"Earth and sky, woods and fields, lakes and rivers, the mountain and the sea, are excellent schoolmasters and teach some of us more than we can ever learn from books."

– John Lubbock

"The period of greatest gain in knowledge and experience is the most difficult period in one's life."

– Dalai Lama

University of Alberta

Interactions between Cattle Grazing and Forestry on Alberta's Public Lands

by

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This thesis is dedicated to the rancher, who despite pressures of urban encroachment, corporate takeover, policy changes, and lobbyist demands, remains a true keeper of the land and provider of wholesome food.

Abstract

The integration of cattle grazing and timber production on forested lands has become a significant resource management issue on Alberta public lands where there is demand to satisfy both uses. This innovative project examined interactions between cattle grazing and forestry operations within rangelands containing recently harvested deciduous and coniferous cut blocks of west-central and south-western Alberta during 2008 and 2009. Two and 3 years following logging, cattle avoided regenerating deciduous and coniferous cut blocks. Cattle forage use was positively associated with greater forage biomass, crude protein concentration, and distance to roads, but was negatively associated with increasing distance to water, and greater elevation, slope gradient, slash accumulation and tree regeneration densities. Cattle-related damage to trees was minimal, yet reflective of stocking rate. Results confirm that cut block reforestation can occur despite cattle presence given sustainable grazing management.

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List of Symbols and Abbreviations

-2 LL – Negative 2 Log Likelihood

AFPA – Alberta Forest Products Association

ADF – Acid Detergent Fibre

AIC – Akaike Information Criterion

AIC_c – Akaike Information Criterion Corrected for Small Sample Size

$AICc_i$ – Akaike Information Criterion Score for Candidate Model

$AICc_{min}$ – Minimum Akaike Information Criterion Score

ΔAICc – Change in Akaike Information Criterion Score

ANOVA – Analysis of Variance

ASRD – Alberta Sustainable Resource Development

ATS – Advanced Telemetry Systems

AUM – Animal Unit Month

AUM/ha – Animal Unit Month per Hectare (Stocking Rate)

β – Beta Coefficient

C – Carbon

^{o}C – Degrees Celsius

Ca - Calcium

cm – Centimetre

CEC – Cation Exchange Capacity

CP – Crude Protein

DEM – Digital Elevation Model

DU – Distribution Unit

Exp - Exponent

FMA – Forest Management Agreement

GIS - Geographic Information System

GPS – Global Positioning System

Ha – Hectare

K – Number of Parameters

Kg/ha – Kilograms per Hectare

LRT – Likelihood Ratio Test

m – Metre

n – Sample Size

N – Nitrogen

NDF – Neutral Detergent Fibre

PDOP – Positional Dilution of Precision

Proc GLIMMIX – General Linear Mixed Model Statistical Procedure

Proc GLM – General Linear Model Statistical Procedure

Proc MIXED – Mixed Model Statistical Procedure

Proc REG – Regression Statistical Procedure

Proc TTEST – T-test Statistical Procedure

Proc UNIVARIATE – Univariate Statistical Procedure

r – correlation coefficient

R^2 – Regression goodness of fit measure

RMFR – Rocky Mountain Forest Reserve

RSF – Resource Selection Function

RSPF – Resource Selection Probability Function

SE – Standard Error

Spp - Species

TOL - Tolerance

UTM – Universal Transverse Mercator

VIF – Variance Inflation Factor

ωi – Model Probability

1. Integrating Livestock Grazing and Timber Production on Public Land

1.1. Introduction

Alberta Sustainable Resource Development (ASRD) employs and promotes an integrated resource management approach to balance multiple expectations and demands relating to a single land base. Alberta's forested crown lands support several resource uses including timber production, livestock grazing, recreation, and mineral extraction. At times, vested interests associated with forest use conflict due to the sacrifice of one resource for the gain of another (Willoughby 1995). Such can be the case with the integration of cattle grazing and timber production on forested public lands (Clary et al. 1975; Krzic et al. 2001, 2003, 2004).

Forest and livestock industries have a long history in Alberta and are valued contributors to the provincial economy. As of July 1st 2009, Alberta's cattle herd totalled nearly 5.9 million head (Statistics Canada 2009). Pasture for approximately 14 % of these animals is provided by provincial public rangelands, which supplies more than 1.6 million animal unit months (AUMs) of forage and generates over $4 million in grazing revenue, each year (ASRD 2003). Approximately 2.4 million ha of public land support grazing dispositions in the form of leases and licenses. Long term leases make up the majority of public grazing land in Alberta, while a small portion of grazing licences are granted to cattle producers operating in forested areas that simultaneously support timber production, an area referred to as the green area. Large grazing allotments within the Rocky Mountain Forest Reserve (RMFR) of south western Alberta provide 0.8 million ha of public rangeland. Grazing on public land within the green area is administered under the *Public Lands Act*, while the Rocky Mountain Forest Reserves are managed under the *Forest Reserves Act*.

Alberta's Grazing Lease Stewardship Code of Practice (ASRD 2007) provides leaseholders with guidelines on how to meet provincial expectations for maintaining rangeland ecological health and functionality. Lessees are required to set stocking rates at a sustainable level (25-50% use), manage for appropriate timing, frequency and duration of grazing, preserve wildlife habitat and watersheds, and accommodate industrial and recreational use of the land. Failure to meet these commitments upon field inspection will result in penalties, or in extreme cases loss of grazing rights.

Forests occupy 57% of the provincial land base or approximately 38 million ha throughout Alberta (ASRD 2009*a*). In 2007, primary and secondary forest industries in 50 Alberta communities employed a total of 44,000 full time equivalents and generated nearly $11 billion in revenue, making forestry the third largest economic sector in the province (Alberta Forest Products Association [AFPA] and ASRD 2008).

Forest companies are granted dispositions including timber permits, licences, quotas, and forest management agreements (FMA) issued by the government under the *Forests Act* (ASRD 2001). FMAs represent large tracts of land within the green area that are managed by forest companies, making them accountable for establishing, growing, and harvesting timber using environmentally sustainable practices (ASRD 2001). The development of detailed forest management plans outlining when, where and how trees are harvested and regenerated, along with how other land uses will be accommodated, is a requirement for FMA holders. Forest management plans address social, economic, and ecological aspects of timber production. All forest companies must adhere to timber harvesting planning and operating ground rules relating to harvesting operations, reforestation, watershed, wildlife and fisheries conservation, soil disturbance and erosion, and the consideration of other land uses including grazing.

Less than 1% of Alberta forests are harvested each year to allow timber growth to surpass the amount of forest resources removed. For example, annual growth of crown forests was assessed at 44.5 million m^3 in 2007, while the actual amount of wood harvested did not exceed 23 million m^3 (AFPA and ASRD 2008); the total annual allowable cut deemed sustainable for the province was determined to be slightly greater than 27 million m^3.

Reforestation following harvest has been mandated since 1966, when Alberta was the first province to institute this law (ASRD 2009*a*). Timber companies are required to reforest harvested areas within 2 years following logging and must report their regeneration status to be audited by ASRD. Tree establishment and performance surveys are conducted based on procedures listed in the *Regeneration Survey Manual* (ASRD 2008). Establishment surveys are performed 3 to 8 years following harvest and determine whether logged areas are sufficiently stocked and evenly distributed with suitable trees (ASRD 2009*a*). In the case of inadequate regeneration, amendments to reforestation are required within one year. Performance surveys are done 8 to 14 years following timber removal and assess tree growth (ASRD 2009*a*); where unsatisfactory, future harvest levels are reduced to account for the lack of production.

Stocking is the key measure used to assess reforestation and is calculated as the proportion of plots (within a grid layout) containing trees of acceptable height, form and vigour (ASRD 2009*a*). Reforestation is considered successful if stocking meets or exceeds 80%, corresponding to an average of 5700 trees per ha. During the 2007-08 reporting year, 92% of cut blocks surveyed had greater than 80% stocking (ASRD 2009*a*). Stocking values have progressively increased, suggesting reforestation practices have become more successful with the application of improved knowledge and technology.

In 2003, ASRD was approached by the beef and forest industries to discuss respective issues and opportunities associated with overlapping grazing and timber dispositions on Alberta's crown forests. Alberta ranchers expressed concern over the potential negative outcomes of timber harvest, such as altered vegetation composition and production, decreased forage accessibility due to slash accumulation, and compromise of their implemented grazing systems and infrastructure (Newman et al. 1994; Krzic et al. 2004). Any factor limiting forage production or availability may have a negative impact on cattle stocking rates and production efficiency for ranchers.

Similarly, timber producers were apprehensive about the potential effects of cattle grazing on forest regeneration. From a forest management perspective, the timing, duration, intensity, and frequency of livestock grazing can all have detrimental effects on the regeneration success of tree seedlings (Allen and Bartolome 1989; Pitt et al. 1998; Irving 2001; Dockrill et al. 2004). High levels of browsing, trampling and soil compaction caused by livestock have been associated with conifer seedling mortality

(McLean and Clark 1980; Eissenstat et al. 1982), in addition to decreased aspen sucker reproduction and subsequent stand density (Krzic et al. 2003, 2004). Reduced tree regeneration on harvested sites equates to a decline in timber production efficiency and loss of profit for forest companies.

The extent to which a harvested forest is effectively regenerated is a measure of accountability for forest companies operating in Alberta, as adherence to the regeneration standards enforced by ASRD (2008) suggests environmental and industrial integrity and sustainability. Those seedlings included as acceptable in a regeneration survey must be undamaged during assessment (Dockrill et al. 2004). Failure to meet regeneration expectations has negative implications for forest companies in terms of the pursuit of future timber harvesting opportunities on public lands (McLean and Clark 1980; Mike Alexander, Rangeland Management Branch, ASRD, personal communication 2007).

Despite the potential issues that may arise during simultaneous forestry and grazing operations on a single land base, these two land uses can be quite complementary (McLean and Clark 1980; Allen and Bartolome 1989). For example, forested ranges are highly valued sources of summer and fall forage, ample water, and shelter from weather, insects and disease (Allen and Bartolome 1989). During drought years in particular, forests are valuable sources of forage and moisture when grasslands have senesced. Overstory removal resulting from sustainable timber harvesting allows for the release of herbaceous vegetation, thereby contributing to greater rangeland carrying capacity and production efficiency for livestock (Bartos and Mueggler 1982; Bergquist and Örlander 1998).

Conversely, under proper grazing management, tree seedlings benefit from reduced herbaceous competition resulting from ongoing livestock grazing (McLean and Clark 1980; Zimmerman and Neuenschwander 1984; Allen and Bartolome 1989; Newman et al. 1994; Kie and Boroski 1996; Cutter et al. 1999). The presence of *Calamagrostis canadensis* (Michx.) Beauv., a competitive native grass that invades and dominates harvested areas, can negatively affect seedling and sapling growth by limiting light and nutrient availability (Landhausser and Lieffers 1998). Additionally, the resulting litter accumulation from this grass causes snow compression damage to young trees and prevents soil warming by insulating the soil surface (David et al. 2001). Consumption of forage by cattle can also reduce fuel loads, thereby reducing the risk of fire. Grazing activities may improve nutrient cycling through excretion of nutrients in a more readily available form for uptake by forest vegetation, as well as through litter and slash disturbance acting to improve decomposition of this material.

To deal with any potential harmful effects that each land use may have on the prosperity of the other, multiple use management agreements can be implemented to guide the successful integration and collaboration of different activities and interests on a common land base. From 2003 to 2006, a provincial committee comprised of beef and timber industry representatives, in cooperation with ASRD staff, joined efforts to identify and discuss concerns, issues, needs and opportunities related to combining grazing and timber harvesting activities. In June 2006, ASRD implemented a new grazing and timber integration policy to provide direction required for sustainable cattle and timber production on Alberta's forested public lands. As a result, the *Grazing and Timber Integration Manual* (Milligan and Ehlert 2009) was developed to manage and administer planning, operations, agreements, monitoring, and conflict resolution pertaining to cattle grazing and forestry on shared crown lands. Other documents created to aid in the assimilation of timber harvesting and cattle grazing include *Recommended Grazing and Timber Best Management Practices in Coniferous and Deciduous Cutblocks in Alberta* (ASRD 2009*b*), *Cutblock Assessment Tool* (Forest Range Health Assessment Working Group 2008), and *Guidelines for Integrating Timber Harvesting and Domestic Grazing in the Green Area* (ASRD 2002). Ultimately, forest and range managers alike are stewards of the land and value watershed function, carbon sequestration, biodiversity, wildlife habitat conservation, aesthetics, and accommodating multiple use activities.

1.2. Study Purpose and Objectives

This research was created to provide scientific knowledge essential to support a balance between cattle grazing and timber harvesting on the same land base. More specifically, the project was designed to contribute information applicable to the evolution of beneficial management practices that would minimize conflict between livestock grazing and sustainable forest management. In addition to furthering our understanding of the basic factors influencing cattle grazing behaviour, results of this research could aid the development of prescriptions useful in minimizing the impact of grazing activity on regeneration while maintaining site productivity for long-term timber supply.

Understanding cattle behaviour within forested landscapes is beneficial to the successful management and coordination of multiple uses on a common land base (Roath and Krueger 1982). By researching cattle behavioural patterns, more insight and information can be applied to managing livestock distribution and the timing of grazing to accommodate other resource users (Launchbaugh and Howery 2005). In efforts to alter herbivore behaviour for the purpose of achieving desired landscape management goals, environmental attributes can be changed and cattle trained to respond uniquely to different conditions. Within the scope of this research project, observed cattle behaviour in heterogeneous forested landscapes will be related to surrounding abiotic and biotic environmental conditions. This knowledge will subsequently be applied to designing best management practices in order to accommodate forestry practices.

Specific objectives included:

1. To determine cattle foraging behaviour and habitat preference within heterogeneous forested landscapes following conifer or deciduous clear-cutting.
2. To identify the mechanisms regulating cattle foraging behaviour within these areas, including forage quantity, quality and accessibility.
3. To determine effects of cattle grazing on subsequent tree regeneration, including growth (i.e. size) and survival.

4. To determine the effects of woody slash (i.e. forest debris) accumulation on cattle behaviour, including forage utilization patterns and associated tree damage.

1.3. Literature Cited

Alberta Forest Products Association and Alberta Sustainable Resource Development. 2008. Economic impact of the Alberta forest industry. Edmonton, Alberta, Canada. Publication No. I/308. ISBN No. 978-0-7785-7045-5 (On-line Edition).

Alberta Sustainable Resource Development. 2001. Management of Alberta's forest resource. Publication No. I/032. ISBN No. 0-7785-1808-6.

Alberta Sustainable Resource Development. 2002. Guidelines for integrating timber harvesting and domestic grazing in the green area: for Weyerhaeuser of Canada-Edson Division, Millar Western Forest Products Ltd. and affected grazing disposition holders. Publication No. I/063. ISBN No. 0-7785-2169-9 (On-line Edition).

Alberta Sustainable Resource Development. 2003. About public lands: grazing statistics for public land. Lands Division, Edmonton, Alberta, Canada.

Alberta Sustainable Resource Development. 2007. Alberta's grazing lease stewardship code of practice. Rangeland Management Branch, Lands Division, Edmonton, Alberta, Canada.

Alberta Sustainable Resource Development. 2008. Alberta regeneration survey manual. Forest Management Branch, Edmonton, Alberta, Canada. Publication No. T/181. ISBN No. 978-0-7785-7039-4 (On-line Edition).

Alberta Sustainable Resource Development. 2009*a*. 2009 annual status of reforestation in Alberta. Forest Management Branch, Forestry Division.

Alberta Sustainable Resource Development. 2009*b*. Recommended grazing best management practices in coniferous and deciduous cutblocks in Alberta. Approximation 1. Rangeland Management Branch, Lands Division, Edmonton, Alberta, Canada. Publication No. I/285. ISBN No. 978-0-7785-6528-4. (On-line Edition).

Alexander, M. 2007. Personal communication. Rangeland Management Branch, Alberta Sustainable Resource Development. Pincher Creek, Alberta, Canada.

Allen, B.H. and J.W. Bartolome. 1989. Cattle grazing effects on understory cover and tree growth in mixed conifer clearcuts. Northwest Science 63(5): 214-220.

Bartos, D.L. and W.F. Mueggler. 1982. Early succession following clearcutting of aspen communities in northern Utah. Journal of Range Management 35(6): 764-768.

