Delta_i) / \sum \exp(-0.5\Delta_r) \qquad [4]$$

To assess whether the ZINB or ZIP provided the best model fit, the -2LL values were used to generate a pseudo R^2 (goodness-of-fit) for each model to compare the percentage of deviance explained by all models in comparison to the null (Cameron and Windmeijer 1997, Windmeijer 1995) (see Equation [5]).

McFadden's pseudo R^2 = 1 – (log likelihood candidate model / log likelihood null model) [5]

Finally, RSPFs (Manly et al. 2002) were developed using the beta estimates from the ZIP models to quantify relationships between horse abundance and the different landscape characteristics (see Equation [6]).

$$\mathrm{RSPF} = \exp(\beta_o + \beta_1 x_1 + \ldots + \beta_p x_p) / 1 + \exp(\beta_o + \beta_1 x_1 + \ldots + \beta_p x_p) \qquad [6]$$

Beta (β) coefficients were obtained from the Proc COUNTREG (SAS 9.2) output used to obtain the -2LL, and provide the directionality and magnitude of the association between factors. The same methodology was used to develop resource selection functions for cattle and wild ungulates (See Appendix F and Appendix G).

4.4 Results

4.4.1. Forage Characteristics and Utilization Trends among Habitats

The biomass of forb but not grass and shrub components varied between years (Table 4.1). Grassland and shrubland had the greatest grass production, followed by cutblocks and mixedwood forest, and finally conifer forest (Table 4.1). In 2009 forb biomass was similar in grassland, shrubland and cutblock habitats, with mixedwood and conifer forests being significantly lower; in 2010 forb biomass was similar across all habitats. Shrub biomass was greatest in riparian shrubland, followed by conifer forest, then cutblocks and mixedwood forest, with grassland having the lowest shrub production (Table 4.1).

Forage quality differed between years for forb nitrogen content, as did ADF concentrations for grasses and forbs. Grass N values were similar between years and among all habitats (Table 4.1). In general, forb quality was highest in mixedwood forest and grassland, followed by cutblocks, and lowest in shrubland and conifer forest (Table 4.1), a pattern evident in both years. Grass and forb ADF concentrations in 2009 were 35.4 ± 1.6 and 28.1± 2.1, both of which remained lower ($p<0.05$) than in 2010 (grass ADF, 37.9 ±1.1; forb ADF 34.8± 1.5).

Analysis of pellet counts among habitats indicated that horse counts were greatest in grassland, conifer cutblocks, and riparian shrubland, followed by mixedwood and conifer forest (Table 4.2). Cattle counts were greatest in grassland and riparian shrubland, followed by mixedwood forest, conifer cutblocks and then conifer forest (Table 4.2). Measurement of wild ungulates had the opposite pattern, as counts were greatest in conifer forest, followed by riparian shrubland and then the remaining three habitats. Biomass utilization estimates were greatest in grassland, conifer cutblocks and riparian shrubland communities, followed by mixedwood forest, with very low use of conifer forest (Figure 4.2).

Correlations between the abundance of cattle, feral horses, and ungulates based on pellet counts indicated there were similar relationships in 2009 and 2010. As the data from 2010 were considered more robust due to the larger sample size of plots, these data are emphasized in this chapter, with additional results from 2009 provided in Appendix H. There was a significant relationship between vegetation utilization estimations and the pellet counts of all three ungulate groups ($p<0.0001$) (Table 4.3). Horse and cattle pellet counts were both positively associated with utilization estimations, with cattle most strongly correlated. In contrast, wild ungulate counts were negatively associated with utilization. While horse pellet counts were not correlated with any habitat characteristic (Table 4.3), cattle pellet counts were positively associated with forb biomass ($p<0.01$). Wild ungulate pellet counts were negatively associated with forb and grass biomass ($p<0.01$), but positively associated with shrub biomass ($p<0.001$).

4.4.2. Resource Selection

4.4.2.1. Zeromodel Selection

Initial comparison of *a-priori* models used to test for the presence of ungulates based on the pellet count data and subsequently develop zeromodels, revealed that most of the same variables were brought forward between years to the final assessment for the majority of themes (Tables 4.4 and 4.5). Adjusted biomass was consistently brought forward as the only variable to represent forage characteristics; however, prior analysis of the limited dataset with forage quantity and quality revealed that this would likely have been the case in the larger analysis. In both years, distance to roads and trails was brought forward within the disturbance theme. Within the competition theme pellet counts of competing ungulates were brought forward in both years. Within the water and topography theme, ruggedness was brought forward in 2009, which changed over to water distance in 2010. Variables brought forward within the thermal theme included solar radiation in 2009 and distance to any forest in 2010.

During 2009, the variables that explained the most deviance in horse pellet counts were ranked in descending order as follows: thermal > disturbance > competition > water and topography > biomass. The final model analysis revealed that the zeromodel for 2009 was the thermal model, explaining 5.83% variance in horse pellet counts and a 0.48 (i.e. 48%) probability of being the best model among those tested (Table 4.6). According to the beta (β) coefficient, horse occupancy increased as solar radiation increased (Table 4.12). During 2010, however, the ranking of themes was altered substantially as follows: competition > disturbance > biomass > thermal > water and topography. The best model for 2010 was the disturbance model, which explained 3.13% of variance in horse pellet counts and had a 0.46 (46%) probability of being the best model (Table 4.7) According to the β coefficients, horse occupancy decreased as distance to roads and trails decreases.

4.4.2.2. Occupancy Model Selection

The initial *a-priori* ZIP models indicated that all but three variables (distance to roads and trails, cattle pellet count, and solar radiation) were suitable to move on to the final analysis in 2009 (Table 4.8). Consequently, the variables moving forward included adjusted biomass, ruggedness, water distance, cutlines, forest distance and ungulate pellet count. Variance in horse abundance explained by the 2009 variables was ranked as follows (in descending order): water and topography > competition > disturbance > thermal > forage.

During 2010 the variables chosen to move forward from the individual themes differed slightly from the year before (Table 4.9). Adjusted biomass was the leading variable within the forage characteristics theme. Similar to 2009, water distance and ruggedness both moved forward within the water and topography theme. Distance to both roads/trails as well as cutlines moved forward within the disturbance theme. Distance to forest and solar radiation variables were both important in the thermal theme, while cattle and ungulate pellet counts both moved forward from the competition theme. Ranking among variables in 2010 was similar to the previous year, except that water and topography moved from most important to least important: competition > disturbance > thermal > forage > water and topography.

Final model analysis of the 2009 data demonstrated that the "water and topography plus competition" model was the best model (Table 4.10). Variables included in this model were distance to water, ruggedness, and other ungulate presence, which together explained 10.2% of variance in horse pellet counts and had a 0.46 (46%) probability of being the best model out of those tested (Table 4.10). In 2010, the best model identified by the AIC analysis was the "competition plus disturbance plus thermal plus water and topography" model (Table 4.11). Specific variables included in this model were distance to water, ruggedness, distance to both roads/trails and cutlines, distance to forest, solar radiation, and both cattle and ungulate pellet counts. The combination of variables explained 22.1% of variance in pellet counts and had a 0.74 (74%) probability of being the best model (Table 4.11).

The β estimates for 2009 indicated that as distance to water increased the probability of horse use became greater (Table 4.12). In contrast, β estimates for the ruggedness and ungulate themes both showed a negative relationship, such that as ruggedness and ungulate pellet counts increased the probability of horse use decreased. In 2010, β estimates for water showed a different relationship, with the probability of horse use decreasing as distance to water increased (Table 4.13). Ungulate pellet count and ruggedness variables had negative relationships in 2010, similar to the trend the year before. Overall, when water and topography were examined together the probability of horse use decreased in both years as either variable decreased (Figure 4.1). Evidence of wild ungulates also decreased the probability of horse use, a relationship that remained similar between years (Figure 4.2). The cattle relationship was the opposite however, as cattle use increased the probability of horse use also increased (Table 4.13, Figure 4.2). For the disturbance variables in 2010, the probability of horse use decreased as distance to roads/trails and cutlines increased (Table 4.13, Figure 4.3). Lastly, within the thermal theme, horse use increased as the distance to forest increased, as did horse use with increasing solar radiation (Figure 4.4).

Final abundance RSPF's and count models created for each year used the aforementioned β variables to predict the probability of horse use (see Equations [7] and [8]) and the expected horse count (see Equations [9] and [10]).

$RSPF_{2009}$ = exp (1.430 + 0.004* water distance (m) – 0.077* ruggedness – 0.190* ungulate) / [1 + exp(1.430 + 0.004* water distance (m) – 0.077* ruggedness – 0.190* ungulate) [7]

$RSPF_{2010}$ = exp(0.400 + 0.410 x 10^{-3}* cattle – 0.130* ungulates -0.6 x 10^{-3}* roads/trails distance – 0.320 x 10^{-3}* cutline distance + 0.008* forest distance + 0.1 x 10^{-3}* solar radiation – 0.002* water distance – 0.036* ruggedness) / [1 + exp(0.4 + 0.004* cattle – 0.130* ungulates -0.600 x 10^{-3}* roads/trails distance – 0.320* cutline distance + 0.008* forest distance + 0.100 x 10^{-3}* solar radiation – 0.002* water distance – 0.036* ruggedness)] [8]

Count $Model_{2009}$ = exp (1.430 + 0.004* water distance (m) – 0.077* ruggedness – 0.190* ungulate) [9]

Count $Model_{2010}$ = exp(0.400 + 0.004* cattle – 0.130* ungulates -0.600 x 10^{-3}* roads/trails distance – 0.320 x 10^{-3}* cutline distance + 0.008* forest distance + 0.100 x 10^{-3}* solar radiation – 0.002* water distance – 0.036* ruggedness) [10]

4.5. Discussion

4.5.1. Pellet Count Correlation

Relationships between estimated forage utilization and the abundance of different ungulate groups (feral horses, cattle or ungulates) based on pellet counts provide insight as to which herbivore may have caused the majority of forage use during summer. These trends suggest that the field plots sampled here, despite their relatively small, isolated nature, are capable of providing some resolution relative to this important question within the McLean Creek watershed. Given that cattle, horses, and some wild ungulates (i.e. elk) are predominantly grazers, it is not surprising that the greatest biomass utilization occurred within lowland grassland and neighbouring riparian shrubland habitats, throughout the study area.

Among ungulates, the majority of forage utilization appeared to be attributable to cattle, which graze only seasonally in the region. This is not surprising as cattle would be less susceptible to human activity, including recreational traffic, allowing them to spend extended time periods within their preferred habitats. It was also not surprising to see that the highest cattle pellet counts were found in grassland and shrubland communities since they have the greatest grass production and cattle prefer graminoids (McInnis and Vavra 1987). On the other hand, close association of cattle presence with forb biomass availability was unexpected due to cattle preference, although forbs can offer forage of significant quality in mid summer within foothills grasslands of Alberta (Bork et al., In press). However, interpretation of these relationships remains problematic, as our biomass estimates were subject to adjustment for biomass removed, which in turn may not be entirely accurate. Within the study area, grasslands had the greatest values of forb biomass, although once data were normalized it remained similar to most of the other habitats in either year. In addition, the close association of cattle use with forb biomass may instead reflect vegetation responses to the ongoing impacts of repeated cattle use of this habitat, rather than actual selection by cattle for forbs. Combined summer grazing from cattle and feral horses may have altered these native rough fescue grassland communities, which are known to be sensitive to summer grazing, including being prone to reductions in the dominant grass (Willms et al. 1985). Further changes in composition attributed to grazing include increasing species diversity (Rambo and Faeth 1999), in turn reflecting the release of forbs following reduced competition from grasses, and thus account for the association between cattle presence and forb biomass. This conclusion was further supported by the observation that many of the forb species in the study area, particularly within grasslands, were introduced, disturbance tolerant species [i.e. dandelion, strawberry and white clover (Appendix D)].

Feral horses were also shown to be a contributor to total utilization within the McLean Creek area, as evidenced by the relation between horse fecal counts and total biomass utilization, although no clear associations were observed between horse counts and the habitat characteristics. The latter suggests horse behaviour in using habitats may have been determined by factors other than forage quantity or quality. Additionally, fecal counts for horses suggest they were utilizing predominantly grassland and shrubland habitats, areas similarly used by cattle. Similarity of grassland use by feral horses and cattle, as indicated by pellet counts, is not surprising as both these herbivores have similar dietary preferences and have previously demonstrated large habitat overlap with one another during summer (McInnis and Vavra 1987). Prolonged and intensive simultaneous use of these habitats by feral horses and cattle may increase the risk of ecosystem degradation including reductions in forage production, range health and biodiversity. Range health assessments conducted by ASRD in the region have revealed many plant communities with range health scores that are low (i.e. unhealthy) or moderate (i.e. healthy with problems) (Michalsky 2010).

Wild ungulate populations had a strong negative relationship with total biomass utilization estimates, suggesting that wild ungulates used areas that were not as readily used by horses or cattle. Pellet count data suggest that wild ungulates used conifer forest and riparian shrubland habitats more, potentially because these habitats were more likely to provide the preferred forage of wild ungulates, which are either partly (elk) or heavily (moose and deer) reliant on browse for forage (Salter and Hudson 1980). Conversely, forested habitats with abundant browse are those least likely to experience use by feral horses and cattle, particularly during summer when selected habitats had abundant growth. Finally, there may be other reasons besides vegetation that accounts for why wild ungulates avoid sites with higher utilization. RSPF analysis of the wild ungulate data (Appendix G) indicated that their presence was negatively associated by the presence of cattle and horses. Thus, the latter could be displacing wild ungulates into non-preferred habitats.

4.5.2 Summer Habitat Use

Factors affecting feral horse habitat use of field plots during summer varied modestly between 2009 and 2010. Only three variables were identified (water distance, ruggedness, ungulates) the first year, all of which were again important one year later but were joined by both disturbance and thermal factors. The increased number of significant variables found during 2010 explained more than twice as much variation in horse use as in 2009. These findings likely reinforce the importance of the larger sample size of field plots in 2010 in improving the ability to detect relationships between horse abundance and various landscape attributes.

Horse counts within field plots in relation to primary water sources exhibited divergent responses between years. During the first year, horses used areas further from water, while the opposite was evident in 2010. Several potential explanations exist for these observations. Differences in precipitation may account for these patterns, as increased rainfall in June 2009 (Figure B.1, Appendix B) could have increased water availability distant from 'primary' water sources, allowing horses to spend more time away from primary waterways. In 2010, increased horse use of areas near expected water sources may be a response to reduced spring and early summer precipitation that year (Figure B.1, Appendix B). In any case, caution should be exercised when interpreting horse responses to water availability, particularly as not all water sources are likely to be known and accounted for in our water availability maps (see Chapter 3). If water was limited in this region it could impact the presence of horses (Stevens 1988), however findings by Salter and Hudson (1979) suggest that water is not limiting in the area and that horses are not impacted by it.