Bergquist, J. and G. Örlander. 1998. Browsing damage by roe deer on Norway spruce seedlings planted on clearcuts of different ages 1. Effect of slash removal, vegetation development, and roe deer density. Forest Ecology and Managment 105: 283-293.

Clary, W.P., W.H. Kruse, and F.R. Larson. 1975. Cattle grazing and wood production with different basal areas of ponderosa pine. Journal of Range Management 28(6): 434-437.

Cutter, B.E., K. Hunt, and J.D. Haywood. 1999. Tree/wood quality in slash pine following longterm cattle grazing. Agroforestry Systems 44: 305-312.

David, A.J., J.C. Zasada, D.W. Gilmore, and S.M. Landhäusser. 2001. Current trends in the management of aspen and mixed aspen forests for sustainable production. The Forestry Chronicle 77(3): 525-532.

Dockrill, C.W.M., P.V. Blenis, A.W. Bailey, and J.R. King. 2004. Effect of summer cattle grazing on aspen stem injury, mortality and growth. The Forestry Chronicle 80(2): 257-261.

Eissenstat, D.M., J.E. Mitchell, and W.W. Pope. 1982. Trampling damage by cattle on northern Idaho forest plantations. Journal of Range Management 35(6): 715-716.

Forest Range Health Assessment Working Group. 2008. Cutblock assessment tool: level 1 assessment tool approximation #1. Rangeland Management Branch, Lands Division, Alberta Sustainable Resource Development, Edmonton, Alberta, Canada. Publication No. T/182.

Irving, B.D. 2001. The impacts of horse grazing on conifer regeneration in west-central Alberta. Ph.D. Dissertation. University of Alberta, Edmonton, Alberta, Canada.

Kie, J.G. and B.B. Boroski. 1996. Cattle distribution, habitats, and diets in the Sierra Nevada of California. Journal of Range Management 49(6): 482-488.

Krzic, M., R.F. Newman, and K. Broersma. 2003. Plant species diversity and soil quality in harvested and grazed boreal aspen stands of northeastern British Columbia. Forest Ecology and Management 182: 315-325.

Krzic, M., H. Page, R.F. Newman, and K. Broersma. 2004. Aspen regeneration, forage production, and soil compaction on harvested and grazed boreal aspen stands. BC Journal of Ecosystems and Management 5(2): 30-38.

Krzic, M., K. Broersma, R.F. Newman, T.M. Ballard, and A.A. Bomke. 2001. Soil quality of harvested and grazed forest cutblocks in southern British Columbia. Journal of Soil and Water Conservation 56(3): 192-197.

Landhäusser, S.M. and V.J. Lieffers. 1998. Growth of Populus tremuloides in association with Calamagrostis Canadensis. Canadian Journal of Forest Resources 28: 396-401.

Launchbaugh, K.L and L.D. Howery. 2005. Understanding landscape use patterns of livestock as a consequence of foraging behaviour. Rangeland Ecology and Management 58(2): 99-108.

McLean, A. and M.B. Clark. 1980. Grass, trees, and cattle on clearcut-logged areas. Journal of Range Management 33(3): 213-217.

Milligan, S. and G. Ehlert. 2009. Grazing and Timber Integration Manual. Forestry Division, Forest Management Branch; and Lands Division, Rangeland Management Branch, Alberta Sustainable Resource Development.

Newman, R.F., B.M. Wikeem, M.D. Pitt, D. Quinton, P. Youwe, and G.W. Powell. Grass/tree/cattle research on forest range in British Columbia, Canada. Managing Canadian Rangelands for Sustainability & Profitability: Proceedings of the First Interprovincial Range Conference in Western Canada. Pgs. 175-181.

Pitt, M.D., R.F. Newman, P.L. Youwe, B.M. Wikeem, and D.A. Quinton. 1998. Using a grazing pressure index to predict cattle damage of regenerating tree seedlings. Journal of Range Management 51(2):152-157.

Roath, L.R. and W.C. Krueger. 1982. Cattle grazing and behavior on a forested range. Journal of Range Management 35(3): 332-338.

Statistics Canada. 2009. Cattle Statistics. Catalogue no. 23-012-X, vol. 8, no. 2.

Willoughby, M.G. 1995. The effects of grazing on deciduous plant communities in the Boreal Ecoprovince of Alberta. Rangelands in a Sustainable Biosphere. Proceedings of the Fifth International Rangeland Congress, Volume 1.

Zimmerman, G.T. and L.F. Neuenschwander. 1984. Livestock grazing influences on community structure, fire intensity, and fire frequency within the Douglas-fir/ninebark habitat type. Journal of Range Management 37(2): 104-110.

2. Background Literature

2.1. Cattle Foraging Behaviour

Drivers of cattle foraging behaviour include both biotic factors such as vegetation characteristics, predation risk, insect density, and abiotic factors such as slope, topography, distance to water, and microclimate (Mueggler 1965; Roath and Krueger 1982; Senft et al. 1983; Senft et al. 1987; Allen and Bartolome 1989; Hart et al. 1991; Owens et al. 1991; Pinchak et al. 1991; Wallis de Vries and Schippers 1994; Bailey et al. 1996; Kie and Boroski 1996). The primary motivating factors that determine habitat preference of cattle are forage quality and quantity, as cattle strive to optimize nutrient quality and intake. Elements affecting forage quality and quantity include species composition, plant morphology, the presence of secondary compounds, palatability, and productivity (Senft et al. 1987; Senft 1989; Chapman et al. 2007).

Those habitats that provide the most favourable forage attributes will experience greater cattle occupancy as compared to those areas with less desirable vegetation. Roath and Krueger (1982) found that forage quality and vegetation type could be related to cattle distribution and degree of use across forested ranges. In scenarios where forage quantity and quality are lacking, intake rates of forage will decrease while time spent travelling across the landscape increases. Forage depletion resulting from high stocking rates can motivate cattle to access less favourable grazing sites farther from water sources or on steep slopes (Senft et al. 1983; Hart et al. 1991). When cattle are faced with limited forage availability, they may be forced to consume greater amounts of lower quality forage in order to meet intake requirements (Senft et al. 1987; Owens et al. 1991; Chapman et al. 2007), a strategy that has been used for biological weed control (De Bruijn and Bork 2006).

Abiotic factors act as constraints in the search for forage across the landscape. Cattle typically avoid grazing slopes greater than 10%, with steeper slopes receiving less use (Bailey et al. 1996). Vertical distance above water has been found to be the primary factor responsible for limiting forage utilization on moderately steep slopes (Roath and

Krueger 1982). Slopes in excess of 60% were avoided by cattle regardless of vegetation type. Physical barriers to grazing such as heavy accumulation of coarse woody debris can also impede grazing activity, and are discussed in detail in section 2.4.

In addition to ease of access, cattle distribution is further affected by habitat suitability based on temperature, shelter from the elements, and protection from pests and predators (Owens et al. 1991; Beaver and Olsen 1997; Launchbaugh and Howery 2005). Time after sunrise and relative humidity were found to influence the type and timing of cattle behaviour, while temperature was found to have a lesser effect on the timing of activity (Roath and Krueger 1982). Cattle commenced grazing shortly after sunrise and began a long feeding period for approximately 3 hours. Following this feeding period, cattle would spend the afternoon travelling to water and bedding in shaded areas. Cattle began grazing again during the late afternoon and remained grazing until sunset, at which time they bedded until sunrise (Roath and Krueger 1982).

In order for herbivores to retain information regarding their foraging decisions and habitat preference, they apply cognitive mechanisms such as accurate spatial memory, perceptual abilities, and post-ingestive feedback (Bailey et al. 1989, 1996; Wallis de Vries and Schippers 1994; Launchbaugh and Howery 2005). Spatial memory allows cattle to relate forage quality and quantity with certain locations and this information can be retained for up to 20 days (Bailey et al. 1996). In order to decide between foraging options, herbivores will use acute perception to discriminate among plant parts, vegetation types and grazing sites. Identification of shapes and colours provides cattle with insight into forage attributes and location. Post-ingestive feedback processes allow herbivores to associate the forage consumed with resulting nutritional consequences (Provenza 1995). Positive nutritional experiences promote the continued selection of a chosen forage, whereas unpleasant post-ingestive incidents favour avoidance. These mechanisms allow for increased foraging efficiency, as cattle are able to promptly return to areas known to satisfy their needs rather than spending time and energy searching for alternative desirable vegetation. The amount of time cattle spend in nutrient rich environments may be long lasting, as more time is allocated to grazing and ruminating rather than travelling.

Social behaviour of herd animals also plays a role in determining habitat use within a heterogeneous environment (Roath and Krueger 1982; Launchbaugh and Howery 2005). Within the herd dynamic, individuals can be leaders, followers, or independent in regards to their response to herd behaviour and movement (Bailey et al. 1996). Young or inexperienced grazers are more likely to distribute themselves uniformly across the landscape in search of forage, which in turn may hamper their performance due to increased time spent travelling rather than foraging (Launchbaugh and Howery 1982). Social interactions may also affect cattle distribution across rangeland, as noted in the *Campbell Creek Timber-Grazing Demonstration* completed by Hincz (2007). In this study, two herds originating from different farms maintained separate territories when mixed within a single heterogeneous pasture. Novelty also plays a role in livestock distribution, as cattle are more inclined to explore unfamiliar environments as opposed to well-known areas (Launchbaugh and Howery 2005).

Ultimately, cattle seek habitat that provides a combination of food, water, thermal comfort, physical comfort, security, and rest (Launchbaugh and Howery 2005). Conversely, cattle avoid habitats associated with hunger, thirst, stress, pain, or discomfort. Most studies conclude that cattle grazing activities are more abundant within grasslands compared to wooded areas, where livestock are likely to be found lounging and resting (McLean 1972; Holechek et al. 1982; Asamoah et al. 2003). Zuo and Miller-Goodman (2003) found that 90% of total grazing activities took place in grasslands, while 75% of resting observations were noted in forests. On a ponderosa pine (*Pinus ponderosa* Laws.) rangeland in Arizona, forage consumption by cattle was positively influenced by increasing grass production and decreasing forest density (Clary et al. 1978). In a study conducted by Owens et al. (1991), grass abundance, brush abundance, and remoteness were the primary characteristics influencing forage utilization in mixed brush landscapes. Increasing brush abundance appeared to deter grazing, resulting in decreased forage utilization.

2.2. Cattle Grazing on Deciduous Rangelands

Within forested settings, cattle prefer to consume herbaceous species but may find aspen (*Populus tremuloides* Michx.) palatable to some extent (Fitzgerald et al. 1986; Beck and Peek 2005; Dockrill et al. 2006). In a study by Asamoah et al. (2003), graminoids comprised over 92% of the total herbage utilized by cattle grazing heterogeneous Aspen Parkland rangeland. During late spring and early summer, aspen shoots and foliage can provide high crude protein and high moisture forage for cattle when understory grasses and forbs may be limiting in production (Dockrill et al. 2004, 2006). Aspen typically comprises a relatively small portion of cattle diets, but utilization may vary depending on the presence of alternative forages, the phenological stage of all species present, and the stocking rate of livestock (Fitzgerald et al. 1986). Immediately after clear-cutting, young regenerating aspen may be targeted more frequently due to high crude protein concentrations, low availability of alternative forages, and improved accessibility. However, with each successive year following tree harvest, utilization typically declines.

The timing of grazing within aspen forests affects sucker growth, resiliency, and susceptibility to damage and consequentially, mortality (Fitzgerald and Bailey 1984; Fitzgerald et al. 1986; Bailey et al. 1990; Dockrill et al. 2004). Excessive spring and early summer grazing of aspen foliage can result in decreased photosynthetic capabilities and exhausted carbohydrate reserves, thereby increasing the risk of growth inhibition and death of young suckers (Fitzgerald and Bailey 1984; Bailey et al. 1990).Research conducted by Dockrill et al. (2004) indicates that grazing in June and July produced a more negative effect on aspen height and density compared to August and September grazing. Grazing during June and July resulted in 50-200% greater aspen stem mortality as opposed to an ungrazed (i.e. protected) stand of young aspen. In addition, all grazing treatments regardless of timing prevented 50% of trees from being included in a regeneration survey due to unacceptable stem damage. While the activity of grazing may damage aspen suckers, actual defoliation and consumption of material is not as strongly associated with mortality as stem trampling (Dockrill et al. 2004). Saplings on the verge of death were less likely to be browsed due to their unpalatable nature, resulting in greater relative risk of mortality for unbrowsed trees.

A study conducted within the Aspen Parkland natural subregion of Alberta confirmed that heavy grazing reduces the growth potential of young aspen saplings (Fitzgerald and Bailey 1984; Fitzgerald et al. 1986; Bailey et al. 1990). The complete removal of all accessible and edible material through the implementation of extremely high stocking rates lead to the virtual elimination of aspen regeneration following August grazing. Towards the end of the growing season, aspen prepare and store carbohydrate reserves to allow for maintenance throughout the winter months. However, the act of browsing mobilizes energy reserves within the young tree to initiate shoot primordia growth, resulting in a lack of winter preparedness and hardiness for the tree (Fitzgerald and Bailey 1984; Bailey et al. 1990). Subsequent low winter temperatures may eliminate the potential for existing viable primordia to produce aspen suckers the following spring. The impact of heavy grazing (i.e. 9 AUM/ha) during late August in these studies was severe enough to cause elimination of aspen suckers after only one defoliation, whereas grazing during the month of June at 3 AUM/ha sustained aspen regeneration with only a 7% reduction in stem density after 7 years. Similarly, following one year of early season grazing, aspen constituted 29% of total plant biomass, while one year of late season grazing reduced aspen yield to 2.5% (Bailey and Fitzgerald 1984).

Regardless of season of use, repeated heavy foraging by cattle reduces the long-term probability of aspen survival by gradually depleting root carbohydrate reserves within 6-8 years of grazing exposure (Bailey et al. 1990; Dockrill et al. 2004). In order to minimize the harmful effects of grazing on aspen regeneration, stocking rates along with livestock distribution need to be adjusted accordingly (Krzic et al. 2003, 2004,).

Despite literature confirming the detrimental effects of heavy late season grazing, it may be best to defer grazing until later in the summer in association with a light to moderate use stocking rate. July grazing has been found to be more favourable in maintaining aspen sucker density by allowing time for greater stem growth and strength, thereby making suckers more resistant to shearing (Dockrill et al. 2004, 2006). Aspen resistance to shearing was found to increase by 200-2000% over a year of growth (Dockrill et al. 2006). Additionally, aspen growth throughout the season results in the production of cells with thicker walls, which may be associated with increased fibre and lignin content (Dockrill et al. 2006). High levels of these characteristics indicate poor forage quality and palatability, and it is therefore logical to assume that cattle will find aspen growth less desirable later in the summer and fall. During early spring and summer, when understory forage is limited, young, succulent and nutritious aspen shoots and leaves may be targeted for grazing by cattle. Managing for midsummer grazing within regenerating aspen stands at conservative stocking rates may decrease damage experienced by aspen saplings. Improved alternative forage (i.e. herb) abundance during this time, along with greater aspen stem strength and decreased palatability, may be sufficient deterrents for cattle grazing aspen saplings.

2.3. Cattle Grazing on Coniferous Rangelands

Mountainous forested landscapes are comprised of a mosaic of habitats including interspersed grasslands and shrublands among mixed conifer forest. Most research surrounding cattle grazing on conifer rangelands concludes that cattle spend a relatively small proportion of their time within forested areas (Roath and Krueger 1982; Zimmerman and Neuenschwander 1984; Kie and Boroski 1996) and prefer to graze lowland range sites instead (Hart et al. 1991). Cattle grazing within forested areas of the Sierra Nevada Mountains of California exhibited greatest preference for riparian areas, followed by clearcuts, second-growth forest, and lastly, burned areas (Kie and Boroski 1996). Near identical results were observed for cattle grazing mountain rangelands in northeastern Oregon (Gillen et al. 1984). Most grazing activities occurred within riparian areas or uplands due to a lack of adequate forage within the understory of mixed-conifer forests. Similar research conducted by Roath and Krueger (1982) found that within forested mountainous rangeland, bluegrass (*Poa* spp.) lowlands provided 81% of the forage consumed despite contributing only 21% of the total herbaceous biomass available. This high level of utilization within lowlands was not observed within any of the other vegetation types. Those habitats adjacent to bluegrass lowlands also received greater use by cattle compared to upland vegetation types because they were easily accessible and relatively close to low elevation free standing water. Both studies concluded that distance to water strongly influenced cattle locations and habitat preference (Roath and Krueger 1982; Kie and Boroski 1996). On average, livestock were located approximately 60 m from water (Kie and Boroski 1996). To discourage cattle interference with conifer seedlings, water placement could be situated long distances from regenerating cut-blocks.

Livestock avoidance of certain habitats within mountainous forested landscapes was associated with steep slopes, closed overstory canopies, north and west aspects, and sparse understory vegetation (Roath and Krueger 1982; Kie and Boroski 1996). In order for cattle to distribute themselves across forested rangelands, logging roads were used as primary routes of travel.

Research conducted on forested rangelands within the Blue Mountains of Oregon showed that cattle diets were composed of 61% grasses, 16% forbs, and 23% shrubs (Holechek et al. 1982). Diet composition was found to change between years and also with seasonal advances in phenology. The extent to which cattle browsed depended on grass and forb availability, as the level of browse reached 47% of diet composition when herbage was limited. Kie and Boroski (1996) found that cattle only browsed deerbrush (*Ceanothus integerrimus* Hook. & Arn.) during August, at which time forbs and grasses were low in forage quality. Hedrick et al. (1969) found that browse is important for cattle during the fall when crude protein levels of other forages are low. Shrubs and trees tend to maintain better nutritive quality later in the season compared to herbs. Grasses and forbs are preferred during the early part of the growing season when they are of greatest nutrient content.

When livestock stocking rates are too high on regenerating forested range, tree seedlings may be affected by grazing activities such as trampling and browsing (Newman et al. 1994). However, when stocking rates are properly matched to available forage resources, damage to conifer seedlings is usually minimal (McLean and Clark 1980; Cutter et al. 1999). Although cattle typically do not browse coniferous material, as it is generally unpalatable (Lewis 1980b), damage to seedlings could still occur from trampling (Newman et al. 1994). McLean and Clark (1980) found that cattle grazing caused negligible damage to Engelmann spruce (*Picea engelmannii* Parry *ex* Engelm.) and lodgepole pine (*Pinus contorta* Loudon) seedlings, and did not impact the adequacy of tree stocking. Allen and Bartolome (1989) obtained similar results when grazing cattle among white fir (*Abies concolor* (Gordon) Lindley *ex* Hildebrand) and Douglas-fir [*Pseudotsuga menziesii* (Mirb.)] seedlings.

Mortality resulting from natural causes, such as drought and rodents, along with poor planting conditions has been far greater than death resulting from cattle impacts (McLean and Clark 1980). No significant relationship was found between cattle-related tree mortality and the degree of forage utilization, suggesting cattle did not excessively damage seedlings when in search of forage (McLean and Clark 1980). Within one experimental paddock, continuous cattle grazing for 4 months resulted in 11% seedling mortality, with 31% of remaining seedlings experiencing severe trampling damage in the first year. Forage utilization by cattle averaged approximately 70% over 3 years, but varied from 40 to 90%. Lodgepole pine seedlings were significantly taller when protected from grazing but spruce seedlings showed no height response to grazing. Slash pine (*Pinus elliottii* Engelm.) grown in areas supporting long-term grazing showed no decrease in height, diameter, grade (measure of tree quality), or growth rate (Cutter et al. 1999). Irving (2001) found that feral horses preferred to occupy dry pine sites within cut blocks of west central Alberta and consequently caused detectable damage to regenerating trees within these areas; however, the overall impacts were within acceptable limits to ensure reforestation, provided stocking rates remained low to moderate. McLean and Clark (1980) suggest clearcuts are best grazed for only short periods of time with a suitable stocking rate, and where possible using a rotational system.

Cattle grazing activities within Douglas-fir and ponderosa pine forests of Idaho are thought to promote tree regeneration by way of duff disturbance, exposure of mineral soil, and decreased herbaceous competition (Zimmerman and Neuenshwander 1984). Tree species appear to influence seedling response to disturbance, as Douglas-fir is more tolerant of the effects of cattle grazing compared to ponderosa pine. Researchers Zimmerman and Neuenshwander (1984) found that seedlings exposed to grazing activities had slightly lower growth rates compared to ungrazed sites. However, suppressed growth rates within grazed sites were also related to high tree densities and consequently, greater intraspecific competition among trees.

When coniferous seedlings are damaged by trampling or browsing, the likelihood of death is more probable compared to undamaged trees. On a newly established Douglas-fir plantation, Eissenstat et al. (1982) noted that 19% of trees were trampled with 60% of the damage caused by cattle. The resulting survival rate of those injured seedlings was 36%. Girdling of trees is caused by the shearing action of herbivore hooves or teeth, resulting in injury to the tree's cambium layer and phloem. Physical damage not only hinders tree productivity, but also increases susceptibility to environmental stresses and attack by pathogens and harmful insects. In a study simulating girdling, Lewis (1980a) found that slash pine mortality was negligible except when complete girdling of seedlings occurred. Height growth was slightly depressed due to severe girdling treatments, with an average of 0.5 m of height lost over 6 years. Simulated browsing of slash pine had insignificant effects on seedling survival except in the instance when all needles where removed, which is a very unlikely outcome of cattle browsing (Lewis 1980b). Severe browsing treatments caused slight height reductions in slash pine seedlings, with a total loss of less than 1 m growth over a 6 year period. Any damage inflicted upon slash pine seedlings had progressively less impact on tree growth and development as seedlings aged beyond 2 years. Tree mortality due to trampling or browsing can be curbed by deferring cattle grazing for 1 or 2 years following planting to allow seedlings to develop stronger and more resistant bark (Lewis 1980c). Factors that generally influence the outcomes of cattle grazing on conifer plantations are stocking rate, tree species, along with topography and habitat type (Lewis 1980a).

2.4. Effects of Slash Loading on Rangeland Use by Herbivores and Associated Reforestation

After a timber harvesting event, large quantities of slash and wood residue may be left on the soil surface, which may act as a physical and visual barrier to grazing. Accumulated logging slash presents a challenge for livestock in that it physically prevents cattle from accessing forage, or cattle may become injured when attempting to walk over it (Jones 1983; Morgan 1991). Over time, livestock may come to associate areas of high slash accumulation with high energy costs and low forage availability, causing livestock to continually avoid these areas (Parker et al. 1984; Forester et al. 2007a). Thicker and vertically elevated slash accumulation demands greater energy inputs from the herbivore attempting to navigate the area and may require jumping to clear very dense aggregations.

Limited literature exists on the interaction of slash accumulation and livestock grazing, with most studies focusing on the role of slash as refugia from wild ungulate browsing. Research conducted on ungulate browsing within Norway spruce (*Picea abies* (L.) H. Karst) forests of the Swiss Alps showed that areas containing coarse woody debris, roots and boulders were associated with greater seedling occurrence (Kupferschmid and Bugmann 2005). This association suggests that downed wood aided in the protection of seedlings against some species of deer. Unfortunately, logs were not a sufficient deterrent against browsing by chamois (*Rupicapra rupicapra* Linnaeus), as Norway spruce seedlings situated underneath coarse woody debris experienced the same intensity of browsing as exposed seedlings. However, an interaction between elevation and log accumulation also existed, as seedlings located within slash areas of subalpine forests were less likely to be browsed than those growing in montane habitats.

Similar conclusions were reached by Forester et al. (2007b) in their study of aspen regeneration associated with patches of coarse wood in Yellowstone National Park, USA. Fire events within the park created dense arrangements of dead fallen trees up to 2 m thick, which was thought to impede elk (*Cervus canadensis* Erxleben) movement, and consequently discourage elk from acquiring such high cost browse. Contrary to hypothesized outcomes, log density did not appear to alter the abundance of elk based on fecal pellet counts, nor was aspen density or height related to the concentration of downed wood. Once again, elevation likely played a role in preventing some level of browsing, as taller aspen were recorded at higher elevations. Overall, fire-induced coarse woody debris did not provide aspen with sufficient protection from ungulate browsing in the landscape of the Yellowstone plateau (Forester et al. 2007b). Swedish researchers Bergquist and Örlander (1998) found parallel results in that levels of Norway spruce browsing damage were not correlated with slash quantity. A study conducted by Fredericksen et al. (1998) also supports these findings in that neither slash cover nor height offered tree seedlings any protection from browsing by deer.

Several other studies have contradicted the above conclusions. Ripple and Larsen (2001) conducted a closely related study to that of Forester et al. (2007b). Although both studies were located in Yellowstone National Park, they yielded contrasting outcomes. Fallen fire-killed trees were found to be effective barriers to aspen browsing by elk (Ripple and Larson 2001). Aspen saplings positioned within jackstraw piles 0.8 m or greater in height were on average more than twice the height of unprotected saplings in the open. The height discrepancy noted between open and enclosed aspen saplings suggests browsing pressure limited growth of exposed trees. Fallen conifer boles with exposed root wads and dense branches provided the greatest deterrent to ungulate movement (Ripple and Larson 2001; de Chantal and Granström 2007). Slash thickness and area occupied by coarse wood determines whether ungulates will penetrate jackstraw piles or walk around them. As the likelihood of herbivore activity is also a function of animal mobility, less nimble animals may have markedly different responses than the wild ungulates discussed above. For example, cattle would be less inclined to travel through areas of slash accumulation as they are generally less agile compared to wild ungulates.

Burning of spruce and pine forests in Tyresta National Park, Sweden created conditions similar to that observed in Yellowstone National Park. Aggregations of wind-thrown trees killed by fire prevented ungulates from reaching aspen and willow seedlings guarded by slash (de Chantal and Granström 2007). Those saplings that were unable to escape attack by ungulates experienced, on average, three different episodes of browsing, and were less than half the height of unbrowsed saplings. When surrounded by woody obstructions, only 33% of the tallest saplings were browsed, and typically only once. Moreover, protected saplings showed greater basal diameter than their browsed counterparts. Both the vertical height of slash structures along with horizontal expanse (i.e. ground coverage) were positively associated with aspen height and diameter, as taller and wider slash piles were more inhibitive of ungulate travel and browsing.

Browsing by white-tailed deer (*Odocoileus virginianus* Zimmermann) is a significant problem within regenerating balsam fir [*Abies balsamea* (L.) Mill.] cutblocks on Anticosti Island, Quebec (Casabon and Pothier 2007). Woody debris reduced the level of browsing experienced by balsam fir seedlings 8 years after a logging event. Fir seedling abundance was related to the concentration of coarse woody debris; as the number of physical obstacles increased, so did the number of seedlings. The same findings were reported by Grisez (1960) when studying the effects of slash abundance on browsing frequency within a black cherry (*Prunus serotina* Ehrh.) - beech (*Fagus granifolia* Ehrh.) - maple (*Acer saccharinum* L.) stand supporting a healthy population of white-tailed deer. Large slash material provides better restraint and maintains structural integrity for longer periods of time compared to smaller material. It is anticipated that as slash breaks down over subsequent years, the extent to which it prevents browsing action will diminish (Casabon and Pothier 2007).

Besides coarse woody debris, other physical and visual barriers hindering forage availability and herbivore locomotion have been identified, such as boulders, rocky outcrops, and physically abrasive plants (de Chantal and Granström 2007). Dense stands of balsam fir have been deemed responsible for protecting eastern hemlock [*Tsuga canadensis* (L.) Carrière] saplings from browsing pressure by white-tailed deer (Borgmann et al. 1999). Those hemlock saplings situated within patches of balsam fir regeneration were 3 times as dense and twice as tall compared to exposed saplings. Unprotected hemlock seedlings were 4 times more likely to experience browsing by deer compared to those saplings secure within the refuge of balsam fir stands. Tip-up mounds of soil and exposed roots caused by a large-scale wind-throw event in Allegheny National Forest in north-western Pennsylvania were found to provide hemlock seedlings with refuge from browsing by white tailed deer (Long et al. 1998). High levels of brush also discourage cattle from seeking out forage, resulting in decreased forage utilization in dense brush except when large quantities of grass are present to increase the incentive for cattle entry (Owens et al. 1991).

From a forestry standpoint, logging practices that result in high slash accumulation may act to hinder tree reproduction. Great amounts of wood residue shade the ground and inhibit soil warming, which is required to promote aspen growth and water uptake by roots (David et al. 2001; Frey et al. 2003). Abundant residue also provides a physical barrier against emerging aspen sprouts. As the amount of slash on the soil surface increases, regeneration success, as measured by sucker density, has been shown to decrease (Bella 1986; MacIsaac et al. 2006). Effects of slash accumulation in limiting aspen regeneration is of long-term consequence, as noted by MacIsaac et al. (2006) who recorded regeneration gaps in areas where slash piles were created at the time of timber harvest 14 years prior. Research conducted by Corns and Maynard (1998) determined that chip residues greater than 10 cm in depth resulted in reduced plant cover and aspen sucker densities for at least 2 years. However, it was likely that no pronounced effects on aspen stocking and stand density would be noticed after an initial 5 year period, with the density of regenerating suckers being more than adequate for reforestation (Bella 1986; Corns and Maynard 1998). Log decking and storage over summer months was found to reduce aspen regeneration by 50%, while increasing root death by 35% (Renkema et al. 2009). Summer log deck construction was more detrimental to aspen root survival compared to fall log storage, as greater carbohydrate losses occur in warm soils due to high levels of respiration. To limit the negative impacts of log decks and associated slash accumulation, Renkema et al. (2009) recommended avoiding the storage of logs for long periods over summer. Bergquist et al. (1999) observed that slash removal had no significant effect on total plant biomass and that the retention of slash actually promoted tree, shrub, and herb growth along with increased species richness. Additionally, a certain level of slash cover has value in terms of nutrient contributions to soil quality, as long-term removal of woody debris would serve to hamper natural nutrient cycling (Olsson and Staaf 1995).

2.5. Livestock and Forestry Effects on Soil Quality

Both the livestock and forest industries play a role in the responsibility of soil compaction as it relates to diminished aspen regeneration success. Depending on soil type, texture, and moisture content, activity by heavy logging equipment and cattle can increase soil compaction and bulk densities, reduce water infiltration rates, and impede aeration and root penetration, all of which influence the quality and growth of aspen suckers (Wood et al. 1989; Bates et al. 1993; Corns and Maynard 1998; Stone and Elioff 1998; Newman et al. 1999; Krzic et al. 2001; Frey et al. 2003; Berger et al. 2004; Dockrill et al. 2004; MacIsaac et al. 2006; Sharrow 2007). The combined effect of grazing and harvesting disturbance has been found to increase bulk densities of the organic layer and the upper mineral soil layer by up to 64%, while also increasing penetration resistance throughout the soil profile (Krzic et al. 2001). Eight years of cattle grazing on an interior B.C. forest plantation was found to increase soil bulk density by 6%, and increase soil penetration resistance relative to ungrazed exclosures (Krzic et al. 1999; Newman et al. 1999). However, these increases were considered to be below the threshold required to limit root growth, commonly cited to be 2500 kPa (Krzic et al. 2004). Similarly, the bulk density, soil porosity, and water infiltration rate of silvopastures in Oregon were found to be 13% higher, 7% lower, and 38% lower, respectively, after 11 years of grazing (Sharrow 2007). On a positive note, soil bulk density, total porosity, air-filled pore space, and water infiltration appeared to recover quickly with 2 years of rest from grazing.

The depth to which heavy logging equipment can compact soil is greater than the impact of cattle hooves, with equipment affecting the top 50 cm of soil as opposed to the 5 to 10 cm of soil that cattle compact (Sharrow 2007). Lane (1998) found marked decreases in aspen sucker densities associated with heavily compacted skid roads and landings in west central Alberta following logging of aspen stands, with markedly lower effects on aspen due to livestock activities. The effect of soil compaction on aspen regeneration was quantified in a study by Stone and Elioff (1998), who found a 32% decline in sucker density per year, in addition to a decrease in sucker biomass, basal area and height compared to treatments lacking soil compaction. Furthermore, 5 years after soil compaction treatments, neither soil bulk density nor penetration resistance showed any trend towards recovering to levels measured prior to timber harvest. It has been estimated that the time needed for soil to recover from compaction is anywhere from 10 to 21 years depending on soil characteristics, with more time required for the recovery of deep soil compaction (Stone and Elioff 1998; Sharrow 2007).