Terrain ruggedness was a factor impacting horse abundance in field plots sampled during both years, and in conjunction with distance to water in the preliminary analysis, explained more variation in horse use during 2009 than 2010. These findings are consistent with previous work indicating feral horses avoid complex topography and instead use flat terrain (Ganskopp and Vavra 1987). Within the McLean Creek study area, flatter areas were generally the valley bottoms, which also contained the selected habitat of horses (grasslands) and a readily available supply of water. Although there was some evidence to suggest feral horses were willing to make greater use of moderately rugged areas further from water during 2009 (see Figure 4.2), this result may be misleading as it could instead reflect the fact that not all water sources were mapped across the study area. Overall, the presence of a consistent negative relationship between ruggedness and horse use suggests that topography imposes a significant constraint on horse use within these landscapes.

The presence of competing ungulates on one another based on the field plots sampled had mixed results during the study period, with wild ungulates appearing to negatively impact horses in both years, and horses negatively impacting ungulate abundance in a parallel study during 2010 (Appendix G), coincident with larger sample sizes of field plots. The observed negative response in horse use to wild ungulate presence may be explained through several mechanisms. The simplest explanation is that this relationship is a direct reflection of horses and wild ungulates preferring distinctly different habitats, specifically grasslands (or open shrublands) and woodlands, respectively. Previous work has shown that horses and wild ungulates utilize different habitats due to differing dietary requirements (McInnis and Vavra 1987, Hubbard and Hansen 1976). Thus, a second potential explanation is that horses and wild ungulates may exhibit mutual avoidance on the landscape in an attempt to avoid competition or perhaps predators, in effect displacing native ungulates from habitats they would normally use. Moreover, the similar use of habitats by horses and cattle (see below) may result in displacement of wild ungulates by both horses and cattle. Previous work has shown that when livestock move into a region, wild ungulates (i.e. mule deer) move into less preferred areas of the landscape (Stewart et al. 2002, Kie et al. 1991, Loft et al. 1991), results that could apply following exposure to both horses and cattle in the current study. Finally, it is also possible that the observed extent of segregation in habitat use between feral horses and wild ungulates may be overestimated based on the method of using fecal counts to assess ungulate presence. For example, elk have been found to defecate where they bed rather than where they forage (Collins and Urness 1981, 1983), which would overestimate elk use of bedding sites such as forest, and underestimate use of adjacent foraging sites, presumably grasslands. Nevertheless, the observed segregation documented here between feral horses and wild ungulates during summer is important, with further information needed on the specific mechanisms determining this relationship.

In contrast to wild ungulates, feral horse abundance in field plots was positively associated with cattle presence, particularly during 2010. This is not surprising given the dependence of both these herbivores on the same habitats, specifically grasslands, during summer (see Section 4.5.1). Although it was anticipated that cattle and horses, being the predominant large herbivores within this ecosystem, may segregate their use in the landscape, little evidence was apparent to support this notion. One possibility for the strong overlap in habitat use is that both these herbivores may benefit from the prompt regrowth of biomass throughout the summer growing season following frequent defoliation, which is known to attract animals to high quality forage (Belsky 1986). Salter and Hudson (1980) found that the majority of ranges in their study had feral horse use prior to cattle entry, a pattern likely to occur at McLean Creek as well where cattle do not enter the area until June. Thus, spring and early summer use by horses may initially condition vegetation within lowland grasslands, which is then further reinforced throughout the year by ongoing cattle and horse use. Finally, it is worth noting that cattle do not appear to exhibit any relationship with horse presence (Appendix F), suggesting cattle are behaving independently of other herbivores.

Cattle stocking rates in the region were around 2300 AUMs in 2010 based on approximately 1600 animals (unpublished ASRD data) grazing from June 15th until September 15th. In contrast, feral horse stocking rates were approximately 1965 to 2358 AUMS based on 131 individuals, a 1.5 AU equivalent per head, and a 12 month year-long grazing season. A key difference evident between these herbivores is that while cattle use occurs from mid June to mid October, feral horses are using the range throughout the year. This is problematic as production values for habitats obtained in this study indicate that grasslands (primary range) provide only 3805 AUMs for the entire year. As grasslands were shown to be selected by cattle and horses in the region, aggregate use by these herbivores is likely well over this stocking level (i.e. 2300 AUM for cattle + 2000 AUM for horses). If secondary range (shrubland) is included, an assumption that appears to be supported by results of the current study, the total available AUMs available for sustainable grazing increases to 5607 (Figure 4.14). Although cutblocks are also clearly important for contributing to horse grazing capacity, feral horse preference for cutblocks only in winter indicates cutblocks do not reduce summer grazing pressure, but rather provide an abundance source of alternative grazing (9837 AUMs) during winter when no other forage is available. Although the greatest contributor of AUMs is from conifer forests due to their large size (Table 4.14), these areas are not selected or highly utilized by feral horses, potentially limiting their contribution to horse survival.

It should be noted that forage utilization assessments in this study were very conservative, averaging 44% by the time of sampling in late July after only 2-3 months of summer grazing. Although un-quantified in the present investigation, continued grazing by feral horses and cattle into late summer would have increased forage utilization levels substantially on primary ranges (grasslands and shrublands), and also account for the observed lack of litter and standing dead carryover within these habitats during sampling. With grazing capacity in grasslands likely exceeded by summer long grazing from cattle and horses, this likely accounts for observations that the range health of many grasslands in the region is being compromised, as reflected by low range health scores (Michalsky 2010). Moreover, the lack of standing dead litter under heavy use is problematic, as litter is an important indicator of range health, and also helps limit the use of late seral native grasses such as rough fescue (*Festuca campestris*) (Moisey et al. 2006). Reduced litter also means that animals have no choice but to utilize secondary ranges, particularly during winter.

Increased horse use during 2010 of field plots near linear features of the landscape such as roads, trails and cutlines, where human activity was expected to be greater, suggests that horses were not negatively impacted by disturbance.

These results contrast those of Laliberte and Ripple (2004), who found decreased ungulate activity near roads and trails. In fact, results of the current study suggest horses appeared to use areas near linear features of the landscape during summer. Horses may use these areas due to the increased mobility these features provide as travel corridors (Trombulak and Frissel 2000), particularly in a landscape that is otherwise largely forested. Linear features, though relatively small in area, were also relatively unique in that they consisted of previously disturbed ground that is now dominated by herbaceous (i.e. grassland) vegetation. Thus, linear features distributed throughout the landscape may effectively provide an expansion of preferred habitat of feral horses. It should also be noted that modeled differences were observed between the importance of areas surrounding roads/trails and cutlines with respect to their attractiveness for horse use. In general, areas surrounding road/trails appeared to experience increased use by horses, and likely reflects the fact that these areas tend to be situated in valley bottoms (i.e. the most easily traversed areas of the landscape), and thus, were surrounded by preferred grassland habitats. In contrast, cutlines provide only small grasslands traversing cutblocks, and horses may be reluctant to stray off them into adjacent cutblocks (i.e. a non-preferred habitat in summer), or alternatively, be primarily using cutlines as movement corridors to travel between larger, more used roads/trails or grasslands (Table 4.3). Notably, these results based on the field plot data are inconsistent with those found at the landscape level in Chapter 3, where linear disturbances were not found to impact horse habitat selection during summer. It is possible that the linear features were not important to the horses specifically collared for the GPS study, but they may affect other horses on the landscape. Summer data from 2009 may not show a response because of the limited sample size, while 2010 data may be more representative of the feral horse population.

Thermal variables were found to be important in altering horse use of field plots, but only in 2010. Horse use increased with both increasing distance to forest (i.e. edge) and greater levels of solar radiation. While it was hypothesized that horses may use forests as a source of shade for thermal relief in summer (Musterud and Østbye 1999), this did not occur, at least not to the point of expressing selection for those areas. Shade may not be critical in this region due to a limited daytime temperature maximum, and in fact, horse increased use (as well as cattle increased use; Appendix F) of plots with greater solar radiation suggests that even during summer, these animals sought warmer areas of the landscape. Additionally, many grasslands in the region are south-facing, which may also account for the apparent preference of areas with increased solar radiation.

Avoidance of forests by feral horses also paralleled responses evident in cattle (Appendix F), both of which contrasted those of wild ungulates (Appendix G). In addition to the established differences in dietary preferences among these ungulate groups, which would explain at least some of these discrepancies, another distinct possibility is that use or avoidance of forests was impacted more by behavioural responses to cope with predation risk and avoidance of human contact. Cattle and horse use of open areas may reflect a strategy to ensure favourable sight lines of their surroundings, thereby allowing these large animals to detect and avoid predators such as wolves or mountain lions. Similarly, both these herbivores appear to tolerate human presence, at least at a distance (personal observation, Tisa Girard). Conversely, native ungulates may be more likely to avoid all contact with humans (Stankowich 2008), and thus use habitats with high concealment cover (i.e. wooded areas).

4.6. Management Implications

Overall, RSPFs within the study indicated that there were numerous different variables responsible for habitat use by feral horses. Habitat use by feral horses was shown to be affected by cattle and ungulates; distance to roads, trails and cutlines; distance to forests and solar radiation; and distance to water and ruggedness. Assessing these different characteristics on the landscape can allow land managers to determine how likely horses are to use specific locations in the region. Since cattle and wild ungulate pellet counts cannot be determined though a GIS, land-based assessments must be conducted to properly use the RSPFs and count models.

The only theme not included in the final count model was the forage characteristics theme. This was rather surprising as forage was hypothesized to be an important factor affecting habitat selection by horses. However, because vegetation sampling was conducted concurrent with grazing and biomass numbers were generated through back calculation, there is a possibility that this factor was not properly represented. The pellet count analysis indirectly indicated that forage biomass impacted use as pellet counts were greatest in the grassland habitat with the highest biomass production.

Since cattle were also found in these areas it is possible that there could be a conflict between feral horses and livestock producers. At this point in time feral horses are present in smaller numbers than cattle, but their increased size and year-long occupation of the region means that their stocking rate (AUMs) remains very similar to cattle. These numbers are problematic because they exceed the carry capacity of grasslands in the region and future management actions may need to be taken to reduce range health degradation. Three possible options include: 1) reducing the number of cattle, 2) reducing the number of horses through increased horse captures, or 3) increasing efforts to reverse shrub encroachment to increase grassland areas that may have been previously lost. Reduction of animal populations will not be easy, but would be the best long term solution. Allowable cattle stocking rates are unlikely to be reduced given previous declines in allowable stocking and the provinces commitment to maintain 1977 stocking levels (Government of Alberta 1984). Similarly, sporadic horse captures are unlikely to result in the ongoing effort needed to contain growth of feral horse populations. Burning of shrublands would increase the area of grassland and the primary carrying capacity of rangeland in the short term (Bork et al. 1996), but will require continual maintenance, and may also simply postpone the need to make a decision on sustainable population sizes of feral horses. Despite the difficulties involved, managing the collective stocking rates of cattle and horses is imperative for protecting range health in the long-term.

Despite the obvious conflicts that may arise between cattle, feral horses, and the conservation of native grasslands, it is less clear the extent to which there is conflict between wild ungulates and horses. Although feral horses and wild ungulates used different areas of the landscape, several alternative mechanisms could account for this, including 1) different ungulate groups may be avoiding one another, 2) use by wild ungulates may be over-estimated in forests due to increased defecation bedding areas (Collins and Urness 1981, 1983), and 3) horses (alone, or together with cattle) may be displacing wild ungulates (Stewart et al. 2002, Kie et al. 1991, Loft et al. 1991). Further investigation is required to determine which of these mechanisms are leading to the observed relationship between these herbivore groups.

Determining the different factors that explain horse habitat selection and increase our understanding of relationships among large ungulates in the region is beneficial to land managers. However, there are still some factors that need further explanation. Additional research exploring forage characteristics is one important step. Net seasonal forage production numbers would enable a better understanding of how it affects feral horse selection. Determining levels of utilization between different herbivores will be difficult, but nevertheless be beneficial as it would create a better understanding of how each ungulate is affecting rangeland health and sustainability. Ultimately, although there is follow up work to be done; the RSPFs and count models developed in this study will aid resource managers in determining critical habitats based on field characteristics.

Table 4.1. Mean forage characteristic values for various habitats in the Rocky Mountain Forest Reserve of Alberta for summers of 2009 and 2010.

		Biomass (kg/ha)			N Concentration (%)	
Year	Habitat	Grass	Forb	Shrub	Grass	Forb
2009						
	Conifer Forest	--	116.9 ± 120.3 c	--	--	11.3 ± 1.8 c
	Conifer Cutblock	--	553.91 ± 120.3 a	--	--	14.0 ± 1.8 bc
	Grassland	--	783.10 ± 120.3 a	--	--	16.1 ± 1.8 ab
	Mixedwood Forest	--	338.95 ± 121.4 b	--	--	19.7 ± 1.8 a
	Riparian Shrubland	--	534.20 ± 120.3 a	--	--	14.5 ± 1.8 c
2010						
	Conifer Forest	--	97.9 ± 86.1 a	--	--	16.7 ± 1.2 c
	Conifer Cutblock	--	355.6 ± 86.1 a	--	--	15.6 ± 1.2 bc
	Grassland	--	441.5 ± 86.1 a	--	--	17.4 ± 1.2 ab
	Mixedwood Forest	--	244.3 ± 112.8 a	--	--	18.3 ± 1.6 a
	Riparian Shrubland	--	384.4 ± 86.1 a	--	--	16.0 ± 1.2 c
Both						
	Conifer Forest	42.4 ± 148.9 d	--	262.7 ± 87.0 b	12.7 ± 1.0	--
	Conifer Cutblock	645.0 ± 148.9 bc	--	104.1 ± 87.0 c	12.7 ± 1.0	--
	Grassland	1139.7 ± 148.9 a	--	0.2 ± 87.0 d	13.6 ± 1.0	--
	Mixedwood Forest	361.7 ± 175.6 c	--	46.7 ± 101.6 cd	14.3 ± 1.2	--
	Riparian Shrubland	871.1 ± 148.9 ab	--	732.2 ± 87.0 a	12.6 ± 1.0	--

Within a year and column, means with different letters differ, $p<0.05$.
*Measurement of digestibility.
-- Indicates there are no values due to year effects.