With both cattle grazing and aspen harvesting occurring on the same land base, a reduction in the thickness of the organic matter layer of up to 50% has been found (Krzic et al. 2001). Aspen stands are typically harvested using a clear-cutting approach, which has the potential to disrupt nutrient cycling through the removal of large quantities of biomass, in turn altering decomposition and site productivity, and mixing organic residues into the mineral soil (Wood et al. 1989; Corns and Maynard 1998; Maynard and MacIsaac 1998; Stone and Elioff 1998; Krzic et al. 2001). Krzic et al. (2001) noted a 45% decrease in total soil carbon and 33% decrease in nitrogen within the organic matter of clear-cut soils. Similarly, grazing by cattle has been found to remove and redistribute organic matter and nutrients, and heavy grazing has been linked to nutrient loss through erosion (Krzic et al. 2001, 2003). It is therefore imperative to understand the individual and combined effects of both cattle grazing and timber harvesting on soil porosity and organic matter, as these two soil properties influence microbial energy reserves, water and air balance, water infiltration and runoff, root growth, reaction to load forces, and site productivity (Corns and Maynard 1998).

Soil scarification can be a silvicultural cause of regeneration failure. Aspen roots are shallow, with 70 and 90% of aspen roots occurring within 8 and 12 cm of the soil surface, respectively, making them vulnerable to logging activities that remove soil or cause ruts (Schier and Campbell 1978). Reduced sucker regeneration, along with reduced tree length and crown closure, have been associated with an increased level of rutting and soil scarification (Bates et al. 1993). Scarification and rutting can cause stress to aspen roots by reducing insulation, fluctuating temperatures, creating water-logged and anaerobic conditions, depleting carbohydrate reserves, and creating entry ports for pathogens (Bates et al. 1993; MacIsaac et al. 2006). Removal of litter layers on the soil surface causes increased soil warming, which will initially increase sucker density dramatically. However, extremely high sucker densities result in lower mean sucker height and biomass, with aspen productivity reduced by one-third and total biomass reduced by one-half for at least 5 years (Stone and Elioff 1998). In the interest of accommodating cattle grazing, it is important to limit soil disturbance in order to allow for the modest recovery of understory plant communities and thereby maintain acceptable levels of forage production (Berger et al. 2004).

Due to the impenetrability of frozen soil and protection from deep snow, winter harvesting of aspen is more favourable than summer harvesting in achieving fewer undesirable impacts on soil properties and sucker reproduction (Bella 1986; Bates 1993; Berger et al. 2004; MacIsaac et al. 2006). Harvesting timber during winter months decreases soil disturbance and nutrient loss, which provides better potential for aspen regeneration and increased forage production (Bates 1986; Krzic et al. 2004). Aspen roots are more susceptible to damage during early spring and summer logging, which may result in the depletion of carbohydrate reserves before they can be replenished via photosynthesis (Bates et al. 1993). Summer harvesting has also been deemed responsible for reduced aspen height growth and crown closure (Bates 1993). Other logging considerations that may reduce soil disturbance and impact on aspen regeneration include restricting the use of heavy equipment when soil water content is high, especially on soils high in clay particles that are most prone to compaction (MacIsaac et al. 2006).

Overall, most research concludes that light to moderate grazing and winter timber harvesting will not alter physical or chemical soil properties to the extent that aspen regeneration is compromised (Bates et al 1993; Krzic et al 2003). Similarly, long-term grazing with consecutive forage utilization levels of 50% will not lead to root limiting increases in soil compaction or a considerable decline in water infiltration (Wood et al. 1989; Krzic et al. 1999, 2001; Newman et al. 1999). In addition, light to moderate grazing acts to conserve both above and belowground biomass, which in turn helps to increase water infiltration and soil porosity. Notably, Krzic et al. (2001) found that soil chemical properties appear to degrade with the complete removal of logging activities and livestock grazing, as disturbance can lead to improved rooting media through observed increases in CEC, exchangeable Ca, and C and N values at soil depths up to 15 cm. Therefore, although logging activities and livestock grazing do play a role in increasing soil compaction to some extent, these changes may not necessarily correspond with reduced tree or forage growth in silvo-pastures (Sharrow 2007). Ultimately, it is important to remember that the extent of treatment impact is closely dependent on the magnitude and duration of disturbance (Stone and Elioff 1998).

2.6. GPS and GIS Applications to Assess Animal Behavioural Patterns

Herbivore foraging patterns are temporally and spatially dynamic in response to abiotic factors (slope, topography, climate, distance to water) and biotic factors (forage quality, quantity, and accessibility). Global positioning system (GPS) technology is becoming widely used as the primary method of tracking animal locations and behaviour in response to biotic and abiotic conditions (Schlecht et al. 2004). Collars or backpacks outfitted with GPS receivers are placed on animals and as they interact with the surrounding environmental conditions, waypoints are taken at a set time interval (ranging from minutes to hours) to record animal locations. In addition to tracking locations, GPS technology can be paired with various devices that record grazing behaviour such as head or body position and walking speed, in addition to temperature as a factor influencing behaviour (Schlecht et al. 2004; Ungar et al. 2005).

Comprehensive GPS datasets can then be downloaded with specialized computer software and superimposed onto digital maps using Geographic Information Systems (GIS) (Sheehy and Vavra 1996; Brock and Owensby 2000; Turner et al. 2000). GIS applications can be used to map physical and spatial attributes of a portion of land such as habitat types, slope, distance to water, silvicultural regimes, and areas of slash accumulation. By relating GPS locations of animals to various physical attributes across the landscape, theories can be devised to explain animal responses and behaviour to the surrounding environmental conditions (Ungar et al. 2005). Wade et al. (1998) used GIS to rate the grazing potential of Oregon rangelands, concluding that large tracts of land within mountainous regions are unsuitable for cattle grazing due to steep slopes and dense forest cover with limited forage and accessibility. Similarly, Ganskopp et al. (2000) employed GIS to analyze how cattle traverse rugged mountainous terrain and found that cattle establish least-effort trails.

GPS applications operate by obtaining coordinates of latitude, longitude and elevation from the triangulation of radio signals transmitted by a system of 24 geo-orbiting satellites (Turner et al. 2000; Schlecht et al. 2004). Successful contact with at least three satellites is required to obtain a two-dimensional (latitude and longitude) fix, while the acquisition of four satellites results in a more accurate three-dimensional fix (latitude, longitude, and elevation) (Rempel et al. 1995; D'Eon et al. 2002; Di Orio et al. 2003). GPS collars are programmed to allow a certain amount of time to record a positional fix. Chances of attaining a 3-D fix increase as more time is allowed to search for satellites, but the collar energy budget is sacrificed as a consequence (Rempel et al. 1995). Positional dilution of precision (PDOP) is an output value from GPS units that measures location accuracy based on satellite configuration geometry (Rempel et al. 1995; Moen et al. 1996; Moen et al. 1997). An increase in PDOP represents poor quality position estimates resulting from GPS receiver contact with as little as three closely spaced satellites.

When using any mobile GPS device, a certain level of error exists in the accuracy of coordinates taken. Sources of GPS error include satellite clock errors, satellite position errors, receiver errors, atmospheric errors, multi-path errors, and selective availability errors. The U.S. Department of Defense was responsible for intentionally creating unpredictable selective availability errors until the security practice was discontinued in May of 2000 (D’Eon et al. 2002). To correct the subsequent 100 m inaccuracy, waypoints taken by a mobile GPS receiver could be greatly improved after a differential correction procedure that uses base station data taken from a stationary GPS receiver that has a known location. Since the base station location remains constant, the magnitude of error related to mobile GPS coordinates can be quantified. For best results, base stations should be within 400 km of mobile GPS units (Rempel et al. 1995; Rempel and Rodgers 1997). Once GPS data has undergone differential correction, the range of error for waypoints is decreased to approximately 2 m (Shlecht et al. 2004). Since selective availability of satellite signals ended, GPS location error has decreased to as low as 14 m without the use of differential correction (Di Orio et al. 2003).

Physical landscape features, such as terrain, aspect, slope, and forest cover may prevent GPS receivers from successfully acquiring satellite contact, resulting in a failed location attempt. Consequently, raw GPS data can exhibit bias relating to false over or under-representation of habitat selection by animals (Dussault et al. 1999; D’Eon et al. 2002; Frair et al. 2004; Hebblewhite et al. 2007). A GPS collar study conducted in mountainous regions by D’Eon et al. (2002) showed that GPS fix rate decreased by 30% where the effects of forest cover and terrain interacted (i.e. in valley bottoms). Use of mature forests by herbivores may be under-estimated, as tree height, basal diameter, density, and canopy closure have all been found to negatively affect GPS fix success and location accuracy (i.e. 2-D fixes with low PDOP values) (Rempel et al. 1995; Moen et al. 1996; Moen et al. 1997; Dussault et al. 1999; D’Eon et al. 2002; Di Orio et al. 2003; Frair et al. 2004; Hebblewhite et al. 2007). GPS location bias can also be associated with season and time of day when collars are placed on free ranging animals. Dussault et al. (1999) observed poor location success during daylight periods from June to September when animals are seeking refuge from heat and insects. Other physical landscape features that have the potential to degrade location accuracy include highly reflective surfaces including rock faces and smooth bark (Rempel and Rodgers 1997). Prior to commencing GPS collar studies using free ranging animals, it is important to understand how specific animal behaviour and landscape features will affect data quality, so as to avoid incorrect conclusions (Moen et al. 1997).

Scale of research is also a significant variable to consider, as location error will have a greater impact on studies done at the patch or feeding site level (Swain et al. 2008). Brand of GPS collar (Advanced Telemetry Systems [ATS], Asanti, MN, USA; LOTEK Engineering, Newmarket, ON, Canada; Televilt, Lindesburg, Sweden) may influence fix rate, as noted by Hebblewhite et al. (2007). ATS collars produced the highest fix rates (97.4%), followed by LOTEK 12 channel (94.5%), LOTEK 8 channel (85.6%), and lastly, Televilt (82.3%). Despite potential errors in satellite acquisition, GPS collars remain the best method for recording animal locations among a variety of habitats, seasons, times of day, and weather conditions (Dussault et al. 1999).

A study conducted by Hincz (2007) implemented GPS and GIS technology to determine the effects of deciduous timber harvest on the grazing behaviour of cattle within the Campbell Creek Grazing Association in north-western Alberta. Ten cows were collared for the duration of the grazing season in order to record cattle locations within heterogeneous forested and non-forested landscapes. Plant community types within the Campbell Creek Grazing Association were identified and delineated using ArcView software (ESRI Inc., Redlands, CA, USA). GPS waypoints from collars were downloaded and superimposed onto detailed maps of plant community types. Results of the study indicate that tame pasture communities were preferred over all other habitat types when available. Secondary range, such as cut blocks and forests, received greater utilization only when tame pastures were depleted of forage resources, which typically occurred under greater stocking rates. Cattle were no more likely to avoid use of cut blocks compared to native forests, and higher utilization of regenerating cut blocks was closely associated with increased proximity to tame pastures. This study provided a supportive account of the successful application of GIS and GPS technology in the tracking of cattle habitat preference within forested areas.

2.7. Resource Selection Functions

Animal selection patterns can be statistically assessed through resource selection functions (RSFs), which quantify the tendency of animals to select or avoid specific habitats based on their observed behaviour. An RSF is based on measured characteristics of a resource unit, and is defined as any model that generates a value proportional to the probability of that unit being used (Manly et al. 2002; Boyce et al. 2002). By gaining insight into animal preference or avoidance related to different physical landscape and community level attributes, better decisions can be made to achieve collective resource management goals.

GPS collar data incorporated into a GIS are commonly used in the development of RSF models (Boyce and McDonald 1999). Care must be taken to account or correct for habitat induced bias within GPS data prior to drawing conclusions about habitat preference from an RSF (Frair et al. 2004; Swain et al. 2008). Each pixel within a satellite image and/or a digital elevation model (DEM) can be thought of as a resource unit that has the potential for being used by the animal in study. Predictor variables such as elevation, aspect, slope, canopy cover, forage quality and biomass, and distance to water and roads are associated with each resource unit to explain factors driving habitat selection (Johnson et al. 2000; Boyce et al. 2002). As the number of environmental variables increases, the ability to predict animal distribution becomes more difficult due to complex and simultaneous interactions (Senft et al. 1983; Gillen et al. 1984; Johnson et al. 2001).

The most common RSF designs are based on either the observation of used vs. unused resource units or used vs. available (Boyce et al. 2002). Logistic regression in the typical statistical approach used to develop habitat selection models and information criteria such as Akaike Information Criteria (AIC) or Bayesian Information Criteria (BIC) can be used to choose the best model from a list of possible candidates (Boyce et al. 2002; Keating and Cherry 2004; Johnson et al. 2006). The most suitable and robust model will accurately and consistently predict animal locations (Wiens et al. 2008). Beaver and Olson (1997) used GIS paired with logistic regression to assess cattle use of Montana rangelands. Experienced cattle 7 to 8 years of age used sheltered areas more than expected (compared to their availability within pastures) for protection from thermal exposure. Standard operative temperatures proved to be the key factor in predicting cattle locations. Johnson et al. (2000) employed similar methods to contrast elk and mule deer (*Odocoileus hemoinus* Rafinesque) habitat selection. Elk preferred gentle slopes, greater distances from roads, and westerly aspects, while mule deer favoured steeper slopes, short distances from roads and easterly aspects.

It is important to consider temporal and spatial scales when applying results from RSF models, which will ultimately depend on the objectives of the study. Habitat selection can occur at many scales of resolution: regional, landscape, plant community, and feeding station. Landscape and regional habitat selection occurs less frequently compared to plant community selection and will have an overall greater impact on the herbivore (Senft et al. 1987). As resource distributions, availability and quality, and foraging costs and gains vary among locations and time periods, RSF models are best applied only to the areas and seasons for which they were developed (Boyce and McDonald 1999; Johnson et al. 2001; Boyce et al. 2002; Boyce 2006). Additionally, social interactions, territoriality, and predation risks can influence patterns of landscape use by animals across space and time (Nielsen et al. 2005). RSFs are designed to accommodate predictor variables measured at multiple scales.

RSF models have a wide range of applications including natural resource management, conservation of rare or endangered species and habitats, and population or abundance estimation (Boyce and McDonald 1999; Boyce et al. 2002; Nielsen et al. 2005). A thorough understanding of the ecology of the animal under investigation is imperative for the development of accurate and applicable RSF models.

2.8. Habitat Preference Indices

Electivity is a commonly applied metric assessing food or habitat preference by animals based on the availability of a given food or habitat within an environment and measured use (Lechowicz 1982). Preference occurs when the habitat or food of interest is used in greater proportion than its availability; conversely, avoidance of a food or habitat results from lower than expected use in proportion to resource availability. Those habitats or foods chosen in direct proportion to availability indicate random selection.

Several electivity indices have been developed that stem from Ivlev's original electivity index (Ivlev 1961) in hopes of improving robustness. Ideally, an electivity index should provide 1) the same magnitude of change given deviation from random selection (regardless of direction), 2) a reliable range whereby a resource is chiefly preferred when it's consumed in its entirety, or completely avoided when the resource has not been selected at all, 3) consistency and linearity in response to any change in resource availability or use, and 4) compatibility with statistical analyses (Lechowicz 1982). However, most electivity indices do not have all of these desired characteristics. For example, Ivlev's index does not allow for maximum preference for a resource that is solely selected for, in a case where it comprises moderate levels of availability. Another flaw of Ivlev's index is a non-linear response to changes in resource use or abundance; the index changes drastically for resource use or availability levels of 30% or less (Lechowicz 1982). This creates electivity errors primarily for resource units that are limited in availability or where resource use is very minimal, thereby necessitating a large sample size to improve accuracy.

Other indices include Jacob's Modified Electivity (Jacobs 1974), Strauss' Linear Index (Strauss 1979), Chesson's α (Chesson 1978), and Vanderploeg and Scavia's Relativized Electivity (Vanderploeg and Scavia 1979), each of which come with their own imperfections. Jacob's and Strauss' indices are subject to the same weakness as Ivlev's; the full range of index values (-1 to +1) cannot be attained under all ranges of resource use and abundance (Lechowicz 1982). Chesson's α together with Vanderploeg and

Scavia's index are also non-linear and asymmetrical in response to changes in resource use or availability. When applying and interpreting electivity analyses to habitat or food preference studies, it is important to be aware and note index deficiencies. Despite the aforementioned flaws, electivity indices remain useful in quantifying a general ranking of resource unit use.