Table 4.2. Mean pellet count and utilization values for various habitat types in the Rocky Mountain Forest Reserve of Alberta for summers of 2009 and 2010 combined.

	Pellet Count Density (#/400m^2)			Utilization (%)
Habitat	Horse	Cattle	Wild Ungulates	
Conifer Forest	1.0 ± 1.2 b[1]	1.0 ± 5.5 c	4.0 ± 0.5 a	3.1 ± 4.4 c
Conifer Cutblock	5.6 ± 1.2 a[2]	4.2 ± 5.5 b[5]c	0.6 ± 0.5 c	21.5 ± 4.4 ab
Grassland	6.0 ± 1.2 a[3]	35.9 ± 5.5 a[6]	0.1 ± 0.5 c	43.5 ± 4.4 a[7]
Mixedwood Forest	1.0 ± 1.4 b[4]	4.8 ± 6.1 bc	0.8 ± 0.5 c	12.4 ± 4.8 b
Riparian Shrubland	2.3 ± 1.2 a[1]b	14.6 ± 5.5 abc	2.6 ± 0.5 b	20.0 ± 4.4 ab

Within a column means with different letters differ, p<0.05.
[1] Conifer forest and riparian shrubland differ, p<0.1.
[2] Conifer cutblock and riparian shrubland differ, p<0.07.
[3] Grassland and shrubland differ, p<0.09.
[4] Mixedwood forest and riparian shrubland differ, p<0.06.
[5] Conifer cutblock and riparian shrubland differ, p<0.08.
[6] Grassland and riparian shrubland differ, p<0.08.
[7] Grassland and shrubland differ, p<0.06.

Table 4.3. Summary of correlations between ungulate use measures, including feral horse and cattle pellet densities, as well as forage use and various plant community characteristics for summer of 2010.

Habitat Characteristic		Use Metric		
	Component	Horse Fecal Count	Cattle Fecal Count	Wild Ungulate Fecal Count
Biomass				
	Grass	0.15	0.23	-0.37**
	Forb	0.21	0.34**	-0.40**
	Shrub	-0.16	-0.20	0.57***
N Concentration				
	Grass	0.072	0.0057	0.011
	Forb	0.19	0.20	-0.036
ADF Concentration				
	Grass	-0.025	-0.048	-0.12
	Forb	-0.0023	0.10	-0.13
Utilization Estimation				
	All Forage	0.55***	0.71***	-0.59***

*,**,*** Indicate significance at $p<0.05$, $p<0.01$ and $p<0.001$, respectively.

Table 4.4. Initial summary results depicting comparative model strength of predictive horse occurrence from field plot data during summer 2009, and various landscape attributes. Bolded and italicized components indicate leading model in a theme, and which were carried forward into the final assessment.

Theme	Component	R^2 [1]	k [2]	-2LL [3]	AIC_c [4]	ΔAIC_c [5]	ω_i [6]
Null [7]							
		0.00	***1***	***78.86***	***80.93***	***0.00***	***1.00***
Forage Characteristics							
	Adjusted Biomass	***0.00***	***2***	***78.86***	***83.08***	***0.00***	***1.00***
Water & Topography							
	Water Distance	0.04	2	78.83	83.05	0.03	0.42
	Ruggedness	***0.08***	***2***	***78.80***	***83.02***	***0.00***	***0.43***
	Water Distance + Ruggedness	0.14	3	78.75	85.20	2.18	0.15
Disturbance							
	Roads/Trails	***0.63***	***2***	***78.36***	***82.58***	***0.00***	***0.47***
	Cutlines	0.00	2	78.86	83.08	0.50	0.37
	Roads/Trails + Cutlines	0.67	3	78.33	84.78	2.20	0.16
Thermal							
	Forest Distance	3.75	2	75.90	80.12	1.64	0.19
	Solar Radiation	***5.83***	***2***	***74.26***	***78.48***	***0.00***	***0.44***
	Forest Distance + Solar	8.28	3	72.33	78.78	0.30	0.37
Competition							
	Cattle	0.05	2	78.82	83.04	0.10	0.42
	Ungulates	***0.18***	***2***	***78.72***	***82.94***	***0.00***	***0.44***
	Cattle + Ungulates	0.20	3	78.70	85.15	2.21	0.14

[1] McFadden's pseudo R^2 goodness of fit measure.
[2] Number of model parameters.
[3] -2 log likelihood.
[4] AIC corrected for sample size of 57 observations.
[5] Difference between AIC_c value and the lowest AIC_c value within each theme.
[6] Model probability.
[7] Null model with intercept only.

Table 4.5. Initial summary results depicting comparative model strength of predictive horse occurrence from field plot data during summer 2010, and various landscape attributes. Bolded and italicized components indicate leading model in a theme, and which were carried forward into the final assessment.

Theme	**Component**	**R^2** [1]	**k** [2]	**-2LL** [3]	**AIC_c** [4]	**ΔAIC_c** [5]	**ω_i** [6]
Null [7]							
		0.00	***1***	***135.49***	***137.56***	***0.00***	***1.00***
Forage Characteristics							
	Adjusted Biomass	***0.40***	***2***	***134.95***	***139.17***	***0.00***	***1.00***
Water & Topography							
	Water Distance	***0.10***	***2***	***135.36***	***139.58***	***0.00***	***0.44***
	Ruggedness	0.01	2	135.48	139.70	0.12	0.41
	Water Distance + Ruggedness	0.10	3	135.35	141.80	2.22	0.15
Disturbance							
	Roads/Trails	***3.13***	***2***	***131.25***	***135.47***	***0.00***	***0.59***
	Cutlines	0.35	2	135.02	139.24	3.77	0.09
	Roads/Trails + Cutlines	3.87	3	130.24	136.69	1.22	0.32
Thermal							
	Forest Distance	***0.29***	***2***	***135.10***	***139.32***	***0.00***	***0.43***
	Solar Radiation	0.20	2	135.22	139.44	0.12	0.41
	Forest Distance + Solar	0.44	3	134.90	141.35	2.03	0.16
Competition							
	Cattle	0.04	2	135.44	139.66	5.10	0.05
	Ungulates	***3.80***	***2***	***130.34***	***134.56***	***0.00***	***0.63***
	Cattle + Ungulates	4.47	3	129.43	135.88	1.32	0.33

[1] McFadden's pseudo R^2 goodness of fit measure.
[2] Number of model parameters.
[3] -2 log likelihood.
[4] AIC corrected for sample size of 98 observations.
[5] Difference between AIC_c value and the lowest AIC_c value within each theme.
[6] Model probability.
[7] Null model with intercept only.

Table 4.6. Summary results of final model analysis, depicting comparative model strength of predictive horse occurrence from field plot data during summer 2009, and various landscape attributes. Bolded and italicized model indicates the best model.

Themes	$\mathbf{R^2}$ [1]	**k** [2]	**-2LL** [3]	$\mathbf{AIC_c}$ [4]	$\mathbf{\Delta AIC_c}$ [5]	$\boldsymbol{\omega_i}$ [6]
Null [7]	0.00	1	78.86	80.93	2.45	0.14
Thermal	***5.83***	***2***	***74.26***	***78.48***	***0.00***	***0.48***
Thermal + Disturbance	7.14	3	73.23	79.68	1.20	0.26
Thermal + Disturbance + Water & Topography	7.16	4	73.21	81.98	3.50	0.08
Thermal + Disturbance + Water & Topography + Competition	7.61	5	72.86	84.04	5.55	0.03
Thermal + Disturbance + Water & Topography + Competition + Forage	7.65	6	72.83	86.51	8.03	0.01

[1] McFadden's pseudo R^2 goodness of fit measure.
[2] Number of model parameters.
[3] -2 log likelihood.
[4] AIC corrected for sample size of 57 observations.
[5] Difference between AIC_c value and the lowest AIC_c value within each theme.
[6] Model probability.
[7] Null model with intercept only.

Table 4.7. Summary results of final model analysis, depicting comparative model strength of predictive horse occurrence from field plot data during summer 2010, and various landscape attributes. Bolded and italicized model indicates the best model.

Themes	**R^2** [1]	**k** [2]	**-2LL** [3]	**AIC_c** [4]	**ΔAIC_c** [5]	**ω_i** [6]
Null [7]	0.00	1	135.49	137.56	2.09	0.16
Disturbance	***3.13***	***2***	***131.25***	***135.47***	***0.00***	***0.46***
Disturbance + Forage	3.56	3	130.67	137.12	1.35	0.20
Disturbance + Forage + Thermal	3.59	4	130.67	139.39	3.92	0.07
Disturbance + Forage + Thermal + Water & Topography	4.10	5	129.93	141.11	5.63	0.03
Disturbance + Forage + Thermal + Water & Topography + Competition	7.43	6	125.42	139.10	3.63	0.08

[1] McFadden's pseudo R^2 goodness of fit measure.
[2] Number of model parameters.
[3] -2 log likelihood.
[4] AIC corrected for sample size of 98 observations.
[5] Difference between AIC_c value and the lowest AIC_c value within each theme.
[6] Model probability.
[7] Null model with intercept only.

Table 4.8. Summary results depicting comparative model strength of zero-inflated poisson (ZIP) models for horse counts from field plot data during summer 2009, and various landscape attributes. Bolded and italicized components indicate leading model in a theme, and which were carried forward into the final assessment.

Theme	Component	R^2 [1]	k [2]	-2LL [3]	AIC_c [4]	ΔAIC_c [5]	ω_i [6]
Null [7]							
		0.00	1	220.20	222.27	0.00	1.00
Forage Characteristics							
	Adjusted Biomass	***0.05***	***2***	***220.10***	***224.32***	***0.00***	***1.00***
Water & Topography							
	Water Distance	3.30	2	212.94	217.16	6.41	0.04
	Ruggedness	1.83	2	216.18	220.40	9.65	0.01
	Water Distance + Ruggedness	***7.22***	***3***	***204.30***	***210.75***	***0.00***	***0.95***
Disturbance							
	Roads/Trails	0.18	2	219.80	224.02	0.83	0.38
	Cutlines	***0.35***	***2***	***219.42***	***223.64***	***0.00***	***0.45***
	Roads/Trails + Cutlines	0.45	3	219.20	225.65	2.01	0.17
Thermal							
	Forest Distance	***0.09***	***2***	***220.00***	***224.22***	***0.00***	***0.45***
	Solar Radiation	0.00	2	220.20	224.42	0.20	0.41
	Forest Distance + Solar Radiation	0.09	3	220.00	226.45	2.23	0.15
Competition							
	Cattle	0.50	2	219.10	223.32	4.66	0.07
	Ungulates	***2.62***	***2***	***214.44***	***218.66***	***0.00***	***0.68***
	Cattle + Ungulates	2.72	3	214.20	220.65	1.99	0.25

[1] McFadden's pseudo R^2 goodness of fit measure.
[2] Number of model parameters.
[3] -2 log likelihood.
[4] AIC corrected for sample size of 57 observations.
[5] Difference between AIC_c value and the lowest AIC_c value within each theme.
[6] Model probability.
[7] Null model with intercept only.

Table 4.9. Summary results depicting comparative model strength of zero-inflated poisson (ZIP) models for horse counts from field plot data during summer 2010, and various landscape attributes. Bolded and italicized components indicate leading model in a theme, and which were carried forward into the final assessment.

Theme	Component	R^2 [1]	k [2]	-2LL [3]	AIC_c [4]	ΔAIC_c [5]	ω_i [6]
Null [7]							
		0.00	1	504.26	506.26	0.00	1.00
Forage Characteristics							
	Adjusted Biomass	***3.63***	***2***	***485.98***	***489.98***	***0.00***	***1.00***
Water & Topography							
	Water Distance	0.69	2	500.76	504.98	1.47	0.25
	Ruggedness	0.65	2	500.98	505.20	1.69	0.23
	Water Distance + Ruggedness	***1.43***	***3***	***497.06***	***503.51***	***0.00***	***0.52***
Disturbance							
	Roads/Trails	2.89	2	489.68	493.90	6.01	0.05
	Cutlines	1.05	2	498.96	503.18	15.29	0.00
	Roads/Trails + Cutlines	***4.53***	***3***	***481.44***	***487.89***	***0.00***	***0.95***
Thermal							
	Forest Distance	3.26	2	487.82	492.04	0.71	0.41
	Solar Radiation	1.06	2	498.92	503.14	11.81	0.00
	Forest Distance + Solar	***3.84***	***3***	***484.88***	***491.33***	***0.00***	***0.59***
Competition							
	Cattle	3.63	2	485.98	490.20	11.16	0.00
	Ungulates	5.84	2	474.82	479.04	5.91	0.05
	Cattle + Ungulates	***7.45***	***3***	***466.68***	***473.13***	***0.00***	***0.95***

[1] McFadden's pseudo R^2 goodness of fit measure.
[2] Number of model parameters.
[3] -2 log likelihood.
[4] AIC corrected for sample size of 98 observations.
[5] Difference between AIC_c value and the lowest AIC_c value within each theme.
[6] Model probability.
[7] Null model with intercept only.

Table 4.10. Summary results of final model analysis, depicting comparative model strength of zero-inflated poisson (ZIP) models for horse counts from field plot data collected during summer 2009, and various landscape attributes. Bolded and italicized model indicates the best model.

Themes	**R^2** [1]	**k** [2]	**-2LL** [3]	**AIC_c** [4]	**ΔAIC_c** [5]	**ω_i** [6]
Null [7]	0.00	1	220.20	222.27	15.78	0.00
Water & Topography	7.22	3	204.30	210.75	4.26	0.05
Water & Topography + Competition	***10.21***	***4***	***197.72***	***206.49***	***0.00***	***0.46***
Water & Topography + Competition + Disturbance	10.21	5	197.72	208.90	2.41	0.14
Water & Topography + Competition + Disturbance + Thermal	11.88	6	194.04	207.72	1.23	0.25
Water & Topography + Competition + Disturbance + Thermal + Forage	12.20	7	193.34	209.63	3.14	0.10

[1] McFadden's pseudo R^2 goodness of fit measure.
[2] Number of model parameters.
[3] -2 log likelihood.
[4] AIC corrected for sample size of 57 observations.
[5] Difference between AIC_c value and the lowest AIC_c value within each theme.
[6] Model probability.
[7] Null model with intercept only.

Table 4.11. Summary results of final model analysis, depicting comparative model strength of zero-inflated poisson (ZIP) models for horse counts from field plot data collected during summer 2010, and various landscape attributes. Bolded and italicized model indicates the best model.

Themes	**R^2** [1]	**k** [2]	**-2LL** [3]	**AIC_c** [4]	**ΔAIC_c** [5]	**ω_i** [6]
Null [7]	0.00	1	504.26	506.33	91.74	0.00
Competition	7.45	3	466.68	473.13	58.54	0.00
Competition + Disturbance	15.14	5	427.94	439.12	24.53	0.00
Competition + Disturbance + Thermal	20.06	7	403.12	419.41	4.82	0.07
Competition + Disturbance + Thermal + Forage	20.14	8	402.68	421.68	7.09	0.02
Competition + Disturbance + Thermal + Water & Topography	***22.11***	***9***	***392.76***	***414.59***	***0.00***	***0.74***
Competition + Disturbance + Thermal + Forage + Water & Topography	22.11	10	392.76	417.54	2.95	0.17

[1] McFadden's pseudo R^2 goodness of fit measure.
[2] Number of model parameters.
[3] -2 log likelihood.
[4] AIC corrected for sample size of 98 observations.
[5] Difference between AIC_c value and the lowest AIC_c value within each theme.
[6] Model probability.
[7] Null model with intercept only.

Table 4.12. Influence of different variables selected by AIC modelling on feral horse occupancy and abundance from logistic regression (occupancy) and zero-inflated poisson regression (abundance) in the Alberta foothills in the summer of 2009.

Variable	**β**[1]	**SE**[2]	***P* value**
Occupancy			
Solar Radiation	0.367 x 10^{-3}	0.184 x 10^{-3}	0.046
Abundance			
Distance to Water	0.004	0.001	0.100 x 10^{-3}
Ruggedness	-0.077	0.027	0.100
Ungulates	-0.190	0.079	0.013

[1] Beta coefficient.
[2] Standard Error.

Table 4.13. Influence of different variables selected by AIC modelling on feral horse occupancy and abundance from logistic regression (occupancy) and zero-inflated poisson regression (abundance) in the Alberta foothills in the summer of 2010.

Variable	**β**[1]	**SE**[2]	***P* value**
Occupancy			
Distance to roads and [illegible]	0.700 x 10^{-3}	0.353 x 10^{-3}	0.05
Abundance			
Cattle	0.004	0.002	0.0544
Ungulates	-0.130	0.062	0.0398
Distance to roads and trails	-0.600 x 10^{-3}	0.100 x 10^{-3}	<0.100 x 10^{-3}
Distance to cutlines	-0.003	0.600 x 10^{-3}	<0.100 x 10^{-3}
Distance to forest (conifer [illegible]	0.008	0.002	<0.100 x 10^{-3}
Solar Radiation	0.100 x 10^{-3}	0.000	0.003
Distance to water	-0.002	0.600 x 10^{-3}	0.014
Ruggedness	-0.036	0.016	0.024

[1] Beta coefficient.
[2] Standard Error.

Table 4.14. Summary of forage production and grazing capacity available for the different habitat types within the study area for a one year period.

Habitat	Area (ha)	Mean Production (kg/ha)	Total Available Forage (kg)	Available Forage (kg)[1]	Grazing Capacity (AUM)[2]
Conifer	18920	868	16421064	82010532	18085
Cutblock	3554	1081	3840374	1920337	4230
Grassland	1150	3004	3455236	1727618	3805
Mixedwood	2466	1168	2880364	1440182	3172
Shrubland	1142	1432	1635984	817992	1802

[1]Available forage after accounting for a safe use factor of 0.5 (i.e. 50% use).
[2]Grazing Capacity = Available Forage (kg) / 454 kg

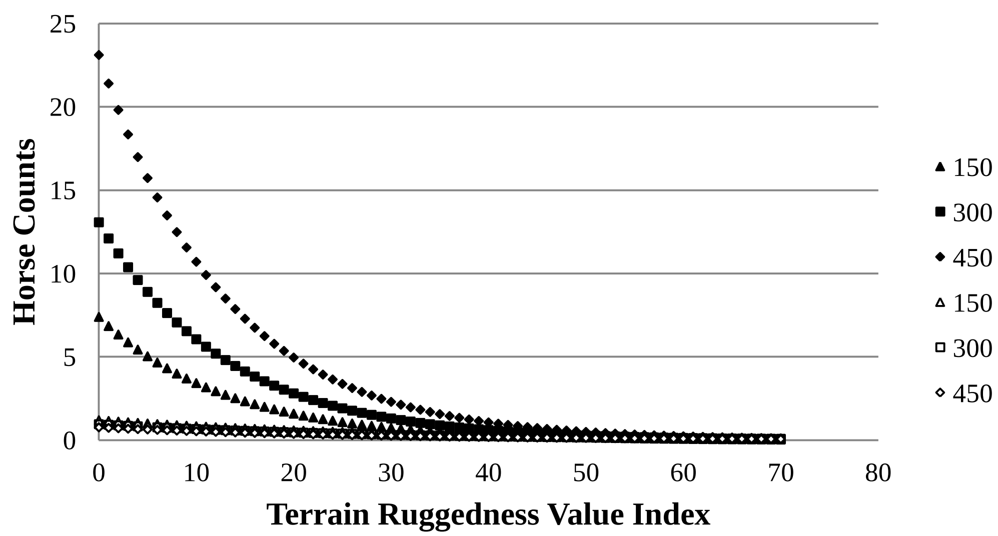

Figure 4.1. Horse abundance probability (top) and count (bottom) models demonstrating the relationship between horse occupancy in 2009 (solid black) and 2010 (hollow), as influenced by the water and topography variables of ruggedness with three levels of distance to water (150m, 300m and 450m). Functions were developed using β coefficients from the best model from ZIP regression, with other variables not included held constant.

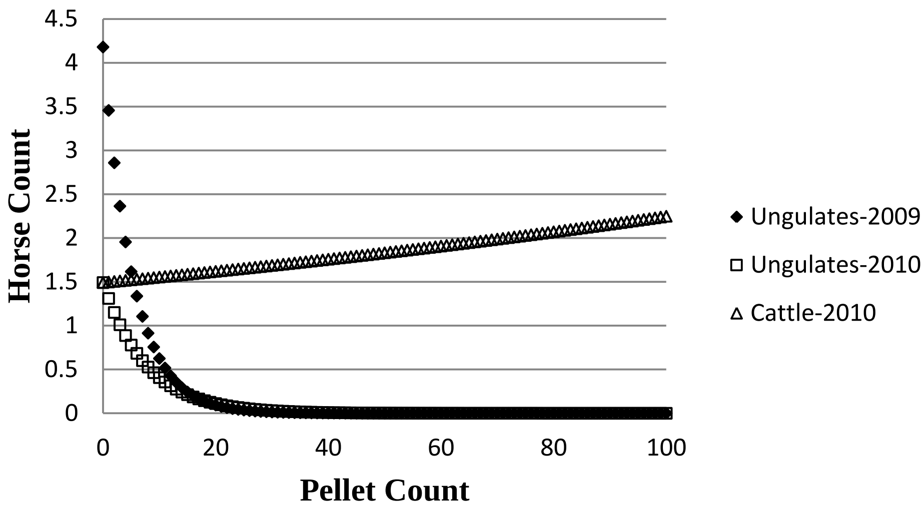

Figure 4.2. Horse abundance probability (top) and count (bottom) models demonstrating the relationship between horse occupancy in 2009 (solid black) and 2010 (hollow), influenced by the competition variable of ungulate pellet counts. Functions were developed using β coefficients from the best model from ZIP regression, with other variables not included held constant.

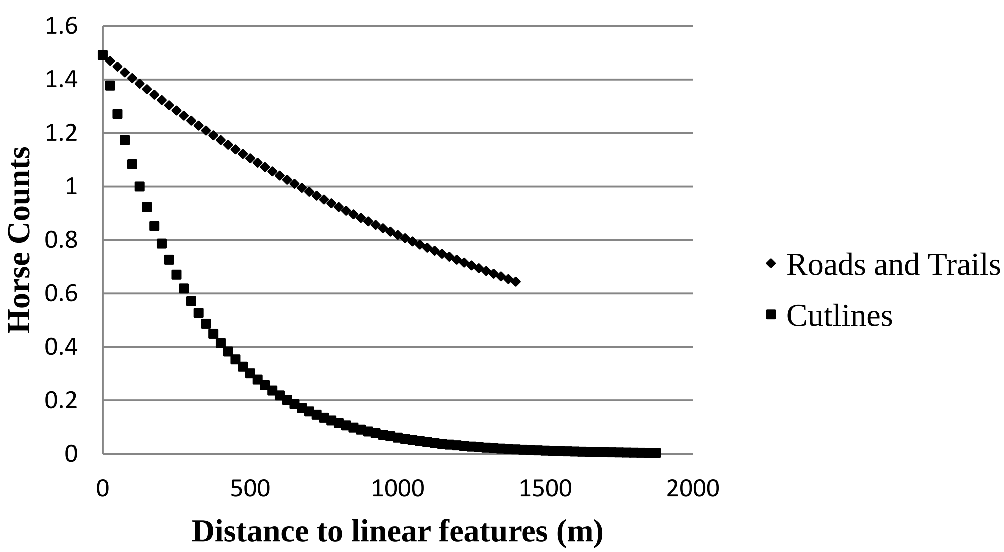

Figure 4.3. Horse abundance probability (top) and count (bottom) models demonstrating the relationship between horse abundance in 2010, influenced by the disturbance variables of distance to roads and trails and the distance to cutlines. Functions were developed using β coefficients from the best model from ZIP regression, with other variables not included held constant.

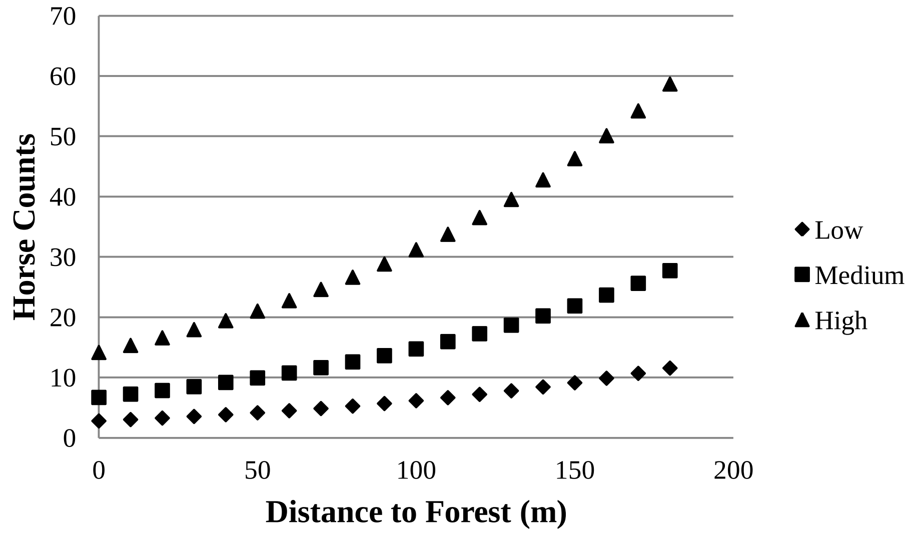

Figure 4.4. Horse abundance probability (top) and count (bottom) models demonstrating the relationship between horse abundance in 2010, influenced by the thermal variables of distance to forest with three levels (low, medium and high) of solar radiation. Functions were developed using β coefficients from the best model from ZIP regression, with other variables not included held constant.

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5. Synthesis

5.1. Research Summary

Competition for resources within the Rocky Mountain Forest Reserve (RMFR) is becoming an increasingly pertinent management issue for resource managers in Alberta. This research was the result of integrated efforts between the University of Alberta, the Rocky Mountain Forest Reserve Association (RMFRA), and Alberta Sustainable Resources Development (ASRD) to work towards improving management plans in the region. Specific objectives of this study included assessing habitat selection by feral horses seasonally and temporally using GPS locational data, and subsequent interpretation using landscape features, and the further examination of habitat selection in summer using field plots, as well as comparison of selection by horses with that of cattle and wild ungulates.

In Chapter 3, selection for different habitat types was shown to vary seasonally. Grasslands were the most important habitat type for horses as they were highly selected in all seasons. Shrublands were also selected, but only in spring and summer (i.e. the growing season). Cutblocks were particularly important during winter. Conifer forests were conspicuously avoided in all seasons, despite being the largest habitat type in the region. Mixedwood forests were neither selected nor avoided at all times except spring, when they were preferred.

Further analysis in Chapter 3 indicated that while habitat types were the largest contributor to habitat selection by feral horses, other factors provided valuable explanatory power. In all seasons the thermal variables (distance to mixedwood and conifer forests, and solar radiation) indicated that horses avoid forests and with warm temperatures. Disturbance variables (distance to roads or trails, and distance to cutlines) were important in the spring and fall, and were likely to deter feral horse use.

Field data analyses were conducted to further examine horse behavioural patterns in summer and incorporate forage characteristics (Chapter 4). There was some inconsistency in results between years, which may be due to the limited sample size in 2009. From the 2010 analysis, thermal, disturbance, water and topography, and competition variables were all shown to be important themes. Linear features, cattle and open habitats were preferred by feral horses. On the other hand, rugged terrain and wild ungulates (or the habitats they use) were avoided. Despite initial hypotheses that forage characteristics would be a significant factor in predicting habitat selection by horses, this was not the case in this study.

The variables explaining habitat preference identified by the RSFs and RSPFs in this study were not consistent. The RSFs identified habitat type (avoided, neutral, selected), thermal and disturbance variables to be affecting selection throughout the year; while the RSPFs identified thermal, disturbance, water and topography, and competition. Although some of the variables were not present in both studies (habitat type and competition), there were still variables present in the RSPFs that could have been, but were not, accounted for in the RSFs. Neither RSFs nor RSPFs explained large amounts of variance in horse presence and abundance. It is possible that some important factors were not considered in the study conducted here, such as the presence and influence of predators. There was also a higher probability of error in the forage quantity information that may account for this variable not being included in the final models. Nevertheless, the objectives of this study were generally met as I was able to determine how horse habitat selection varied spatially and temporally across the study area.

5.2 Management Implications

Management of feral horses within the RMFR is an increasing challenge for resource managers. As information regarding feral horses within the region is almost 30 years old (Salter and Hudson 1982) and approximately 10 years old further north (Irving 2001), results of the current study are needed to provide current information on feral horse habitat selection. The resource selection functions (RSFs) and resource selection probability functions (RSPFs) developed in this study provide a tool for resource managers to categorize different habitats of the region into areas of varying importance for feral horse survival, as well as areas at varying risk of use or even overuse, depending on the season and presence of other herbivores. Low to moderate range health scores and overall evidence of high stocking rates means that specific areas (i.e. grasslands) within the region are at high risk of degradation. This problem may be further exacerbated by the fact that utilization estimates were nearing 50% by mid-June to late-July, with still two months of cattle grazing and nine more months of horse grazing until green-up the following year.