2.9. Literature Cited

Allen, B.H. and J.W. Bartolome. 1989. Cattle grazing effects on understory cover and tree growth in mixed conifer clearcuts. Northwest Science 63(5): 214-220.

Asamoah, S.A., E.W. Bork, B.D. Irving, M.A. Price, and R.J. Hudson. 2003. Cattle herbage utilization patterns under high-density rotational grazing in the aspen parkland. Canadian Journal of Animal Science 83: 541-550.

Bailey, A.W., B.D. Irving, and R.J. Fitzgerald. 1990. Regeneration of woody species following burning and grazing in aspen parkland. Journal of Range Management 43(3): 212-215.

Bailey, D.W., L.R. Rittenhouse, R.H. Hart, D.M. Swift, and R.W. Richards. 1989. Association of relative food availabilities and locations by cattle. Journal of Range Management 42(6): 480-482.

Bailey, D.W., J.E. Gross, E.A. Laca, L.R. Rittenhouse, M.B. Coughenour, D.M. Swift, and P.L Sims. 1996. Mechanisms that result in large herbivore grazing distribution patterns. Journal of Range Management 49 (5): 386-400.

Bates, P.C., C.R. Blinn, and A.A. Alm. 1993. Harvesting impacts on quaking aspen regeneration in northern Minnesota. Canadian Journal of Forest Resources 23: 2403-2412.

Beaver, J.M. and B.E. Olson. 1997. Winter range use by cattle of different ages in southwestern Montana. Applied Animal Behaviour Science 51:1-13.

Beck, J.L. and J.M. Peek. 2005. Diet composition, forage selection, and potential for forage competition among elk, deer, and livestock on aspen-sagebrush summer range. Rangeland Ecology and Management 58(2): 135-147.

Bella, I.E. 1986. Logging practices and subsequent development of aspen stands in east-central Saskatchewan. The Forestry Chronicle 62: 81-83.

Berger, A.L, K.J. Puettmann, and G.E. Host. 2004. Harvesting impacts on soil and understory vegetation: the influence of season of harvest and within-site disturbance patterns on clear-cut aspen stands in Minnesota. Canadian Journal of Forest Resources 34: 2159-2168.

Bergquist, J. and G. Örlander. 1998. Browsing damage by roe deer on Norway spruce seedlings planted on clearcuts of different ages 1. Effect of slash removal, vegetation development, and roe deer density. Forest Ecology and Managment 105: 283-293.

Bergquist, J., G. Örlander, and U. Nilsson. 1999. Deer browsing and slash removal affect field vegetation on south Swedish clearcuts. Forest Ecology and Management 115: 171-182.

Borgmann, K.L., D.M. Waller, and T.P. Rooney. 1999. Does balsam fir (Abies balsamea) facilitate the recruitment of eastern hemlock (Tsuga Canadensis)? The American Midland Naturalist 144: 391-397.

Borman, M.M. 2005. Forest stand dynamics and livestock grazing in historical context. Conservation Biology 19(5): 1658-1662.

Boyce, M.S. 2006. Scale for resource selection functions. Diversity and Distributions 12: 269-276.

Boyce, M.S. and L.L. McDonald. 1999. Relating populations to habitats using resource selection functions. Tree 14(7): 268-272.

Boyce, M.S., P.R. Vernier, S.E. Nielsen, and F.K.A. Schmiegelow. 2002. Evaluating resource selection functions. Ecological Modelling 157: 281-300.

Brock, B.L. and C.E. Owensby. 2000. Predictive models for grazing distribution: a GIS approach. Journal of Range Management 53(1): 39-46.

Casabon, C. and D. Pothier. 2007. Browsing of tree regeneration by white-tailed deer in large clearcuts on Anticosti Island, Quebec. Forest Ecology and Management 253: 112-119.

Chapman, D.F., A.J. Parsons, G.P. Cosgrove, D.J. Barker, D.M. Marotti, K.J. Venning, S.M. Rutter, J. Hill, and A.N. Thompson. 2007. Impacts of spatial patterns in pasture on animal grazing behaviour, intake, and performance. Crop Science 47: 399-415.

Chesson, J. 1978. Measuring preference in selective predation. Ecology 59: 211-215.

Clary, W.P., P.F. Ffolliott, and F.R. Larson. 1978. Factors affecting forage consumption by cattle in Arizona ponderosa pine forests. Journal of Range Management 31(1): 9-10.

Corns, I.G.W. and D.G. Maynard. 1998. Effects of soil compaction and chipped aspen residue on aspen regeneration and soil nutrients. Canadian Journal of Soil Science 78: 85-92.

Cutter, B.E., K. Hunt, and J.D. Haywood. 1999. Tree/wood quality in slash pine following longterm cattle grazing. Agroforestry Systems 44: 305-312.

David, A.J., J.C. Zasada, D.W. Gilmore, and S.M. Landhäusser. 2001. Current trends in the management of aspen and mixed aspen forests for sustainable production. The Forestry Chronicle 77(3): 525-532.

De Bruijn, S.L. and E.W. Bork. 2006. Biological control of Canada thistle in temperate pastures using high density rotational cattle grazing. Biological Control 36: 305-315.

de Chantal, M. and A. Granström. 2007. Aggregations of dead wood after wildfire act as browsing refugia for seedlings of *Populus tremula* and *Salix caprea*. Forest Ecology and Management 250: 3-8.

D'Eon, R.G., R. Serrouya, G. Smith, and C.O. Kochanny. 2002. GPS radiotelemetry error and bias in mountainous terrain. Wildlife Society Bulletin 30(2): 430-439.

Di Orio, A.P., R. Callas, and R.J. Schaefer. 2003. Performance of two GPS telemetry collars under different habitat conditions. Wildlife Society Bulletin 31(2): 372-379.

Dockrill, C.W.M., P.V. Blenis, A.W. Bailey, and J.R. King. 2004. Effect of summer cattle grazing on aspen stem injury, mortality and growth. The Forestry Chronicle 80(2): 257-261.

Dockrill, C.W.M., A.W. Bailey, P.V. Blenis, and J.R. King. 2006. Seasonal variation in resistance of aspen stems to shearing force. Rangeland Ecology and Management 59(2): 212-215.

Dussault, C., R. Courtois, J. Ouellet, and J. Huot. 1999. Evaluation of GPS telemetry collar performance for habitat studies in the boreal forest. Wildlife Society Bulletin 27(4): 965-972.

Eissenstat, D.M., J.E. Mitchell, and W.W. Pope. 1982. Trampling damage by cattle on northern Idaho forest plantations. Journal of Range Management 35(6): 715-716.

Fitzgerald, R.D. and A.W. Bailey. 1984. Control of aspen regrowth by grazing with cattle. Journal of Range Management 37(2): 156-158.

Fitzgerald, R.D., R.J. Hudson, and A.W. Bailey. 1986. Grazing preferences of cattle in regenerating aspen forest. Journal of Range Management 39(1): 13-18.

Forester, J.D., A.R. Ives, M.G. Turner, D.P. Anderson, D. Fortin, H.L. Beyer, D.W. Smith, and M.S. Boyce. 2007a. State-space models link elk movement patterns to landscape characteristics in Yellowstone National Park. Ecological Monographs 77(2): 285-299.

Forester, J.D., D.P. Anderson, and M.G. Turner. 2007b. Do high-density patches of coarse wood and regenerating saplings create browsing refugia for aspen (*Populus tremuloides* Michx.) in Yellowstone National Park (USA)? Forest Ecology and Management 253:211-219.

Fredericksen, T.S., B. Ross, W. Hoffman, M. Lester, J. Beyea, M.L. Morrison, and B.N. Johnson. 1998. Adequacy of natural hardwood regeneration on forestlands in northeastern Pennsylvania. Northern Journal of Applied Forestry 15(3): 130-134.

Frey, B.R., V.J. Lieffers, S.M. Landhäusser, P.G. Comeau, and K.J. Greenway. 2003. An analysis of sucker regeneration of trembling aspen. Canadian Journal of Forest Resources 33: 1169-1179.

Frair, J.L., S.E. Nielsen, E.H. Merrill, S.R. Lele, M.S. Boyce, R.H.M. Munro, G.B. Stenhouse, and H.L. Beyer. 2004. Removing GPS collar bias in habitat selection studies. Journal of Applied Ecology 41: 201-212.

Ganskopp, D., R. Cruz, and D.E. Johnson. 2000. Least-effort pathways?: a GIS analysis of livestock trails in rugged terrain. Applied Animal Behaviour Science 68: 179-190.

Gillen, R.L., W.C. Krueger, and R.F. Miller. 1984. Cattle distribution on mountain rangeland in northeastern Oregon. Journal of Range Management 37(6): 549-553.

Grisez. T.J. 1960. Slash helps protect seedlings from deer browsing. Journal of Forestry 58: 385-387.

Hart, R.H., K.W. Hepworth, M.A. Smith, and J.W. Waggoner, Jr. 1991. Cattle grazing behavior on a foothill elk winter range in southeastern Wyoming. Journal of Range Mangement 44(3): 262-266.

Hebblewhite, M., M. Percy, and E.H. Merrill. 2007. Are all global positioning system collars created equal? Correcting habitat-induced bias using three brands in the central Canadian Rockies. Journal of Wildlife Management 71(6): 2026-2033.

Hedrick, D.W., B.R. Eller, J.A.B. McArthur, and R.D. Pettit. 1969. Steer grazing on mixed coniferous forest ranges in Northeastern Oregon. Journal of Range Management 22(5): 322-325.

Hincz, C. 2007. Campbell Creek timber-grazing demonstration: cattle use of regenerating deciduous cutblocks. Rangeland Management Branch, Lands Division, Alberta Sustainable Resource Development, Grande Prairie, Alberta, Canada.

Holechek, J.L., M. Vavra, J. Skovlin, and W.C. Krueger. 1982. Cattle diets in the blue mountains of Oregon II. Forests. Journal of Range Management 35(2): 239-242.

Huffman, R.D., M.A. Fajvan, and P.B. Wood. 1999. Effects of residual overstory on aspen development in Minnesota. Canadian Journal of Forest Resources 29: 284-289.

Irving, B.D. 2001. The impacts of horse grazing on conifer regeneration in west-central Alberta. Ph.D. Dissertation. University of Alberta, Edmonton, Alberta, Canada.

Ivlev, V.S. 1961. Experimental ecology of the feeding of fishes. Yale University Press, New Haven, Connecticut, USA.

Jacobs, J. 1974. Quantitative measurement of food selection. Oecologia 14: 413-417.

Johnson, B.K., J.W. Kern, M.J. Wisdom, S.L. Findholt, and J.G. Kie. 2000. Resource selection and spatial separation of mule deer and elk during spring. Journal of Wildlife Management 64(3): 685-697.

Johnson, C.J., K.L. Parker, and D.C. Heard. 2001. Foraging across a variable landscape: behavioral decisions made by woodland caribou at multiple spatial scales. Oecologia 127: 590-602.

Johnson, C.J., S.E. Nielsen, E.H. Merrill, T.L. McDonald, and M.S. Boyce. 2006. Resource selection functions based on use-availability data: theoretical motivation and evaluation methods. Journal of Wildlife Mangement 70(2): 347-357.

Jones, K.L. 1983. Current knowledge of the effects of cattle grazing on aspen in the Alberta parkland. Rangelands 5(2): 59-60.

Keating, K.A. and S. Cherry. 2004. Use and interpretation of logistic regression in habitat-selection studies. Journal of Wildlife Management 68(4): 774-789.

Kie, J.G. and B.B. Boroski. 1996. Cattle distribution, habitats, and diets in the Sierra Nevada of California. Journal of Range Management 49(6): 482-488.

Krzic, M., R.F. Newman, and K. Broersma. 2003. Plant species diversity and soil quality in harvested and grazed boreal aspen stands of northeastern British Columbia. Forest Ecology and Management 182: 315-325.

Krzic, M., R.F. Newman, K. Broersma, and A.A. Bomke. 1999. Soil compaction of forest plantations in interior British Columbia. Journal of Range Management 52: 671-677.

Krzic, M., H. Page, R.F. Newman, and K. Broersma. 2004. Aspen regeneration, forage production, and soil compaction on harvested and grazed boreal aspen stands. BC Journal of Ecosystems and Management 5(2): 30-38.

Krzic, M., K. Broersma, R.F. Newman, T.M. Ballard, and A.A. Bomke. 2001. Soil quality of harvested and grazed forest cutblocks in southern British Columbia. Journal of Soil and Water Conservation 56(3): 192-197.

Kupferschmid, A.D. and H. Bugmann. 2005. Effect of microsites, logs and ungulate browsing on *Picea abies* regeneration in a mountain forest. Forest Ecology and Management 205: 251-265.

Lane, C.T.P. 1998. Effects of full-tree skidding and livestock grazing on aspen regeneration. M.Sc. Thesis, University of Alberta, Edmonton, Alberta, Canada.

Launchbaugh, K.L and L.D. Howery. 2005. Understanding landscape use patterns of livestock as a consequence of foraging behaviour. Rangeland Ecology and Management 58(2): 99-108.

Lechowicz, M.J. 1982. The sampling characteristics of electivity indices. Oecologia 52: 22-30.

Lewis, C.E. 1980a. Simulated cattle injury to planted slash pine: girdling. Journal of Range Management 33(5): 337-339.

Lewis, C.E. 1980b. Simulated cattle injury to planted slash pine: defoliation. Journal of Range Management 33(5): 345-348.

Lewis, C.E. 1980c. Simulated cattle injury to planted slash pine: combinations of defoliation, browsing, and trampling. Journal of Range Management 33(5): 340-345.

Long, Z.T., W.P. Carson, and C.J. Peterson. 1998. Can disturbance create refugia from herbivores: an example with hemlock regeneration on treefall mounds. Journal of the Torrey Botanical Society 125(2): 165-168.

MacIsaac, D.A., P.G. Comeau, and S.E. Macdonald. 2006. Dynamics of regeneration gaps following harvest of aspen stands. Canadian Journal of Forest Resources 36: 1818-1833.

Manly, B.F.J., L.L. McDonald, D.L. Thomas, T.L. McDonald, and W.P. Erickson. 2002. Resource selection by animals: statistical analysis and design for field studies. Second Edition. Kluwer, Boston, Massachusetts, USA.

Maynard, D.G. and D.A. MacIsaac. 1998. Soil nutrient and vegetation response to patch clear cutting of an aspen forest near Meadow Lake, Saskatchewan. Canadian Journal of Soil Science 78: 59-68.

McLean, A. 1972. Beef production on lodgepole pine-pinegrass range in the caribou region of British Columbia. Journal of Range Management 25(1): 10-11.

McLean, A. and M.B. Clark. 1980. Grass, trees, and cattle on clearcut-logged areas. Journal of Range Management 33(3): 213-217.

Moen, R., J. Pastor, and Y. Cohen. 1997. Accuracy of GPS telemetry collar locations with differential correction. Journal of Wildlife Management 61(2): 530-539.

Moen, R., J. Pastor, Y. Cohen, and C.C. Schwartz. 1996. Effects of moose movement and habitat use on GPS collar performance. Journal of Wildlife Management 60(3): 659-668.

Morgan, R.K. 1991. The role of protective understorey in the regeneration system of a heavily browsed woodland. Vegetation 92: 119-132.

Mueggler, W.F. 1965. Cattle distribution on steep slopes. Journal of Range Mangement 18(5): 255-257.

Newman, R.F., K. Broersma, M. Krzic, and A. Bomke. 1999. Soil compaction on forest plantations following cattle use. Extention Note 34, British Columbia Ministry of Forests Research Program.

Newman, R.F., B.M. Wikeem, M.D. Pitt, D. Quinton, P. Youwe, and G.W. Powell. 1994. Grass/tree/cattle research on forest range in British Columbia, Canada. Managing Canadian Rangelands for Sustainability & Profitability: Proceedings of the First Interprovincial Range Conference in Western Canada. Pgs. 175-181.

Nielsen, S.E., C.J. Johnson, D.C. Heard, and M.S. Boyce. 2005. Can models of presence-absence be used to scale abundance? Two case studies considering extremes in life history. Ecography 28: 1-12.