The RSFs and RSPFs both show that feral horses avoid conifer forest at all times. As conifer forests are the predominant habitat type in this region, this implies that in the absence of clearcutting, horses would likely utilize only a small portion of the landscape. With increasing feral horse populations and a stable or even declining land base of preferred habitat (e.g. under tree encroachment), or associated reductions in the availability of forage under expanded shrublands (Bork and Burkinshaw 2009), these areas may be at risk of increased degradation. This problem may be further exacerbated by cattle in the same region as they were shown to utilize similar habitats. Our work supported previous findings that cattle and feral horses have extensive habitat overlap (McInnis and Vavra 1987, Salter and Hudson 1980). The RSPFs generated for feral horses and cattle have the potential to be used to determine the amount of area preferred by these species and develop appropriate carrying capacities, especially since current carry capacities may be exceeded. Since feral horse populations are continuing to increase (Unpublished ASRD data) and cattle graze the area every summer there is the possibility that sustainable carrying capacities may be quickly surpassed in the future. Should this occur, there is a possibility of conflict developing between feral horses [or their social advocacy groups, the Wild Horses of Alberta Society (WHOAS)] and livestock producers as populations of one or the other may need to be reduced.

Previous research indicated that feral horses and wild ungulates have limited habitat overlap (Salter and Hudson 1980). This study supported these findings as feral horses and cattle both tended to occupy areas with fewer wild ungulates and vice versa. However, there are several mechanisms that may account for this segregation, including divergent habitat use, displacement by feral horses (and/or livestock), or a systematic bias in the wildlife pellet count data in favour of bedding areas, and warrants further investigation.

Both the electivity analysis in Chapter 3 and the pellet count field data indicated that there was some selection for cutblocks in the region. Electivity analysis showed that cutbocks were selected during winter. Grazing of cutblocks may result in trampling damage to seedlings and regenerating vegetation (Graham et al. 2010, McLean and Clark 1980). Pellet count analysis also revealed that although the collared feral horses selected cutblocks in winter, there is still a lot of use occurring on cutblocks during summer. Again, this use could lead to increased trampling and reduced tree regeneration, conflicting with forestry objectives of sufficient tree stocking to meet Alberta provincial regeneration standards. This has the potential to create significant problems between feral horse management and commercial forestry, especially if horse populations continue to grow.

Ultimately, the habitat selection functions developed in this study can be used to determine where horses are likely to be found on the landscape according to the different seasons. The RSPFs identified for the cattle and wild ungulates can also be used, and it may be possible to determine habitat usage of all ungulates. Identifying the habitats that different ungulates prefer would allow managers to identify the areas of the range that should be included in calculating carrying capacities of the region, in turn generating sustainable population levels. These functions can also be used to determine how much habitat is selected or avoided, which is useful in calculating individual and collective ungulate carrying capacities for the region.

5.3 Future Research Recommendations

The RSFs and RSPFs developed in this study are helpful towards developing an understanding of feral horse habitat selection in the landscape. Despite their success, there are some limitations associated with these selection functions, and thus, there is more work that can be done to improve them in the future. Increasing the number of horses sampled would be beneficial as observed discrepancies between the collar data and pellet data in Chapters 3 and 4, respectively, indicate that there may be landscape factors influencing horse use that were missed in the former analysis. Some possible factors that were missed are the impact of predator presence and the impact of different types of disturbance and their intensities (i.e. counts of different recreation types; bikers, hikers, off-highway vehicle users). Moreover, increasing the amount and type of forage data collected may be beneficial in providing a more rigorous assessment of horse responses to foraging conditions. Although the expected effect of forage characteristics was demonstrated in the cattle analysis (Appendix G), it is possible that forage characteristics may not be affecting horse habitat selection.

It may also be beneficial to look further into the different sub-types of forest to see if horses select some cover types differently due to a unique (i.e. more desirable) understory composition. Additionally, attempts to attribute utilization to the different ungulate species would help to determine the impact of different large grazing mammals on these rangelands, but this may be difficult to do as there are so many different types of users in a relatively small space. Furthermore, given the potential for conflict with forestry in the future it would be advantageous to study the impact of seasonal feral horse grazing on cutblock regeneration, including the development of more specific information on how horse use may change with different time periods since logging. Lastly, further studies of the impacts of cattle and horse grazing continuously on small preferred habitat areas within the region would be beneficial to determine if there are detrimental impacts. Overall, this study provides a solid foundation for other studies examining more detailed spatial and temporal characteristics of feral horse habitat selection in Montane environments.

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Appendix A: Study Area

Table A.1. Areas occupied by the different habitat groups within the study area.

Habitat	Area (ha)	Percent of Study Area (%)
Conifer	18 920	69
Cutblock	3 554	13
Grassland	1 150	4
Mixedwood	2 466	9
Shrubland	1 142	4
Water	71	1

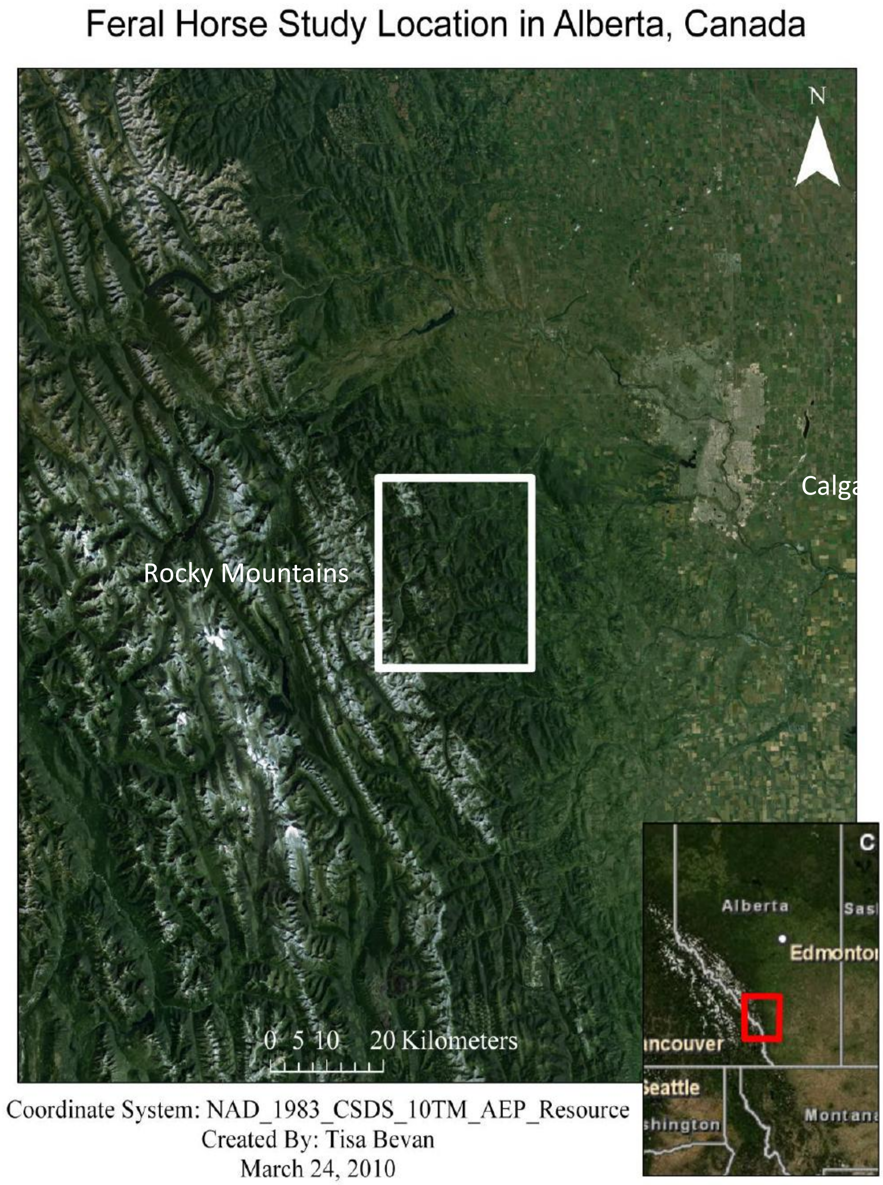


Figure A.1. General location for feral horse study in the Rocky Mountain Natural Region of Alberta.

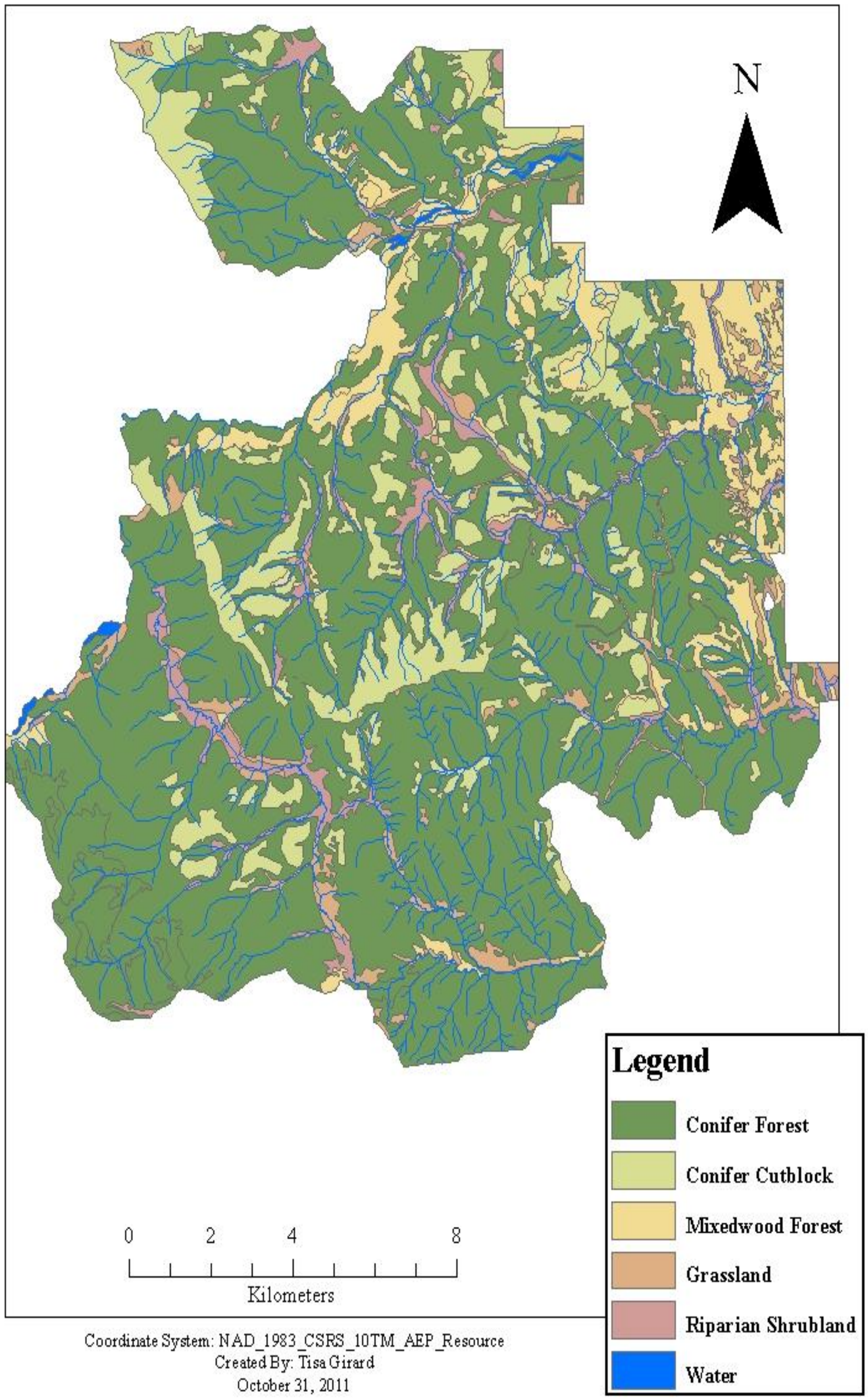


Figure A.2. Map of vegetation distribution over the study area, condensed into 5 habitat types based on information from Alberta Sustainable Resources Development sources (Unpublished ASRD data).

Appendix B: Climatic Data

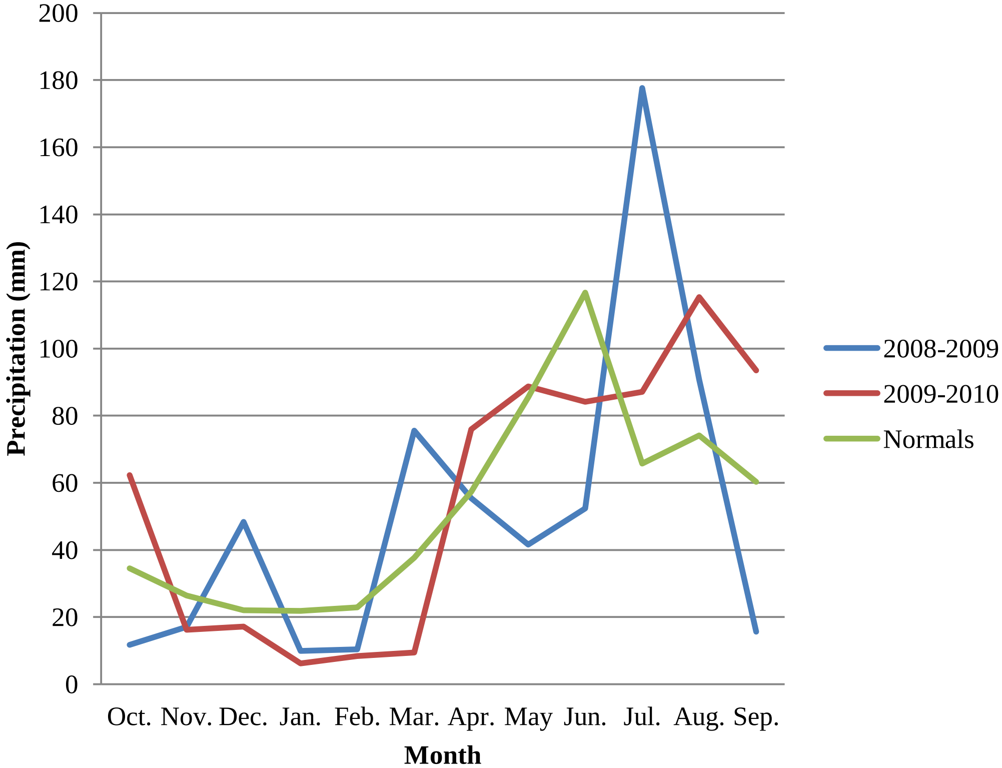


Figure B.1. Actual and long-term mean monthly precipitation for the study area according to Environment Canada's Elbow River Ranger Weather Station, 2009 and 2010.