Olsson, B.A. and H. Staaf. 1995. Influence of harvesting intensity of logging residues on ground vegetation in coniferous forests. Journal of Applied Ecology 32: 640-654.

Owens, M.K., K.L. Launchbaugh, and J.W. Holloway. 1991. Pasture characteristics affecting spatial distribution of utilization by cattle in mixed brush communities. Journal of Range Management 44(2): 118-123.

Parker, K.L., C.T. Robbins, and T.A. Hanley. 1984. Energy expenditures for locomotion by mule deer and elk. Journal of Wildlife Management 48(2): 474-488.

Pinchak, W.E., M.A. Smith, R.H. Hart, and J.W. Waggoner Jr. 1991. Beef cattle distribution patterns on foothill range. Journal of Range Management 44(3): 267-275.

Provenza, F.D. 1995. Postingestive feedback as an elementary determinant of food preference and intake in ruminants. Journal of Range Management 48: 2-17.

Remple, R.S. and A.R. Rodgers. 1997. Effects of differential correction on accuracy of a GPS animal location system. Journal of Wildlife Management 61(2): 525-530.

Rempel, R.S., A.R. Rodgers, and K.F. Abraham. 1995. Performance of a GPS animal location system under boreal forest canopy. Journal of Wildlife Management 59(3):543-551.

Renkema, K.N., V.J. Lieffers, and S.M. Landhäusser. 2009. Aspen regeneration on log decking areas as influenced by season and duration of log storage. New Forests 38(3): 323-335.

Ripple, W.J. and E.J. Larsen. 2001. The role of postfire coarse woody debris in aspen regeneration. Western Journal of Applied Forestry 16(2): 61-64.

Roath, L.R. and W.C. Krueger. 1982. Cattle grazing and behavior on a forested range. Journal of Range Management 35(3): 332-338.

Schier, G.A. and R.B. Campbell. 1978. Aspen sucker regeneration following burning and clearcutting on two sites in the Rocky Mountains. Forest Science 24: 303-308.

Schlecht, E., C. Hülsebusch, F. Mahler, and K. Becker. 2004. The use of differentially corrected global positioning system to monitor activities of cattle at pasture. Applied Animal Behaviour Science 85: 185-202.

Senft, R.L. 1989. Hierarchical foraging models: effects of stocking and landscape composition on simulated resource use by cattle. Ecological Modelling 46: 283-303.

Senft, R.L., L.R. Rittenhouse, and R.G. Woodmansee. 1983. The use of regression models to predict spatial patterns of cattle behavior. Journal of Range Management 36(5): 553-557.

Senft, R.L., M.B. Coughenour, D.W. Bailey, L.R. Rittenhouse, O.E. Sala, and D.M. Swift. 1987. Large herbivore foraging and ecological hierarchies. BioScience 37(11): 789-799.

Sharrow, S.H. 2007. Soil compaction by grazing livestock in silvopastures as evidenced by changes in soil physical properties. Agroforesty Systems 71: 215-223.

Sheehy, D.P. and M. Vavra. 1996. Ungulate foraging areas on seasonal rangeland in northeastern Oregon. Journal of Range Management 49(1): 16-23.

Stone, D.M. and J.D. Elioff. 1998. Soil properties and aspen development five years after compaction and forest floor removal. Canadian Journal of Soil Science 78: 51-58.

Strauss, R.E. 1979. Reliability estimates for Ivlev's electivity index, the forage ratio, and a proposed linear index of food selection. Transactions of the American Fisheries Society 108: 344-352.

Swain, D.L., T. Wark, and G.J. Bishop-Hurley. 2008. Using high fix rate GPS data to determine the relationship between fix rate, prediction errors and patch selection. Ecological Modelling 212: 273-279.

Turner, L.W., M.C. Udal, B.T. Larson, and S.A. Shearer. 2000. Monitoring cattle behavior and pasture use with GPS and GIS. Canadian Journal of Animal Science 80: 405-413.

Ungar, E.D., Z. Henkin, M. Gutman, A. Dolev, A. Genizi, and D. Ganskopp. 2005. Inference of animal activity from GPS collar data on free-ranging cattle. Rangeland Ecology and Management 58(3): 256-266.

Vanderploeg, H.A. and D. Scavia. 1979. Calculation and use of selectivity coefficients of feeding: zooplankton grazing. Ecological Modelling 7: 135-149.

Wade, T.G., B.W. Schultz, J.D. Wickham, and D.F. Bradford. 1998. Modeling the potential spatial distribution of beef cattle using a Geographic Information System. Journal of Arid Environments 38: 325-334.

Wallis de Vries, M.F. and P. Schippers. 1994. Foraging in a landscape mosaic: selection for energy and minerals in free-ranging cattle. Oecologia 100: 107-117.

Wiens, T.S., B.C. Dale, M.S. Boyce, and G.P. Kershaw. 2008. Three way k-fold cross-validation of resource selection functions. Ecological Modelling 212: 244-255.

Wood, J.C., W.H. Blackburn, H.A. Pearson, and T.K. Hunter. 1989. Infiltration and runoff water quality response to silvicultural and grazing treatments on a longleaf pine forest. Journal of Range Management 42(5): 378-381.

Zimmerman, G.T. and L.F. Neuenschwander. 1984. Livestock grazing influences on community structure, fire intensity, and fire frequency within the Douglas-fir/ninebark habitat type. Journal of Range Management 37(2): 104-110.

Zuo, H. and M.S. Miller-Goodman. 2003. An index for description of landscape use by cattle. Journal of Range Management 56(2): 146-151.

3. Cattle Habitat Selection and Foraging Behaviour Following Deciduous Timber Harvest

3.1. Introduction

Public lands in Western Canada are important for supporting multiple uses such as cattle grazing and timber harvest. Balancing multiple uses provides the basis for public land management and is fundamental to maintaining the ecological integrity of deciduous forests. However, a lack of cooperation between forest and cattle industries pursuing independent resource goals on a common land base can create conflict, thereby complicating the process of integrated resource management.

In the case of trembling aspen (*Populus tremuloides* Michx.) forests, cattle grazing of regenerating cut blocks has been associated with increased mortality and reduced growth of aspen saplings (Bailey et al. 1990; Dockrill et al. 2004) resulting from browsing, trampling, soil compaction, and hoof shear damage to shallow aspen roots. Timber companies operating in Alberta are ultimately responsible for meeting minimum regeneration standards within cut blocks. Provincial regeneration assessments require that aspen saplings be undamaged in the determination of adequate tree stocking densities (ASRD 2008). Any factor causing substandard regeneration increases reforestation costs, reduces profit, and jeopardizes future timber harvesting opportunities.

Logging of aspen creates a mosaic of habitats based on harvest regime and often includes areas of clear cut, partial harvest, uncut forest, and slash accumulated skid roads whereon fallen trees are removed during logging. Following logging, aspen clear cuts naturally re-establish high density stands with up to 100,000 stems/ha (Bella 1986), and initially experience a pronounced increase in herb growth following understory release from shading and competition (Wollis 1991). Where livestock grazing coincides with commercial aspen harvest, the timing, duration and intensity of livestock grazing within regenerating stands can affect cattle grazing preferences (Fitzgerald and Bailey 1984; Fitzgerald et al. 1986) and associated damage to regenerating aspen saplings.

High density ‘mob’ grazing systems have been employed in the Aspen Parkland to force cattle to move from open grasslands into adjacent aspen forests and defoliate regenerating aspen, thereby providing an effective form of biological control (Fitzgerald and Bailey 1984; Alexander 1995). Within boreal regions however, the ensuing increase in herbaceous forage following timber harvest may make these logged habitats particularly vulnerable to regeneration damage and mortality when exposed to cattle grazing.

Cattle occupancy of cut blocks during spring and early summer creates the greatest potential for aspen browsing due to limited understory herbage availability and the favourable quality (i.e. high crude protein) of young, succulent aspen saplings (Dockrill et al. 2004). June grazing led to 50% greater aspen stem mortality compared to that in ungrazed young aspen stands (Dockrill et al. 2004). Conversely, deferring cattle grazing until late summer, or for 1 or more years following logging, helped maintain aspen by allowing for advanced sapling phenologic development, which in turn, promoted stem strength and resistance to shearing during animal prehension (Dockrill et al. 2004, 2006).

In order to mitigate cattle induced regeneration damage and minimize conflict between forest and ranching industries, a greater understanding is required of how cattle utilize harvested areas and the factors influencing their site selection. Aside from accessibility, the primary factors influencing habitat preference by cattle are forage quantity and quality, as cattle strive to optimize nutrient intake (Senft et al. 1987) at minimal energetic cost. Roath and Krueger (1982) found that vegetation type and forage quality were related to cattle distribution and use across forested ranges. On a ponderosa pine (*Pinus ponderosa* Laws.) rangeland in Arizona, forage consumption by cattle was positively influenced by increasing grass biomass and decreasing forest density (Clary et al. 1978).

Cattle distribution is further affected by habitat suitability based on ease of accessibility, temperature, shelter from the elements, and protection from pests (Owens et al. 1991; Beaver and Olson 1997; Launchbaugh and Howery 2005). As a result, despite abundant forage following overstory removal, cattle may not be sufficiently motivated to utilize clear cuts or partial cut habitats where forage remains visually obstructed and/or inaccessible due to densely regenerating aspen saplings. Increased brush abundance influenced cattle use of mixed brush landscapes in Texas (Owens et al. 1991).

Following timber harvest, large quantities of slash and wood residue may be left on and above the soil surface, and may act as a physical or visual barrier to grazing. Accumulated logging slash presents a challenge for livestock in that it physically prevents cattle from accessing forage, or cattle may become injured when attempting to walk over it (Jones 1983; Morgan 1991). Over time livestock may associate areas of high slash accumulation with high energy costs and low forage availability, leading them to continually avoid these areas (Parker et al. 1984; Forester et al. 2007a). The obstruction provided by accumulated slash ultimately impacts cattle stocking rate and production efficiency for ranchers.

Intensity and duration of grazing affects range use by cattle. Forage depletion under high stocking rates can force cattle to access less favourable grazing sites that are unproductive, nutrient poor, or less accessible (Senft et al. 1983; Hart et al. 1991). Longer periods of cattle grazing (i.e. 2 months vs 1 month) within cut blocks have resulted in greater damage to aspen saplings (Dockrill et al. 2004), and therefore both stocking rates along with livestock distribution need to be adjusted accordingly to limit the detrimental effects of cattle grazing on tree regeneration (Krzic et al. 2003, 2004).

The goal of this study was to assess cattle foraging behaviour patterns in deciduous forest of west central Alberta, and quantify the associated mechanisms influencing cattle preferences for the selection of various habitats, including clear cuts, partially harvested areas, uncut forest, and skid roads. Specific research objectives included to:

1. Determine cattle preferences for various habitats (i.e. harvest regimes),
2. Identify mechanisms regulating cattle forage utilization, including forage quantity, quality, accessibility as influenced by slash accumulation, and physical site factors,

3. Establish how cattle stocking rates alter foraging behaviour and habitat selection by cattle.

3.2. Materials and Methods

3.2.1. Study Area

This study was conducted within two commercial cut blocks (Fig. A.1, see Appendix A) situated within a pair of cattle grazing leases situated approximately 5 km northwest of Lodgepole in west central Alberta from 2008 through 2009. The area is situated along the easternmost extent of the Lower Foothills Natural Subregion. At lower elevations forests are dominated by deciduous tree species including aspen, balsam poplar (*Populus balsamifera* L.) and paper birch (*Betula papyrifera* Marsh.), with secondary succession to white spruce [*Picea glauca* (Moench)]. Soils in the area include Dark Gray Chernozems and Gray to Dark Gray Luvisols. Other ecosite characteristics include predominantly east to southern aspects, slopes from 0 to 16%, soils with medium to rich nutrient status, and mesic to subhygric moisture regimes, with drainage varying from well to imperfect on upper to mid slope positions (Lawrence et al. 2005).

During 2008 and 2009, a temporary weather station erected at the study site recorded a maximum temperature of 33.3^{o}C and a minimum temperature of -39.9^{o}C, while the average annual temperature was 3.8^{o}C. Average monthly temperatures closely resembled the 30 year norm (1971-2000) from Environment Canada's nearby weather station located at Shining Bank, 94 km northwest from the study site (Fig. B.1, see Appendix B). As precipitation data were not available for the study period from Shining Bank, data for 2008-09 were obtained from Environment Canada's Violet Grove weather station, 23 km northeast from the study area: total precipitation during 2008 was 375 mm (Fig. B.2), 70% of normal for the region (Environment Canada Shining Bank Normal, 1971 – 2000). Similarly, during 2009, total precipitation was 381 mm, 72% of normal (Environment Canada Shining Bank Normal, 1971-2000). Thirty year weather normals were not available for the Violet Grove station.

The specific study site for this research included deciduous cut blocks 1086 and 1021 (Fig A.1), located within provincial grazing leases 920022 (legal location: SE 8 – Twnshp 48 – Rge 10 – West 5, 53^{o} 7’43.70$^{''}$N 115^{o} 22’18.65$^{''}$W) and 39275 (NE 4 - Twnshp 48 - Rge 10 – West 5, 53^{o} 7’15.46$^{''}$N 115^{o} 22’55.03$^{''}$W), respectively. Cut blocks were established in January 2006 using standard selective harvesting procedures by Weyerhaeuser Ltd., and led to a mixture of various habitat types including clear cut (47% of area), partial harvest (24%), slash accumulated skid road (8%), and uncut forest (19%). Cut blocks also contained brush piles (1%), which were burned during the winter of 2007 and remained as ash pits during grazing trials.

3.2.2. Cattle Grazing Trials

In 2006, two experimental paddocks were constructed within each cut block for a total of four paddocks, each 2.5 to 3 ha in size (Fig. A.2). Paddocks 1 and 3 were located within cut block 1021, while paddocks 4 and 5 were established within cut block 1086. Paddocks were laid out to include representative areas of all habitat types (Fig. A.3). Grazing trials within paddocks were initiated in early July of 2008 and 2009 using two herds of four mature red angus cross cows obtained from the local grazing lease holder.

In 2008, we tested the effect of two stocking rates: low (0.27 to 0.33 AUM/ha) and high (0.55-0.69 AUM/ha) (Table 3.1). The low stocking rate was in the range of that recommended by Alberta Sustainable Resource Development for mesic and moderately nutrient rich aspen communities within the Lower Foothills Natural Subregion (Lawrence et al. 2005), while the high stocking rate was twice that of the former. In 2009, only a high stocking rate (0.55-0.69 AUM/ha) was implemented due to limited expression of foraging responses resulting from the low stocking rate in year 1. Final stocking rates varied slightly within the low and high treatments due to variability within individual cattle weights and paddock areas. Herd 1 was rotated between paddocks 1 and 3 with the first rotation representing a low stocking rate, while the second rotation throughout the paddocks represented a high accumulative stocking rate (i.e. paddocks were grazed twice to simulate a high stocking rate). Herd 2 followed the same grazing pattern while rotating through pastures 4 and 5. Each grazing period was approximately 5 days long. As a result, the low stocking rate was achieved by grazing four cows for 5 days, while the high stocking rate was attained by grazing four cows for 10 days.

3.2.3. Cattle Spatial Assessment

Lotek Wireless Inc. (Newmarket, ON) 3300LR GPS collars were placed on all cows to track animal locations and study spatial patterns of habitat selection. Collars were correctly fitted to each cow by Alberta Sustainable Resource Development (ASRD) staff to ensure safety and comfort. Prior to releasing cattle into the paddocks and commencing the grazing trial, cattle were given a period of time to become accustomed to the collars, which weighed approximately 0.95 kg. Collars remained on the animals for the duration of the grazing trial in each year: 20 days in 2008 and 10 days in 2009. Collars were programmed to record GPS locations every 5 minutes in order to gather high resolution spatial data within relatively small paddocks comprised of diverse habitats. Data recorded during every GPS fix included animal location (latitude, longitude, and elevation), date and time, the dilution of precision value, fix status (2D or 3D), and ambient temperature. A detailed description of dilution of precision (DOP) and the difference between 2D and 3D fixes is provided in Section 2.6 of Chapter 2.