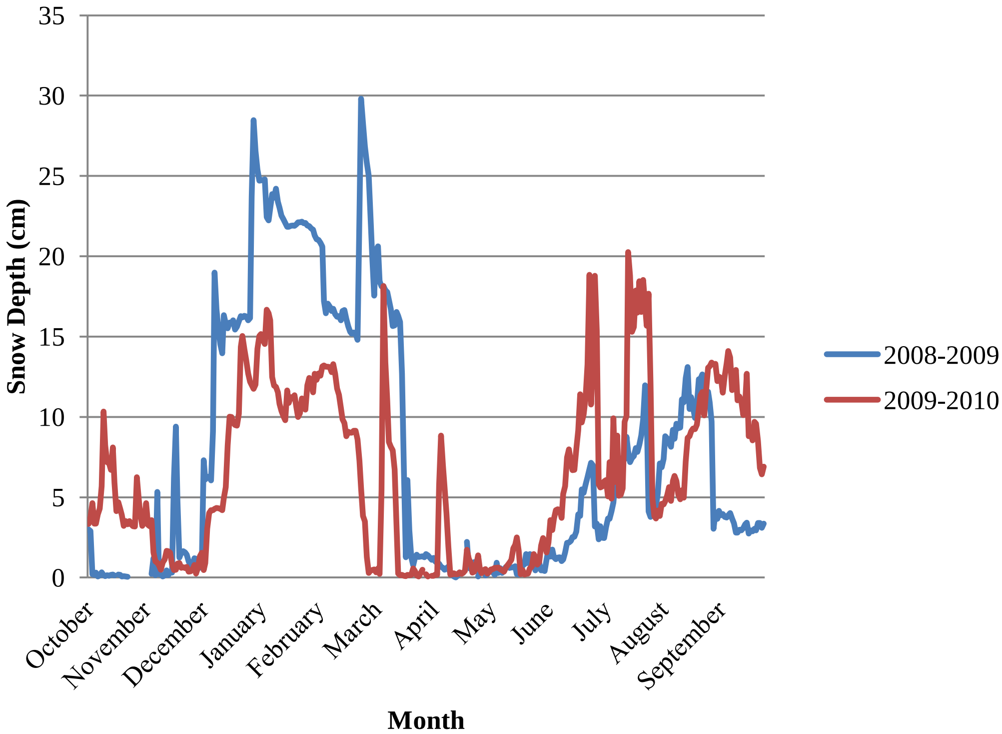


Figure B.2. Actual and mean monthly snow depth for Environment Canada's Banff weather station for the period October 1, 2008 to September 30, 2010.

Appendix C: Alternative Habitat Models

Table C.1. Summary results depicting comparative model strength of feral horse observations from GPS telemetry data collected during spring (1 April – 15 May) 2009 and 2010, and various landscape attributes. Bolded and italicized components indicate leading models in a theme, and which were carried forward into the final assessment.

Theme	Component (Spring Analysis)	k*	R^{2**}
Habitat			
	ANP	***3***	***0.00***
Water and Topography			
	ANP +Water Distance	***4***	***0.03***
	ANP + Ruggedness	4	0.01
	ANP + Ruggedness x Water Distance	4	0.01
	ANP + Water Distance + Ruggedness	5	0.03
	ANP + Water Distance + Ruggedness + Water x Ruggedness	6	0.05
Disturbance			
	ANP + Roads and Trails	***4***	***1.24***
	ANP + Cutlines	4	0.08
	ANP + Roads and Trails + Cutlines	5	1.24
Thermal			
	ANP + Forest Distance	4	1.32
	ANP + Conifer Distance	4	0.09
	ANP + Mixedwood Distance	4	10.35
	ANP + Solar Radiation	4	6.33
	ANP + Conifer + Mixedwood Distance	5	10.48
	ANP + Conifer Distance + Solar Radiation	5	6.33
	ANP + Mixedwood Distance + Solar Radiation	***5***	***15.50***
	ANP + Forest Distance + Solar Radiation	5	7.90
	ANP + Mixedwood + Conifer Distance + Solar Radiation	6	15.73

* Indicates the number of parameters used.
** McFadden's pseudo R^2 goodness of fit measure.

Table C.2. Summary results depicting comparative model strength of feral horse observations from GPS telemetry data collected during summer (16 May – 15 September) 2009 and 2010, and various landscape attributes. Bolded and italicized components indicate leading models in a theme, and which were carried forward into the final assessment.

Theme	Component (Summer Analysis)	k*	R^{2**}
Habitat			
	ANP	***3***	***0.00***
Water and Topography			
	ANP +Water Distance	4	0.69
	ANP + Ruggedness	4	1.46
	ANP + Ruggedness x Water Distance	4	0.02
	ANP + Water Distance + Ruggedness	***5***	***2.02***
	ANP + Water Distance + Ruggedness + Water x Ruggedness	6	2.07
Disturbance			
	ANP + Roads and Trails	***4***	***0.77***
	ANP + Cutlines	4	0.34
	ANP + Roads and Trails + Cutlines	5	1.00
Thermal			
	ANP + Forest Distance	4	1.07
	ANP + Conifer Distance	4	0.45
	ANP + Mixedwood Distance	4	7.30
	ANP + Solar Radiation	4	1.33
	ANP + Conifer + Mixedwood Distance	5	8.76
	ANP + Conifer Distance + Solar Radiation	5	1.78
	ANP + Mixedwood Distance + Solar Radiation	5	8.56
	ANP + Forest Distance + Solar Radiation	5	2.45
	ANP + Mixedwood + Conifer Distance + Solar Radiation	***6***	***10.02***

* Indicates the number of parameters used.
** McFadden's pseudo R^2 goodness of fit measure.

Table C.3. Summary results depicting comparative model strength of feral horse observations from GPS telemetry data collected during fall (16 September – 31 October) 2009 and 2010, and various landscape attributes. Bolded and italicized components indicate leading models in a theme, and which were carried forward into the final assessment.

Theme	Component (Fall Analysis)	k*	R^{2**}
Habitat			
	ANP	***3***	***0.00***
Water and Topography			
	ANP +Water Distance	4	0.12
	ANP + Ruggedness	***4***	***0.95***
	ANP + Ruggedness x Water Distance	4	0.01
	ANP + Water Distance + Ruggedness	5	1.05
	ANP + Water Distance + Ruggedness + Water x Ruggedness	6	1.55
Disturbance			
	ANP + Roads and Trails	4	0.50
	ANP + Cutlines	***4***	***1.51***
	ANP + Roads and Trails + Cutlines	5	1.86
Thermal			
	ANP + Forest Distance	4	0.51
	ANP + Conifer Distance	4	0.19
	ANP + Mixedwood Distance	4	6.75
	ANP + Solar Radiation	4	1.11
	ANP + Conifer + Mixedwood Distance	***5***	***7.62***
	ANP + Conifer Distance + Solar Radiation	5	1.29
	ANP + Mixedwood Distance + Solar Radiation	5	7.68
	ANP + Forest Distance + Solar Radiation	5	1.61
	ANP + Mixedwood + Conifer Distance + Solar Radiation	6	8.55

* Indicates the number of parameters used.
** McFadden's pseudo R^2 goodness of fit measure.

Table C.4. Summary results depicting comparative model strength of feral horse observations from GPS telemetry data collected during winter (1 November – 31 March) 2009 and 2010, and various landscape attributes. Bolded and italicized components indicate leading models in a theme, and which were carried forward into the final assessment.

Theme	Component (Winter Analysis)	k*	R^{2**}
Habitat			
	ANP	***3***	***0.00***
Water and Topography			
	ANP +Water Distance	4	0.21
	ANP + Ruggedness	***4***	***2.18***
	ANP + Ruggedness x Water Distance	4	0.85
	ANP + Water Distance + Ruggedness	5	2.40
	ANP + Water Distance + Ruggedness + Water x Ruggedness	6	2.75
Disturbance			
	ANP + Roads and Trails	***4***	***0.65***
	ANP + Cutlines	4	0.03
	ANP + Roads and Trails + Cutlines	5	0.65
Thermal			
	ANP + Forest Distance	4	1.18
	ANP + Conifer Distance	4	0.14
	ANP + Mixedwood Distance	4	8.28
	ANP + Solar Radiation	4	2.82
	ANP + Conifer + Mixedwood Distance	5	8.87
	Conifer Distance + Solar Radiation	5	2.98
	ANP + Mixedwood Distance + Solar Radiation	***5***	***10.72***
	ANP + Forest Distance + Solar Radiation	5	4.06
	ANP + Mixedwood + Conifer Distance + Solar Radiation	6	11.33

* Indicates the number of parameters used.
** McFadden's pseudo R^2 goodness of fit measure.

Appendix D: Species Composition

Table D.1. Dominant plant species found within the different habitat types of the study area.

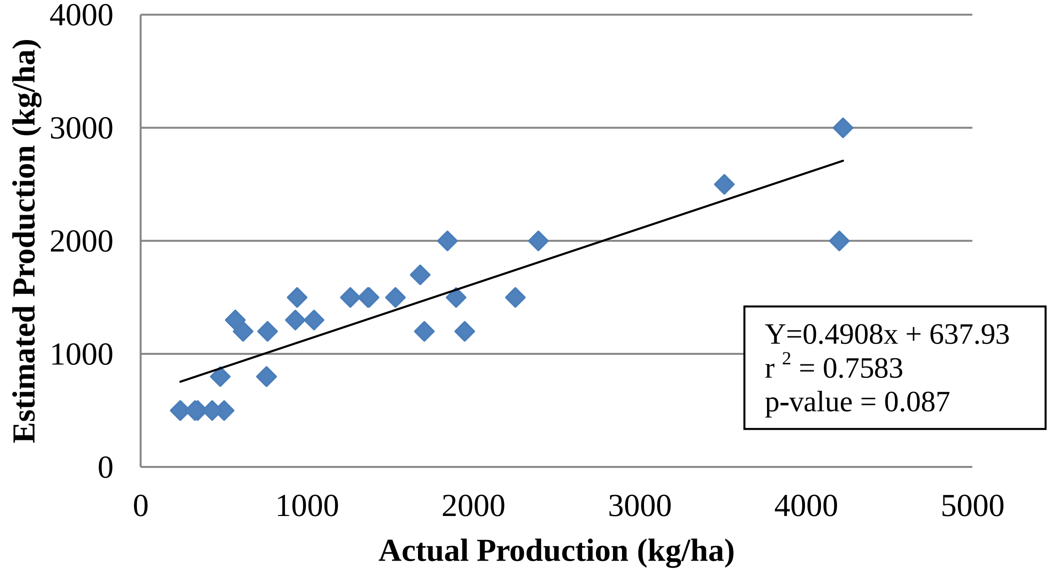
Habitat Type	Species		
	Shrub	**Forb**	**Grass**
Conifer Forests			
	Arctostaphylos uva-ursi	*Arnica cordifolia*	*Agropyron sp.*
	Cornus stolonifera	*Epilobium angustifolium*	*Calamagrostis sp.*
	Rosa acicularis	*Fragaria virginiana*	
		Lathyrus ochroleucus	
Conifer Cutblocks			
	Populus seedlings	*Achillea millefolium*	*Calamagrostis sp.*
	Rosa acicularis	*Epilobium angustifolium*	*Carex sp.*
		Fragaria virginiana	*Leymus innovatus*
		Trifolium repens	*Poa sp.*
		Taraxacum officinale	
Lowland Grasslands			
		Achillea millefolium	*Carex sp.*
		Fragaria virginiana	*Deschampsia caespitosa*
		Taraxacum officinale	*Festuca sp.*
		Trifolium sp.	*Juncus sp.*
			Phleum pratense
			Poa sp.
Mixedwood Forests			
	Rosa acicularis	*Fragaria virginiana*	*Bromus sp.*
		Geum trifolium	*Calamagrostis sp.*
		Lathyrus ochroleucus	*Deschampsia cespitosa*
			Poa sp.
Riparian Shrubland			
	Betula glandulosa	*Fragaria virginiana*	*Carex sp.*
	Potentilla fruticosa	*Geum trifolium*	*Deschampsia cespitosa*
	Salix sp.		*Fescue sp.*
	Sheperdia canadensis		*Juncus sp.*
			Potentilla fruticosa

Appendix E: Validation of Biomass Estimation Data

Table E.1. Summary of the linear relationships between estimated and actual biomass by individual habitat type during each of 2009 and 2010.

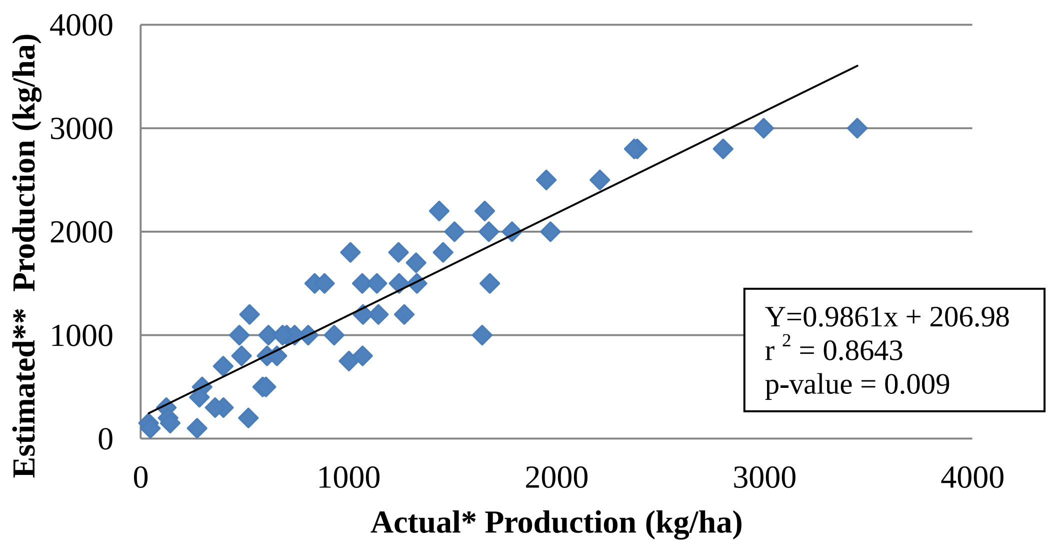
Habitat Type	Year	Sample Size	Linear Equation*	r^2**	p-value
Cutblock	2009	6	y = 565 + 0.4670x	0.2954	0.1533
	2010	12	y = 374 + 0.8452x	0.8735	<0.0001
Lowland Grassland	2009	6	y = 1308 + 0.2026x	0.4519	0.0864
	2010	12	y = 440 + 0.8172x	0.7502	0.0002
Mixedwood Forest	2009	6	y = 569 + 0.9877x	0.3893	0.1102
	2010	7	y = 7 + 1.6949x	0.8434	0.0022
Riparian Shrubland	2009	6	y = 555 + 0.5514x	0.9215	0.0015
	2010	12	y = 348 + 0.9762x	0.6299	0.0013
Uncut Forest	2009	n/a	n/a	n/a	n/a
	2010	12	y = 99 + 0.5767x	0.6903	0.0005

* Empirical relationship based on the linear regression.
** Adjusted r^2.