Upon completion of the grazing trials in each year, collars were removed and location data downloaded. In order to improve spatial accuracy, data were converted to RINEX format using Lotek's N4 computer program and differentially corrected using Pleiades Data Corp. (Calgary, AB) reference station data from Edmonton. Accuracy of GPS locations using Lotek 3300LR collars is within 5 m or less following differential correction, and can be influenced by atmospheric, satellite and receiver errors. Once corrected, all GPS fixes with a DOP value greater than 6 were removed to improve data quality, resulting in 39,468 locations remaining from 2008, and 41,342 from 2009.

Locations were converted to Universal Transverse Mercator (UTM) values and intersected with spatial files of habitats using ArcGIS 9.2 (ESRI®, Redlands, CA, USA). Prior to initiation of the study, habitats were mapped using a Trimble® (Sunnyvale, CA, USA) Geo XT GPS unit with Tempest antenna, which eliminates signal interference and multipath errors. Ivlev's electivity index (Ivlev 1961) (see Equation [1]) was used to determine cattle habitat preference by comparing habitat use (proportion of time spent in each habitat) in relation to habitat availability (proportion of total habitat available consisting of a given habitat).

$$\text{Electivity}_{\text{habitat}} = (\%\ \text{time spent}_{\text{habitat}} - \%\ \text{area}_{\text{habitat}}) / (\%\ \text{time spent}_{\text{habitat}} + \%\ \text{area}_{\text{habitat}}) \quad [1]$$

Electivity values theoretically range from +1 to -1, with +1 indicating perfect habitat preference or selection, while -1 indicates complete habitat avoidance. Values at or near zero indicate random selection (i.e. habitat use in direct proportion to habitat availability).

3.2.4. Cattle Use and Vegetation Measures

Collection of field data served to support cattle GPS locations and explain patterns of habitat use. Within each paddock a total of 60 to 70 permanently marked plots were distributed in a systematic manner (30 to 40 m spacing) to achieve adequate representation of all habitat types (Fig. A.3). Each plot was sampled twice in 2008: once after the low stocking treatment and again after the high stocking treatment. During 2009, data were collected once following the high stocking rate treatment.

All plots were circular and 10 m^2 in area. Within each paddock and habitat type, two 1 m^2 range cages were paired with randomly selected plots for the assessment of ungrazed biomass and forage utilization. In order to complement GPS data and gather information on the factors hypothesized responsible for cattle habitat preference, the following data were collected at each plot:

1. Evidence of cattle visitation in the form of tracks, grazing, or defecation (presence/absence per plot),
2. Ocular estimates of standing biomass by growth form, to the nearest 250 kg/ha increment.
3. Following the high stocking rate treatment, biomass clippings within a 0.5 m^2 quadrat from a subsample of plots where range cages were present: two cages per habitat

type per paddock. Biomass clippings were taken inside and outside cages and separated into grass, forb and shrub (current annual growth only) vegetation components. Biomass clippings were used to validate biomass estimates. Simple regressions showing the relationships between actual and estimated biomass values and the ability to recognize incremental changes in production for each year are shown in Figure C.1 (see Appendix C). Biomass samples were retained for quality analysis at a later date. To assess the quality of tree saplings as a source of forage, current year's growth from four to six randomly selected saplings of each of aspen and balsam poplar immediately adjacent to each plot were harvested and retained with the other samples.

4. Ocular assessment of forage utilization in increments of 5%. Where range cages were present, actual utilization was calculated by comparing dry matter biomass (kg/ha) inside and outside of cages using Equation [2]. Simple regressions showing the relationships between actual biomass removal and estimated utilization values, and the ability to distinguish incremental use for each year are provided in Figure C.2. These relationships should be interpreted with care, as field biomass sampling is prone to experimental error due to heterogeneity within the plant community. While ocular estimates can account and compensate for variation, small field samples are generally less able to do so.

   $$\text{Forage utilization (\%)} = (\text{ungrazed biomass} - \text{grazed biomass}) / \text{ungrazed biomass} * 100 \qquad [2]$$

5. Biophysical attributes of the ecosite at each plot, including plant species composition (i.e. foliar cover) of the three dominant herbs and three dominant shrubs, canopy cover (%) of trees greater than or equal to 2 m in height, slope gradient (%) using a clinometer, and aspect (^{o}) using a compass.
6. Quantification of slash (i.e. woody debris) abundance, including ocular assessment of the proportion (%) of ground covered by slash, measurement of average and maximum slash height (cm) per plot, and a slash impedance rating for cattle based on a scale of 1 to 10, with 1 indicating low obstruction and 10 indicating high obstruction. The slash impedance rating took into account factors such as slash

height, cover and spatial distribution, and was determined within a 10 m radius of plot centre. A slash impedance rating of 10 indicated a site with vertically elevated, dense, and uniformly distributed slash that would provide a major obstacle to cattle movement. Additionally, from the point of maximum slash height, the distance to the nearest grazing patch (cm) was measured.

7. In 2009, sapling impedance to animal access was assessed as low (1: neither visual nor physical impairment), moderate (2: visual but not physical impairment) or high (3: both visual and physical impairment) (Forester et al. 2007b).

3.2.5. Forage Quality Analysis

All plant biomass samples were dried at 45°C for at least 48 hrs to constant mass, and weighed. Samples were then ground to 1 mm using a Thomas® Scientific (Swedesboro, NJ, USA) Wiley Mill in preparation for proximate analysis. Crude protein (CP) and acid detergent fibre (ADF) concentrations were assessed for grass, forb, shrub, aspen and balsam poplar samples. Where the amount of biomass available for quality assessment was limited, protein analysis was prioritized over ADF due to the greater importance of protein intake over digestible energy in determining herbivore selection (Senft et al. 1987). Crude protein content was estimated by measuring the nitrogen concentration of forage using the Dumas (1831) method in association with a LECO® (St. Joseph, MI, USA) TruSpec FP-428 analyzer. The Dumas method employs high temperature (800 to 1000°C) combustion to convert all forms of nitrogen within vegetation first to nitrogen oxides, followed by reduction to N_2, which is subsequently measured by thermal conductivity detection (Kowalenko 2001; Jung et al. 2003). Percent nitrogen was subsequently converted to CP concentration by multiplying nitrogen values by 6.25. Concentrations of CP were calculated separately for forb, grass, shrub, and tree saplings.

The ANKOM 200 (ANKOM Technology, Macedon, NY, USA) filter bag technique was used to determine ADF concentrations, which uses a sulphuric acid and cetyl trimethylammonium bromide solution to digest plant matter, leaving largely cellulose and lignin residues (Vogel et al. 1999). The portion of sample lost through the process is considered to be available digestible energy for herbivores. Following digestion, samples are cleansed with acetone to remove any remaining impurities and dried at 100°C for 2 hrs. Upon removal from the drying oven, samples are placed in a desiccator to prevent moisture uptake prior to weighing to the nearest 0.0001 gram.

3.2.6.Statistical Analysis

All data were first checked for normality and equality of variances by assessing histograms and scatter plots of the residuals, in addition to output from the Shapiro-Wilk and Levene's tests using Proc UNIVARIATE and Proc GLM (SAS Institute Inc. 2009, Cary, NC, USA), respectively. Although all data were normally distributed, some variables had heterogeneous variances. For these data, log likelihood ratio tests (LRT) were employed to determine whether models accounting for heterogeneous variances provided a better fit over homogeneous models (West et al. 2007). Where the resulting statistic (p-value) was larger than 0.05, the homogenous variance model was considered to provide a better fit. Models accounting for heterogeneous variances were used for shrub CP, slash cover, and tree canopy cover variables. All other variables were analyzed using homogeneous variance models.

Differences in forage and environmental characteristics, cattle electivity, forage use and the proportion of plots with cattle occupancy, were each analyzed using an analysis of variance (ANOVA) in Proc MIXED (SAS Institute Inc. 2009). Analysis of the 2008 electivity, forage use, and plot occupancy, when two stocking rates were examined within the same plots and paddocks, was considered a strip-plot design (2 fixed factors: stocking rate and habitat), while that in 2009 was a randomized complete block (1 fixed factor: habitat). Paddock (i.e. block) and year were considered random in all data sets and LRTs were employed to determine if the inclusion of random interactions (i.e. block*year, block*habitat, habitat*year) improved model fit. All ANOVA analyses included the calculation of least-squares means for each variable, with main effects and interactions considered significant at $p<0.10$. A liberal p-value was used due to the limited number of experimental units (i.e. paddocks = 4) and associated statistical power. Differences of least-squares means ($p<0.05$) were computed for all pairwise comparisons using Fisher's least significant difference test (i.e. no multiple comparison adjustment). Electivity values were further tested to determine significant ($p<0.10$) deviation from zero using a one-sample t-test (Proc TTEST) with a two-tailed hypothesis (SAS Institute Inc. 2009).

To identify the environmental factors associated with cattle forage use at the patch (i.e. plot) and paddock levels under a high stocking rate, multiple regression (Proc REG) with stepwise model selection (SAS Institute Inc. 2009) was employed, with model entry and stay levels set at $p\leq0.10$ for predictor variables. Prior to regression, residuals were checked for normality by examining residual plots of observed vs. expected values. Additionally, data were assessed for collinearity among variables by applying variance inflation factor (VIF) and tolerance (TOL) options; VIF values less than 10 and TOL values greater than 0.1 indicated no collinearity (Belsley et al. 1980). Correlations were also conducted to identify variables associated with a correlation coefficient (r) greater than or equal to 0.6. As a result of strong correlation between forage CP and ADF, the ADF variable was removed from the model. White's test was employed to test the assumption of homogeneous variances (White 1980).

Ocular estimations of forage utilization (%) at the plot level across all paddocks were related to several independent variables including forage biomass estimates, forage protein, slope and aspect (cosine transformed (Platts et al. 2008)), slash maximum height and cover, sapling density and canopy cover, as well as distance to water. Paddock level multiple regressions, whereby response and independent variables were averaged for each habitat within each block and year (i.e. four habitats*four paddocks*two years = 32 observations), were also conducted to examine foraging patterns at a larger and more practical (i.e. land management) scale. Biomass estimates were adjusted using forage utilization estimates to determine the available forage prior to grazing (see Equation [3]).

$$\text{Forage biomass} = \text{post grazing biomass estimate} / (1 - \text{estimate of proportion forage used}) \quad [3]$$

CP concentration data for all forage samples at the plot level were obtained using the mean contribution of CP from each of the three growth forms, weighted by their estimated biomass contribution (see Equation [4]).

$$\text{Total plot CP concentration} = \quad [4]$$

$$(\text{biomass}_{\text{grass}} * \text{CP}_{\text{grass}} + \text{biomass}_{\text{forb}} * \text{CP}_{\text{forb}} + \text{biomass}_{\text{shrub}} * \text{CP}_{\text{shrub}}) / (\text{biomass}_{\text{grass}} + \text{biomass}_{\text{forb}} + \text{biomass}_{\text{shrub}})$$

Habitats and paddocks were not included as independent variables because prior exploratory analysis revealed a low proportion of variation (i.e. 3-4% combined) related to these regressors. Models were considered significant at $p<0.05$, with the proportion of variance explained assessed using goodness-of-fit (R^2) values. Standardized beta coefficients were calculated to assess the relative strength of each predictor, while partial R^2 values provided the proportional variance accounted for by each individual variable (i.e. contribution to R^2).

Simple linear regression (Proc REG) was used to identify the specific relationship between cattle accessibility in the form of distance to nearest grazing patch (dependent variable) and maximum slash height (independent variable).

3.3. Results

3.3.1. Cattle Habitat Preference and Foraging Behaviour

Electivity values differed among habitats ($p<0.05$), but not between stocking rates ($p=0.45$) in 2008 (Fig. 3.1). Uncut forests were preferred by cattle, with electivity values greater ($p<0.01$) than zero. Partially harvested areas and brush piles were neither preferred nor avoided as indicated by electivity values similar ($p=0.59$, $p=0.68$) to zero. Habitats avoided by cattle included clear cuts and skid roads, with electivity values less than zero ($p<0.10$).

The proportion of field sample plots exhibiting cattle use in 2008 differed between habitat types ($p<0.05$) and stocking rates ($p<0.01$) (Table 3.2). Averaged across stocking rates, uncut forest plots had the greatest proportion of cattle visitation, followed by partial harvest, clear cut, and skid roads. The proportion of plots showing cattle use increased from 77 to 92% as stocking rate increased from low to high. In 2009, habitat had no effect ($p=0.22$) on the proportion of plots showing cattle occupancy, with 98% of plots visited by cattle. Similarly, forage biomass utilization estimates failed to differ (2008: $p=0.37$; 2009: $p=0.88$) between habitats (Table 3.2), but increased ($p<0.0001$) from 3 to 17% as stocking rate increased. No habitat by stocking rate interactions ($p>0.10$) were found for the 2008 electivity, utilization, or cattle occupancy data.

Multiple regression of forage utilization at the patch (plot) level against independent variables (forage biomass, protein, slash cover and maximum height, slope and aspect, tree canopy cover, deciduous sapling density, and distance to water) produced a significant model with 19% of the variation accounted for ($p<0.0001$, $R^2=0.19$) (Table 3.3). Analysis revealed forage biomass and distance to water ($p<0.0001$), forage protein ($p<0.01$), slash cover, and sapling density ($p<0.05$) as significant regressors related to forage use. Standardized beta coefficients revealed forage biomass and protein concentration had positive associations with forage use. With each additional 100 kg/ha of forage available, forage use increased by 0.8%. Similarly, a 1% increase in forage CP content resulted in a 1.8% increase in consumption by cattle. Conversely, distance to water, sapling density and slash cover had negative relationships with forage utilization. As distance to water and slash cover increased by 100 m and 1%, respectively, forage use decreased by 5.8% and 0.06%. As sapling density increased by an additional 10 stem/m^2, utilization declined by 7.6%. Partial R^2 values indicate forage biomass and distance to water contributed the greatest variation to forage utilization, although these relationships were weak. Forage CP, slash cover and sapling density each accounted for 1 to 2% variance.

Paddock level multiple regression of forage use averaged for each habitat within each block and year revealed a statistically insignificant model with only 9% of the variation explained ($p=0.10$, $R^2=0.09$). Aspect was the only predictor associated with forage use at the paddock level.

Linear regression of minimum distance to the nearest grazed patch (dependent variable) with maximum slash height (independent variable) revealed a significant relationship ($p<0.0001$), with nearly 20% of the variation in minimum distance to grazing explained by slash height (Fig. 3.2). As maximum slash height increased, cattle access to forage became more restricted to distances further from the point of greatest obstruction within the plot.

3.3.2. Environmental Attributes of Habitats

Total forage biomass (i.e. grasses, forbs and shrubs combined) differed ($p<0.05$) between habitats (Table 3.4). Uncut forests provided less ($p<0.05$) forage than clear cuts, partially harvested areas, and skid roads. Biomass contributed solely by forbs ($p=0.29$) and grasses ($p=0.31$) did not vary between habitats (Table 3.4). However, shrub biomass differed among habitats ($p<0.05$), with skid roads producing more ($p<0.05$) shrub biomass than partially harvested and uncut areas (Table 3.4). Additionally, clear cuts had greater ($p<0.05$) shrub production than partially harvested areas.

Crude protein (CP) concentrations of grass ($p=0.43$) and forb ($p=0.70$) did not vary among habitats (Table 3.4). Shrub CP differed ($p<0.05$) between habitats, but due to heterogeneous variances, only uncut forest shrubs were higher in CP content than those in skid roads. Forbs provided the greatest forage CP, followed by shrubs and lastly grasses. Aspen crude protein concentration (13.1% CP) was greater ($p<0.0001$) than that of balsam poplar (10.5% CP).

Forb ($p=0.29$), grass ($p=0.16$) and shrub ($p=0.89$) ADF concentrations did not vary among habitats (Table 3.4). Among growth forms, shrubs had the lowest ADF concentrations (corresponding to the greatest digestibility), followed by forbs, and lastly grasses (Table 3.4). Aspen (31.7% ADF) was more digestible ($p<0.0001$) than balsam poplar (38.2% ADF).

Average slash height was taller ($p<0.05$) within skid roads than clear cuts and partial harvested areas (Table 3.4). However, slash height did not differ ($p=0.31$)

between skid roads and uncut forest due to the inclusion of fallen mature trees in measurements from uncut areas. Maximum slash height, however, did not differ ($p=0.24$) between habitats (Table 3.4). Skid roads had greater ($p<0.05$) slash cover than all other habitats (Table 3.4). Similarly, cattle impedance due to slash accumulation was greater ($p<0.001$) within skid roads than all other habitats (Table 3.4).