* Actual production refers to samples that have been clipped, dried, and weighed.
** Estimated production refers to ocular assessments that were made in the field.

Figure E.1. Linear regression of estimated biomass production on actual biomass production for all habitat types in 2009.



* Actual production refers to samples that have been clipped, dried, and weighed.
** Estimated production refers to ocular assessments that were made in the field.

Figure E.2. Linear regression of estimated biomass production on actual biomass production for all habitat types in 2010.

Appendix F: Cattle Selection Results

F.1. Cattle Resource Selection

Cattle fecal pellet density data (#/400m^2) were collected at the same time as the fecal counts from feral horses. To assess the resource selection of cattle in the area, a similar analysis was performed as that done on the feral horse pellets (see Chapter 4), with the exception that poisson regression was used instead of zero-inflated poisson regression. The same themes and variables were tested for both 2009 and 2010 (Tables F.1 and F.2). Comparison of the initial *a-priori* models within themes indicated that the same variables or variable combinations were chosen to move forward for all but the disturbance theme. Adjusted biomass represented the forage characteristic selected to move forward to the final analysis. The water distance and ruggedness model was carried forward within the water and topography theme. For the thermal theme, distance to forest (either mixedwood or conifer) combined with solar radiation, was carried forward. Ungulate pellet counts were carried forward within the competition theme. The key difference between years occurred in the disturbance theme: in 2010, distance to roads and trails combined with distance to cutlines remained important, while only distance to roads and trails was important in 2009. When leading preliminary models from all themes were compared the explanatory power of themes for each year was as follows, in descending order of importance: forage characteristics > competition > water and topography > thermal > disturbance.

In the final analysis (i.e. model combination) the best model for 2009 was the “forage plus competition plus water and topography plus thermal”, and explained 61.3 % of variation in cattle presence (Table F.3). This model included the variables adjusted biomass, water distance, ruggedness, distance to any forest, solar radiation, and ungulate pellet counts. The best model in 2010 was the “forage plus competition plus water and topography plus thermal plus disturbance”, and explained 50.7 % of variation in cattle use (Table F.4). The latter model included the same variables from 2009, but included distance to roads and trails as well as distance to cutlines.

Available forage provided the most explanatory power in both years, explaining 52.6 % and 33.5 % of variance in cattle use during 2009 and 2010, respectively. Beta (β) estimates from the poisson regression revealed that there was a positive relationship between the amount of forage and cattle use (Tables F.5 and F.6). This was not surprising as cattle are predominantly grazers (McInnis and Vavra 1987) and areas with the most herbage are likely to maximize intake opportunities. Cattle also typically occupy lower elevation portions of watersheds where biomass levels are high, and are therefore unlikely to move out of these regions unless forage supply is depleted.

The β estimates for ungulates suggest that cattle avoided wild ungulate populations (Tables F.5 and F.6). Cattle in the region may have been avoiding ungulate populations; however, it is more likely that cattle were avoiding the habitat selected by wild ungulates. Cattle and wild ungulates have been found in numerous studies to have minimal habitat overlap (McInnis and Vavra 1987, Ganskopp and Vavra 1987, Hubbard and Hansen 1976). If cattle are simply using different habitat types in the landscape, then a high presence of wild ungulates could simply be an indication that the habitat is not selected by cattle.

Within the water and topography theme, β estimates for the distance to water show that in 2009 cattle used areas closer to water, while in 2010 cattle use increased as distance to water increased. It could be argued that water distance had no significant impact on resource selection by cattle based on p-values rather than AIC scores (Table F.6). However, because AIC scores were used as the overriding ranking factor evaluating models, distance to water was included. The trend evident in 2009 was not surprising as precipitation was below normal leading up to summer in that year (Table B.1, Appendix B). In contrast, precipitation levels during 2010 were above normal leading up to summer, reducing the chance of water shortages in the landscape. β estimates for ruggedness demonstrated that cattle preferred flat areas, regardless of year (Table F.5 and F.6). This observation corroborates findings by Kauffman (2011) and

Ganskopp and Vavra (1987) that cattle avoid rugged terrain. Moreover, these results reinforce the notion that cattle will likely stay in the lower basins and valley bottoms of the study area, potentially minimizing overlap with native ungulates during summer.

The β estimates for the thermal theme indicate that cattle stayed away from forested areas during both years (Table F.5 and F.6). While cattle may have used forested areas for cover and rest, the majority of their time was spent out in open habitats. However, it is also possible that because forested areas tend to have the lowest amount of forage production (ASRD 2005), low forage availability may be the mechanism resulting in cattle avoidance of these areas. Although solar radiation was chosen by the AICc in 2009, the β estimate for this variable was near zero, suggesting little impact of this variable on cattle use. During 2010 there was also a positive relationship between cattle presence and solar radiation, with cattle using areas with more solar radiation (i.e. those without tree cover and more exposed).

Finally, as the distance to roads and trails increased the probability of cattle use decreased during 2010. This could indicate that there was more human activity on these trails in 2010 compared to 2009, although this is unlikely given the popularity of the area. Alternatively, cattle may have been able to express a stronger aversion to recreational activities in 2010 due to the increased rainfall, which would allow cattle to spend more time on selected habitats away from travel corridors before being forced to move elsewhere following their depletion.

The final RSPF models that were developed can be used to predict where cattle are likely to be within the region (see equations [1] and [2]).

$RSFP_{2009}$ = exp(1.660 + 0.500 x 10^{-3}*biomass (kg/ha) - 0.005* water distance (m) -0.010* ruggedness + 0.003*forest distance (m) - 0.320*ungulates) / [1 + exp(1.660 + 0.5 x 10^{-3}*biomass (kg/ha) - 0.005* water distance (m) - 0.010*ruggedness + 0.003*forest distance (m) -0.320*ungulates)] [1]

$RSFP_{2010}$ = exp(-0.013 + 0.500 x 10^{-3}*biomass (kg/ha) + 0.400 x 10^{-3}* water distance (m) -0.140* ruggedness + 0.200 x 10^{-3}*forest distance (m) + 0.200 x 10^{-3} *solar radiation - 0.360*ungulates + 0.100 x 10^{-3}* distance to roads and trails (m)) / [1 + exp(-0.013 + 0.500 x 10^{-3}*biomass (kg/ha) + 0.400 x 10^{-3}* water distance (m) -0.140* ruggedness + 0.200 x 10^{-3}*forest distance (m) - 0.360*ungulates)] [2]

Table F.1. Summary results depicting comparative model strength of cattle use from field plot data during summer 2009, and various landscape attributes. Bolded and italicized components indicate the leading model in a theme, and which were carried forward into the final assessment.

Theme	Component	R^2 [1]	k [2]	-2LL [3]	AIC_c [4]	ΔAIC_c [5]	ω_i [6]
Null [7]							
		0.00	***1***	***2004.44***	***2006.51***	***0.00***	***1.00***
Forage Characteristics							
	Adjusted Biomass	***52.60***	***2***	***950.18***	***954.40***	***0.00***	***1.00***
Water & Topography							
	Water Distance	4.67	2	1910.92	1915.14	197.69	0.00
	Ruggedness	11.92	2	1765.48	1769.70	52.25	0.00
	Water Distance + Ruggedness	***14.64***	***3***	***1711.00***	***1717.45***	***0.00***	***1.00***
Disturbance							
	Roads/Trails	***0.94***	***2***	***1985.56***	***1989.78***	***0.00***	***0.68***
	Cutlines	0.00	2	2004.38	2008.60	18.82	0.00
	Roads/Trails + Cutlines	0.98	3	1984.82	1991.27	1.49	0.32
Thermal							
	Forest Distance	5.27	2	1898.78	1903.00	100.05	0.00
	Solar Radiation	3.84	2	1927.56	1931.78	128.83	0.00
	Forest Distance + Solar Radiation	***10.37***	***3***	***1796.50***	***1802.95***	***0.00***	***1.00***
Competition							
	Horses	0.66	2	1991.28	1995.50	330.56	0.00
	Ungulates	***17.15***	***2***	***1660.72***	***1664.94***	***0.00***	***0.55***
	Horses + Ungulates	17.24	3	1658.86	1665.31	0.37	0.45

[1] McFadden's pseudo R^2 goodness of fit measure.
[2] Number of model parameters.
[3] -2 log likelihood.
[4] AIC corrected for sample size of 57 observations.
[5] Difference between AIC_c value and the lowest AIC_c value within each theme.
[6] Model probability.
[7] Null model with intercept only.

Table F.2. Summary results depicting comparative model strength of cattle use from field plot data during summer 2010, and various landscape attributes. Bolded and italicized components indicate the leading model in a theme, and which were carried forward into the final assessment.

Theme	**Component**	**R^2** [1]	**k** [2]	**-2LL** [3]	**AIC_c** [4]	**ΔAIC_c** [5]	**ω_i** [6]
Null [7]							
		0.00	***1***	***4355.22***	***4357.29***	***0.00***	***1.00***
Forage Characteristics							
	Adjusted Biomass	***33.48***	***2***	***2897.04***	***2901.26***	***0.00***	***1.00***
Water & Topography							
	Water Distance	2.78	2	4234.24	4238.46	526.75	0.00
	Ruggedness	12.89	2	3793.94	3798.16	86.45	0.00
	Water Distance + Ruggedness	***14.92***	***3***	***3705.26***	***3711.71***	***0.00***	***1.00***
Disturbance							
	Roads/Trails	0.27	2	4343.44	4347.66	26.65	0.00
	Cutlines	0.53	2	4332.00	4336.22	15.21	0.00
	Roads/Trails + Cutlines	***0.93***	***3***	***4314.56***	***4321.01***	***0.00***	***1.00***
Thermal							
	Forest Distance	3.43	2	4205.98	4210.20	24.81	0.00
	Solar Radiation	0.99	2	4312.10	4316.32	130.93	0.00
	Forest Distance + Solar Radiation	***4.05***	***3***	***4178.94***	***4185.39***	***0.00***	***1.00***
Competition							
	Horses	1.43	2	4292.85	4297.04	822.80	0.00
	Ungulates	***20.33***	***2***	***3470.02***	***3474.24***	***0.00***	***0.70***
	Horses + Ungulates	20.34	3	3469.46	3475.91	1.67	0.30

[1] McFadden's pseudo R^2 goodness of fit measure.
[2] Number of model parameters.
[3] -2 log likelihood.
[4] AIC corrected for sample size of 98 observations.
[5] Difference between AIC_c value and the lowest AIC_c value within each theme.
[6] Model probability.
[7] Null model with intercept only.

Table F.3. Summary results of final model analysis, depicting comparative model strength of cattle use from field plot data during summer 2009, and various landscape attributes. Bolded and italicized model indicates the best model.

Themes	**R^2** [1]	**k** [2]	**-2LL** [3]	**AIC_c** [4]	**ΔAIC_c** [5]	**ω_i** [6]
Null [7]	0.00	1	2004.44	2006.51	1214.95	0.00
Forage	52.60	2	950.18	954.40	162.84	0.00
Forage + Competition	55.87	3	884.62	891.07	99.51	0.00
Forage + Competition + Water & Topography	60.76	5	786.46	797.64	6.07	0.03
Forage + Competition + Water & Topography + Thermal	***61.32***	***7***	***775.28***	***791.57***	***0***	***0.64***
Forage + Competition + Water & Topography + Thermal + Disturbance	61.39	8	773.86	792.86	1.29	0.33

[1] McFadden's pseudo R^2 goodness of fit measure.
[2] Number of model parameters.
[3] -2 log likelihood.
[4] AIC corrected for sample size of 57 observations.
[5] Difference between AIC_c value and the lowest AIC_c value within each theme.
[6] Model probability.
[7] Null model with intercept only.

Table F.4. Summary results of final model analysis, depicting comparative model strength of cattle use from field plot data during summer 2010, and various landscape attributes. Bolded and italicized model indicates the best model.

Themes	R^2 [1]	k [2]	-2LL [3]	AIC_c [4]	ΔAIC_c [5]	ω_i [6]
Null [7]	0.00	1	4355.22	4357.29	2213.68	0.00
Forage	33.48	2	2897.04	2901.26	757.59	0.00
Forage + Competition	40.27	3	2601.54	2607.99	464.22	0.00
Forage + Competition + Water & Topography	49.55	5	2197.22	2208.40	64.29	0.00
Forage + Competition + Water & Topography + Thermal	50.34	7	2162.72	2179.01	34.39	0.00
Forage + Competition + Water & Topography + Thermal + Disturbance	***51.19***	***8***	***2125.96***	***2143.58***	***0.00***	***1.00***

[1] McFadden's pseudo R^2 goodness of fit measure.
[2] Number of model parameters.
[3] -2 log likelihood.
[4] AIC corrected for sample size of 98 observations.
[5] Difference between AIC_c value and the lowest AIC_c value within each theme.
[6] Model probability.
[7] Null model with intercept only.

Table F.5. Ranked influence of different variables in the leading RSF model for cattle in the Alberta foothills in the summer of 2009.

Variable	β[1]	SE[2]	*P* value
Adjusted biomass	0.500×10^{-3}	0.000	$<0.100 \times 10^{-3}$
Water distance	-0.005	0.001	$<0.100 \times 10^{-3}$
Ruggedness	-0.010	0.009	<0.300
Distance to forest (conifer and mixedwood)	0.003	0.001	0.003
Solar radiation	-0.000	0.000	0.900
Ungulates	-0.320	0.052	$<0.100 \times 10^{-3}$

[1] Beta estimate.
[2] Standard error.

Table F.6. Ranked influence of different variables in the leading RSF model for cattle in the Alberta foothills in the summer of 2010.

Variable	β[1]	SE[2]	*P* value
Adjusted biomass	0.400×10^{-3}	0.000	<0.100
Water distance	0.400×10^{-3}	0.200×10^{-3}	0.150
Ruggedness	-0.140	0.008	<0.300
Distance to roads/trails	0.100×10^{-3}	0.000	$<0.100 \times 10^{-3}$
Solar Radiation	0.200×10^{-3}	0.000	$<0.100 \times 10^{-3}$
Distance to forest (conifer and mixedwood)	0.200×10^{-3}	0.000	$<0.100 \times 10^{-3}$
Ungulates	-0.360	0.026	$<0.100 \times 10^{-3}$

[1] Beta estimate.
[2] Standard error.

F.2. Literature Cited

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Appendix G: Wild Ungulate Selection Results

G.1. Wild Ungulate Resource Selection

Wild ungulate fecal pellet density data (#/400m^2) were collected at the same time as the feral horse fecal data. To assess resource selection by wild ungulates in the area, a similar analysis was performed on the wild ungulate pellet counts as on the feral horse data (see Chapter 4), with the exception that poisson regression was used instead of zero-inflated poisson regression. The same themes and variables were tested for both 2009 and 2010 (Tables G.1 and G.2). Comparison of the initial *a-priori* models within themes indicated that the same variables or variable combinations were chosen between years for the forage characteristics, disturbance, and thermal themes. Adjusted biomass represented forage characteristics and was carried forward to the final models in both years. For the thermal theme, distance to forest (either mixedwood or conifer) combined with solar radiation was carried forward. In the water and topography theme, the ruggedness variable was brought forward in 2009, while water distance was brought forward in 2010. Within the competition theme, only cattle presence was brought forward in 2009, but both horse and cattle presence were brought forward in 2010. When leading preliminary models from all themes were compared the explanatory power of themes for 2009 was as follows, in descending order: forage > competition > thermal > disturbance > water and topography. The 2010 rank order was as follows: competition > forage > thermal > water and topography > disturbance.

In the final analysis (i.e. model combination) the leading model for 2009 was the "forage + competition + thermal + water & topography", which explained 21.2 % of the variation in wild ungulate presence (Table G.3). This model included adjusted forage biomass; cattle pellet counts, distance to forest, solar radiation, and ruggedness. One year later in 2010 the best model was the "competition plus forage plus thermal', which explained 24.0 % of the variation in ungulate presence (Table G.4). Variables included in this model included:

adjusted forage biomass, cattle pellet counts, distance to (any) forest, and solar radiation.

During both years, forage characteristics remained among the top two themes explaining wild ungulate abundance, accounting for a minimum of 10 % of variation in the latter. In both years wild ungulates tended to avoid areas with greater biomass production. Avoidance of these areas may have occurred because of the concentrated selection foraging strategy of many native ungulates. Deer and moose prefer browse over herbage (Hofmann 1989), and may lead these animals to select woodlands over highly productive grasslands, thereby accounting for the contrasting selection by these animals compared to both cattle and feral horses. Wild ungulates may not actually be avoiding the cattle and horses, but simply using different areas of the landscape due to differences in dietary and bedding preferences (Collins and Urness 1981, 1983). Although elk prefer herbaceous material and will switch to browse when needed (Torstenson et al. 2006, Telfer 1994), evidence of elk in the area was relatively sparse, suggesting low populations during the study period.

Patterns of wild ungulate resource selection may also be explained by direct competition from other ungulates. During both years the beta (β) estimates suggested ungulates avoided habitats highly utilized by cattle and horses (Tables G.5 and G.6). Repeated intensive use by horses and cattle of preferred grasslands may, through progressive forage depletion, have forced wild ungulates into other areas of the landscape.

During both years the thermal theme was a significant component of the final model and included both distance from forest and solar radiation. In both 2009 and 2010 wild ungulates used areas near forested environments (Table G.5 and G.6). Ungulates may have used these areas because they provided shelter from wind or other elements, as well as a ready source of escape and hiding cover when disturbed by predators or recreational users. Another possible explanation is that transitional habitats at the edge of forests are often where the majority of selected vegetation is found. Effects of global solar radiation were also present in both years, although in 2009 this relationship was positive, while one year later in

2010 it was negative. This contrasting response between years may be due to influences that were not measured in this study, or more likely, was due to the differences in sample sizes between 2009 and 2010, making the response more reliable. In 2009 ruggedness was also a part of the final model, with wild ungulates avoiding rugged areas. The loss of this effect one year later when a larger number of field plots were sampled suggests this observation may be an artefact of the limited sample size of plots examined in the first year.

The final RSPF models that were developed can be used to predict where wild ungulates are likely to be found in the study area (see equations [1] and [2]).

$$RSFP_{2009} = \exp(-0.650 - 0.400 \times 10^{-3} * \text{biomass (kg/ha)} - 0.037 * \text{cattle} - 0.006 * \text{forest distance (m)} + 0.100 \times 10^{-3} * \text{solar radiation} - 0.059 * \text{ruggedness}) / [1 + \exp(-0.650 - 0.400 \times 10^{-3} * \text{biomass (kg/ha)} - 0.037 * \text{cattle} - 0.006 * \text{forest distance (m)} + 0.100 \times 10^{-3} * \text{solar radiation} - 0.059 * \text{ruggedness})] \quad [1]$$

$$RSFP_{2010} = \exp(2.470 - 0.200 \times 10^{-3} * \text{biomass (kg/ha)} - 0.024 * \text{cattle} - 0.116 * \text{horses} - 0.005 * \text{forest distance} - 0.0001 * \text{solar radiation}) / [1 + \exp(2.470 - 0.200 \times 10^{-3} * \text{biomass (kg/ha)} - 0.024 * \text{cattle} - 0.116 * \text{horses} - 0.005 * \text{forest distance} - 0.100 \times 10^{-3} * \text{solar radiation})] \quad [2]$$

Table G.1. Summary results depicting comparative model strength of wild ungulate use from field plot data during summer 2009, and various landscape attributes. Bolded and italicized components indicate leading model in a theme, and which were carried forward into the final assessment.

Theme	Component	R^2 [1]	k [2]	-2LL [3]	AIC_c [4]	ΔAIC_c [5]	ω_i [6]
Null [7]							
		0.00	***1***	***214.96***	***217.03***	***0.00***	***1.00***
Forage Characteristics							
	Adjusted Biomass	***16.33***	***2***	***179.86***	***184.08***	***0.00***	***1.00***
Water & Topography							
	Water Distance	0.17	2	214.60	218.82	1.08	0.30
	Ruggedness	***0.67***	***2***	***213.52***	***217.74***	***0.00***	***0.51***
	Water Distance + Ruggedness	0.78	3	213.28	219.73	1.99	0.19
Disturbance							
	Roads/Trails	0.18	2	214.58	218.80	6.60	0.02
	Cutlines	***3.25***	***2***	***207.98***	***212.20***	***0.00***	***0.62***
	Roads/Trails + Cutlines	3.78	3	206.84	213.29	1.09	0.36
Thermal							
	Forest Distance	4.03	2	206.30	210.52	0.37	0.45
	Solar Radiation	0.33	2	214.24	218.46	8.31	0.01
	Forest Distance + Solar Radiation	***5.24***	***3***	***203.70***	***210.15***	***0.00***	***0.54***
Competition							
	Horses	1.79	2	211.12	215.34	21.96	0.00
	Ungulates	***12.00***	***2***	***189.16***	***193.38***	***0.00***	***0.65***
	Horses + Ungulates	12.48	3	188.14	194.59	1.21	0.35

[1] McFadden's pseudo R^2 goodness of fit measure.
[2] Number of model parameters.
[3] -2 log likelihood.
[4] AIC corrected for sample size of 57 observations.
[5] Difference between AIC_c value and the lowest AIC_c value within each theme.
[6] Model probability.
[7] Null model with intercept only.

Table G.2. Summary results depicting comparative model strength of wild ungulate use from field plot data during summer 2010, and various landscape attributes. Bolded and italicized components indicate leading model in a theme, and which were carried forward into the final assessment.

Theme	Component	R^2 [1]	k [2]	-2LL [3]	AIC_c [4]	ΔAIC_c [5]	ω_i [6]
Null [7]							
		0.00	***1***	***448.62***	***448.69***	***0.00***	***1.00***
Forage Characteristics							
	Adjusted Biomass	***14.02***	***2***	***384.00***	***388.22***	***0.00***	***1.00***
Water & Topography							
	Water Distance	***0.62***	***2***	***443.86***	***447.86***	***0.00***	***0.59***
	Ruggedness	0.08	2	446.28	450.28	2.42	0.18
	Water Distance + Ruggedness	0.69	3	443.54	449.54	1.91	0.23
Disturbance							
	Roads/Trails	0.02	2	446.54	450.54	2.62	0.16
	Cutlines	***0.60***	***2***	***443.92***	***447.92***	***0.00***	***0.61***
	Roads/Trails + Cutlines	0.67	3	443.64	449.64	1.95	0.23
Thermal							
	Forest Distance	7.59	2	412.70	416.70	5.47	0.06
	Solar Radiation	2.98	2	433.32	437.32	26.09	0.00
	Forest Distance + Solar Radiation	***9.32***	***3***	***405.00***	***411.00***	***0.00***	***0.94***
Competition							
	Horses	7.08	2	415.00	419.00	25.66	0.00
	Ungulates	12.83	2	389.34	393.34	20.67	0.00
	Horses + Ungulates	***17.95***	***3***	***366.44***	***372.44***	***0.00***	***1.00***

[1] McFadden's pseudo R^2 goodness of fit measure.
[2] Number of model parameters.
[3] -2 log likelihood.
[4] AIC corrected for sample size of 98 observations.
[5] Difference between AIC_c value and the lowest AIC_c value within each theme.
[6] Model probability.
[7] Null model with intercept only.

Table G.3. Summary results of final model analysis, depicting comparative model strength of wild ungulate use from field plot data during summer 2009, and various landscape attributes. Bolded and italicized model indicates the best model.

Themes	**R^2** [1]	**k** [2]	**-2LL** [3]	**AIC_c** [4]	**ΔAIC_c** [5]	**ω_i** [6]
Null [7]	0.00	1	214.96	217.03	33.95	0.00
Forage	16.33	2	179.86	184.08	1.00	0.21
Forage + Competition	17.70	4	176.92	185.69	2.61	0.09
Forage + Competition + Thermal	18.59	5	175.00	186.18	3.10	0.07
Forage + Competition + Thermal + Disturbance	18.59	6	175.00	188.68	5.60	0.02
Forage + Competition + Thermal + Disturbance + Water & Topography	21.19	7	169.40	185.69	2.61	0.09
Forage + Competition + Thermal + Water & Topography	***21.19***	***6***	***169.40***	***183.08***	***0.00***	***0.34***
Forage + Thermal + Water & Topography	19.43	4	173.2	181.97	1.30	0.18

[1] McFadden's pseudo R^2 goodness of fit measure.
[2] Number of model parameters.
[3] -2 log likelihood.
[4] AIC corrected for sample size of 57 observations.
[5] Difference between AIC_c value and the lowest AIC_c value within each theme.
[6] Model probability.
[7] Null model with intercept only.

Table G.4. Summary results of final model analysis, depicting comparative model strength of cattle use from field plot data during summer 2010, and various landscape attributes. Bolded and italicized model indicates the best model.

Themes	**R^2** [1]	**k** [2]	**-2LL** [3]	**AIC_c** [4]	**ΔAIC_c** [5]	**ω_i** [6]
Null [7]	0.00	1	446.62	448.69	95.51	0.00
Competition	17.95	3	366.44	372.89	19.71	0.00
Competition + Forage	21.90	4	348.80	357.57	4.39	0.08
Competition + Forage + Thermal	***23.98***	***6***	***339.50***	***353.18***	***0.00***	***0.68***
Competition + Forage + Thermal + Water & Topography	24.01	7	339.38	355.67	2.49	0.20
Competition + Forage + Thermal + Water & Topography + Disturbance	24.02	8	339.36	358.36	5.18	0.05

[1] McFadden's pseudo R^2 goodness of fit measure.
[2] Number of model parameters.
[3] -2 log likelihood.
[4] AIC corrected for sample size of 98 observations.
[5] Difference between AIC_c value and the lowest AIC_c value within each theme.
[6] Model probability.
[7] Null model with intercept only.

Table G.5. Ranked influence of different variables in the leading RSPF model for wild ungulates in the Alberta foothills in the summer of 2009.

Variable	**β[1]**	**SE[2]**	***P* value**
Adjusted biomass	-0.400×10^{-3}	0.200×10^{-3}	0.020
Cattle	-0.037	0.022	0.100
Distance to forest (conifer and mixedwood)	-0.006	0.350×10^{-3}	0.090
Solar radiation	0.100×10^{-3}	0.100×10^{-3}	0.120
Ruggedness	-0.059	0.027	0.030

[1] Beta estimate.
[2] Standard error.

Table G.6. Ranked influence of different variables in the leading RSPF model for wild ungulates in the Alberta foothills in the summer of 2010.

Variable	**β[1]**	**SE[2]**	***P* value**
Adjusted biomass	-0.200×10^{-3}	0.100×10^{-3}	0.005
Cattle	-0.024	0.008	0.003
Horses	-0.116	0.034	0.600×10^{-3}
Distance to forest (conifer and mixedwood)	-0.005	0.002	0.010
Solar radiation	-0.100×10^{-3}	0.000	0.150

[1] Beta estimate.
[2] Standard error.

G.2. Literature Cited

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Appendix H: Utilization Correlations for 2009

Table H.1. Summary of correlations between ungulate use measures, including feral horse and cattle pellet densities, as well as forage use and various plant community characteristics for summer of 2009.

Habitat Characteristic		Animal Use Metric		
Response	Component	Horse Fecal Count	Cattle Fecal Count	Wild Ungulate Fecal Count
Biomass				
	Grass	0.09	0.20	-0.31
	Forb	0.23	0.19	-0.39*
	Shrub	-0.07	-0.23	0.59***
Nitrogen Concentration				
	Grass	0.39	-0.03	-0.05
	Forb	0.14	0.08	-0.10
ADF Concentration				
	Grass	0.15	-0.29	-0.25
	Forb	-0.23	-0.20	-0.09
Biomass Utilization Estimation				
	All Forage	0.54***	0.62***	-0.47**

*,**,*** Indicate significance at $p<0.05$, $p<0.01$ and $p<0.001$, respectively.