Tree canopy cover varied ($p<0.05$) among habitats (Table 3.4). Although canopy cover tended to be greatest within uncut areas, large variance within the data from this area resulted in no differences from other habitats; in contrast, clear cuts had greater ($p<0.01$) canopy cover than skid roads. Sapling impedance for cattle varied ($p<0.001$) among habitats, with clear cuts having the greatest obstruction rating. In contrast, skid roads and uncut areas had the least sapling impedance.

All harvested habitats (skid road, clear cut and partial cut) were dominated by marsh reed grass [*Calamagrostis canadensis* (Michx.) Beauv.], prickly rose (*Rosa acicularis* Lindl.) and tall mertensia [*Mertensia paniculata* (Ait.) G. Don.], while uncut forests were dominated by bluegrass (*Poa* spp.), wild sarsaparilla (*Aralia nudicaulis* L.), bunchberry (*Cornus canadensis* L.), and snowberry [*Symphoricarpos albus* (L.)] (Tables E.1 through E.6, see Appendix E). Skid roads had the greatest cover and occurrence of weedy species, including Canada thistle [*Cirsium arvense* (L.) Scop.] and hemp nettle (*Galeopsis tetrahit* L.).

3.4. Discussion

Herbivore foraging behaviour and habitat selection involve several complex processes including experiential learning, genetic predispositions, interaction with surrounding environmental characteristics, and the social dynamics of a herd (Senft et al. 1983; Bailey et al. 1989; Launchbaugh and Howery 2005). Skinner (1938) originally coined the term ‘operant conditioning’ to describe how animals will search for and actively choose habitats that provide optimal opportunities for satiation, safety, and comfort. Herbivores employ all physical senses to judge the suitability or desirability of habitats, and have the ability to associate certain environmental features with positive or negative consequences (Bailey et al. 1996; Launchbaugh and Howery 2005).

Habitat preference by herbivores has been related to abundant forage of high nutritional quality, ample water supply, safety from predators, and shelter from harsh weather conditions and insects (Bailey et al. 1996; Launchbaugh and Howery 2005; Karki and Goodman 2010). Forage availability and associated dietary preferences are deemed the primary factors influencing habitat selection and spatial distribution of herbivores (Senft et al. 1983; Bailey et al. 1989; Owens et al. 1991; Wallis de Vries and Schippers 1994; Bailey et al. 1996; Asamoah et al. 2003; Launchbaugh and Howery 2005). In this study however, cattle showed preference for uncut forests, which generally provided less forage than logged habitats. Clear cuts and skid roads experienced the greatest increase in herbage production following overstory removal, while partially harvested areas experienced an intermediate release of the understory once shading and competition were reduced (Bartos and Mueggler 1982; Wollis 1991; Powell and Bork 2006).

The strong affinity cattle showed for uncut areas with limited forage availability may be attributed to other benefits including shelter from inclement weather, shading from warm temperatures, and the relative ease of access compared to harvested habitats characterized by dense sapling re-growth and slash accumulation. Putfarken et al. (2008) reported shady conditions for thermoregulation purposes to be the key factor explaining cattle preference for forested patches during hot summer months in northwest Germany. Similarly, Beaver and Olson (1997) found that cattle used protected areas more than expected to avoid climatic extremes on Montana rangelands, and standard operating temperatures were more important in predicting cattle locations than forage quantity or quality. Additionally, it is worth noting that forage abundance was not a limiting factor in any habitat in this study, including clear cuts, due to the implementation of very conservative stocking rates throughout the grazing trials. Forage ADF concentrations of grasses and forbs within uncut forests tended to be lower than other habitats, suggesting that cattle may have cued on greater levels of digestible energy within uncut forests. However, Ganskopp and Bohnert (2009) found that ADF content did not affect where cattle grazed on Oregon rangelands. Forage quality overall was similar among habitats, suggesting that habitat characteristics beyond forage conditions were responsible for influencing observed cattle habitat preferences.

Uncut forests in this investigation likely allowed for greater visibility and accessibility resulting from low impedance by saplings. Conversely, cattle may have avoided clear cuts due to the visual and physical obstruction presented by dense sapling regeneration (x = 33,100 stems/ha) (see Chapter 4). Stem densities of 16,000 to 28,000 per ha, in addition to saplings with a diameter at breast height greater than 1.5 cm, have been found to present an impassable obstruction for mature cows (Krzic et al. 2003, 2004). When observed travelling through clear cut areas, cattle appeared nervous and agitated due to the inability to see through saplings in order to identify potential threats. However, Forester et al. (2007b) found that areas with high sapling impedance were not avoided by elk because they may have provided some protection from wolves, although elk are likely more agile and nimble at traversing forested landscapes than cattle, and previous studies have shown that cattle prefer more open habitats than elk (Hart et al. 1991; Sheehy and Vavra 1996). Bailey (1970) noted the barrier effect that dense stands of silverberry had on cattle accessibility to forage in the Parkland region of Alberta, and related greater use of areas without shrub to a reduction in range condition and herbaceous availability. In the present study, partial harvest produced a habitat with features similar to uncut forests, but also contained areas of greater sapling impedance, which may explain the lack of preference for the latter habitat by cattle.

Skid roads likely were avoided by cattle due to dense slash accumulation, which in turn likely made travel more difficult and therefore represented a potential bio-energetic cost. Ganskopp et al. (2000) showed through the use of a simulated GIS analysis that cattle are expected to use least effort pathways to traverse the landscape. Downed woody debris can obstruct herbivore movement or deter entry into potential foraging sites (Grisez 1960; Jones 1983). Increased dead wood aggregation has been shown to provide a greater obstruction to wildlife seeking to browse deciduous seedlings (de Chantal and Ganstrom 2007).

Last, cattle electivity relating to burned brush piles was slightly positive likely due to the establishment of lush vegetation benefiting from the breakdown of ash and improved soil nutrient status on these severely disturbed sites. Cattle may have been drawn into these areas to consume nutrient rich forage, in addition to wallowing in ash to deter insect pests.

The relationship between cattle forage use and the factors responsible for their consumption was weak given the extremely low stocking rates implemented, suggesting that grazing behaviour may be difficult to consistently predict. The overall weak nature of the empirical relationships between forage use and various biophysical attributes of habitats could be attributed to the low levels of utilization arising from very conservative stocking rates. The cattle stocking rates implemented in the current study were based on light to moderate forage use mandated by Alberta Sustainable Resource Development on public land in Alberta. In comparison, studies focused on the control and removal of aspen through grazing employed stocking rates that were approximately 20 to 30 times greater than those of the current investigation (Fitzgerald and Bailey 1984; Fitzgerald et al. 1986; Bailey et al. 1990). Therefore, the stocking rates used for this study are better defined as very low and low, rather than low and high.

Although one would expect cattle to show more clear and obvious grazing preferences under low stocking rates (Senft et al. 1983; Senft 1989), light stocking is likely to lead to a reduced ‘footprint’ of cattle foraging, which in turn may be more difficult to track and uncover through field sampling protocols (Gillen et al. 1984). Using simulated experiments, Senft (1989) determined that stocking rate had a greater effect on cattle diet selection of individual forage plant species rather than plant community use, and may explain why cattle preferred and avoided habitats similarly despite stocking rate during 2008 in the current study.

Forage biomass was the key factor found to influence and explain forage use by cattle at the patch scale, with utilization showing a small increase with each additional kg/ha of biomass available. Our findings of forage quantity serving as a predominant factor influencing grazing decisions by cattle, concurs with previous research. Gillen et al. (1984) attributed greater utilization by cattle to increased forage biomass in north eastern Oregon. Similarly, independent research done by Clary et al. (1978), Owens et al. (1991), and Pinchak et al. (1991) determined that forage consumption by cattle was correlated with forage biomass.

Due to collinearity issues, we could not compare the relative importance of forage ADF versus CP concentrations. Holechek and Vavra (1982) observed that neutral detergent fibre (NDF) concentrations within cattle diets were more closely associated with forage intake than CP concentrations, while Senft et al. (1987) argue that rate of protein intake is typically more important than rate of digestible energy intake. In the present study, CP concentration was a significant predictor of forage consumption, with utilization increasing in association with higher quality forage. Potential interactions between forage availability and nutritional characteristics may explain the ambiguity surrounding the independent and lone influence of a single forage attribute (Ganskopp and Bohnert 2009).

Sapling density appeared to play a significant role in deterring forage consumption by cattle, with a small decline in forage use related to greater sapling density. Other research confirms the obstructive effect that brush density has on forage accessibility for cattle. Given conditions of abundant green forage, Owens et al. (1991) determined that brush played a vital role in accounting for the variation in utilization by cattle within mixed brush communities of Texas. Dense shrublands presented a physical barrier to cattle, resulting in decreased grass use. Notably, a high frequency of green forbs failed to motivate cattle to penetrate dense stands of brush. Corresponding research done by Clary et al. (1978) concluded that forage consumption by cattle was significantly correlated with tree density.

In addition to dense sapling regeneration, logging debris also posed a deterrent to cattle seeking foraging opportunities; increased slash cover was associated with decreased forage use. Wildlife management research has shown that the predicted energy cost of travel through woody debris increases in relation to obstacle density and depth (Parker et al. 1984). Cattle accessibility to forage declined with increased slash height, results corroborated by Parker et al. (1984) and Ripple and Larson (2001), who found slash depths in excess of 0.5 and 0.8 m, respectively, substantially suppressed wild ungulate use.

Forage use had a negative relationship with distance to water. These results were surprising as small paddock sizes allowed for close proximity to water, which never exceeded 235 m. Nevertheless, cattle concentrated their foraging at sites where water was abundant, regardless of paddock size. Since forage biomass was not a limiting factor due to conservative stocking rates, cattle could easily meet their forage intake requirements without travelling far from the water source. Moreover, resting and socializing behaviour were also commonly observed around watering sites. Many studies corroborate these results, including Gillen et al. (1984) who concluded that cattle preferred areas within 200 m of water and avoided areas greater than 600 m from water. Likewise, Pinchak et al. (1991) observed 77% of cattle use occurred within 366 m of water. Putfarken et al. (2008) found that distance to water was a significant parameter influencing cattle choice of feeding sites. Our results strongly parallel those of Ganskopp and Bohnert (2009) who found distance to water to be a significant predictor of cattle distribution. Clary et al. (1978) found no relationship with distance to water, results which contrast the present investigation where distance to water had the greatest negative association with forage utilization by cattle.

Topography and slope gradient were not significant factors affecting forage use patterns by cattle, likely due to the small paddock sizes employed and an average slope of just 5%. This finding is supported by Clary et al. (1978) who observed no relation between forage consumption by cattle and slope gradient within ponderosa pine rangelands of Arizona. Pinchak et al. (1991) found that cattle concentrated use on slopes less than 7% in foothill ranges of Wyoming, whereas Gillen et al. (1984) noted that cattle would avoid slopes in excess of 20%. Thus, slopes in our study may all have been within the tolerance for cattle.

Examining foraging behaviour at the paddock rather than patch scale may provide more realistic implications and practical applications for management. However, the insignificant associations between average paddock and habitat values for the measured regressors and forage use suggests that there is a limited ability to generalize and predict foraging patterns at the paddock level, given the conservative stocking rates and grazing period implemented. By averaging the response and independent values for each habitat within each paddock and year, the range in forage use was narrowed to 7 to 40% from 3 to 83%, thus making it more difficult to detect relationships. However, the observed range remained large enough to expect to find biologically significant effects.

As with any field study focusing on habitat selection and herbivore foraging behaviour, it is important to remember that the outcomes represent only a snapshot in time and space, and are continually subject to change (Launchbaugh and Howery 2005). Thus, the value of certain habitats to herbivores will vary with grazing management practices and environmental conditions; previously avoided habitats may experience greater use in cases of limited forage availability or relief from obstruction. Cattle foraging patterns within older cut blocks undergoing succession may be difficult to consistently predict, as animals respond to changes in forage and tree dynamics. Finally, other factors may have played a role in regulating cattle foraging behaviour and habitat preference, but were not assessed here, including animal genetics, social dynamics, individual learning experiences, and the effect of daily or hourly weather conditions.

3.5. Management Implications

By satisfying the study objectives, we are able to better understand cattle habitat selection processes within deciduous cut blocks and how patterns of animal use may influence subsequent reforestation. Given the very conservative stocking rates implemented, cattle actively chose to occupy uncut forest rather than logged areas. Without the stress of seeking sufficient forage and meeting intake requirements, cattle showed a clear avoidance for skid road and clear cut habitats that impose obstruction to movement. Dense sapling re-growth limited the ability of cattle to attain and consume forage, thereby allowing these young stands to naturally regenerate with little interference from cattle. Thick slash accumulation on skid roads likely discouraged cattle use, which could present an impediment to cattle distribution and grazing management. If such a situation should arise, action could to be taken to reduce the amounts of logging debris through burning or other forms of removal. Conversely, skid road construction could also be used to intentionally modify foraging patterns and site selection to provide insurance against cattle use of regenerating cut blocks.

Grazing management of rangelands containing cut blocks should take into account the primary factors influencing forage use by cattle including distance to water, and forage quantity and quality. Watering sites would ideally be located away from regenerating cut blocks to limit cattle presence and use. Although cut blocks offer an initial increase in forage production, maintaining stocking rates at pre-harvest levels will account for the gradual decline in understory vegetation as sapling canopy closure and competition occurs. Forage quality, as another important factor influencing livestock behaviour, should be considered when grazing pastures containing regenerating cut blocks. Adequate amounts of forage of sufficient quality should be provided to prevent cattle from resorting to browsing of saplings.

This research supports the use of sustainable stocking rates and responsible grazing management to prevent overuse of regenerating clear cuts, thereby creating a cooperative and integrative environment for forestry and ranching industries to work together. Based on our findings, successful regeneration of the cut blocks in this study should be attainable if conservative stocking rates are maintained and re-evaluated as forage conditions and plant communities change over time. Study outcomes should lead to improved grazing practices that are consistent with optimizing aspen regeneration and sustaining commercial forestry on multiple use lands, while also minimizing conflict between livestock and timber industries.

Table 3.1: Dates of cattle rotation for each herd through paddocks to achieve the low and high stocking rate treatments during the 2008 grazing trial. Only the high stocking rate treatment was implemented and tested during the 2009 grazing trial.

			Stocking Rate			
Year	**Herd**	**Paddock**	Low	Low	High	High
2008	1	1	Jul 8–12		Jul 17–23	
	1	3		Jul 12–17		Jul 23–27
	2	4		Jul 12–17		Jul 23–27
	2	5	Jul 8–12		Jul 17–23	
2009	1	1	-	-	Jul 6–16	
	1	3	-	-		Jul 16–26
	2	4	-	-		Jul 16–26
	2	5	-	-	Jul 6–16	

Table 3.2: Proportion (%) of plots with evidence of cattle occupation and measured forage utilization (%) by cattle during the 2008 and 2009 grazing trials.

	Habitat				
Stocking Rate & Year	Clear Cut	Uncut Forest	Partial Harvest	Skid Road	SE
			% Occupied Plots		
Low Stocking Rate	73 ab[1]	89 a	81 a	64 b	8
High Stocking Rate					
2008	92 ab	100 a	99 a	79 b	8
2009	97	100	95	100	2
			% Forage Utilization		
Low Stocking Rate	2	3	2	6	3
High Stocking Rate					
2008	13	19	15	20	3
2009	17	16	15	17	3

[1] Within a row, means with different letters differ, p<0.05.

Table 3.3: Stepwise regression summary of the relationship between forage utilization and significant predictor variables. Results are representative at the patch (plot) level.

Dependent Variable	**Independent Variable**	**Partial R^2**	**Model R^2**	**β^1**	**Regressor p-value**
Forage Utilization (%)	Forage Biomass	0.10	0.10	0.33	<0.0001
	Distance to Water	0.05	0.15	-0.22	<0.0001
$R^2 = 0.19$	Forage Protein	0.02	0.17	0.13	<0.01
Adj $R^2 = 0.18$	Slash Cover	0.01	0.18	-0.12	<0.05
$p<0.0001$	Sapling Density	0.01	0.19	-0.11	<0.05

[1] Standardized beta coefficients.

Table 3.4: Forage biomass (kg/ha), crude protein concentration (%), and acid detergent fibre concentration (%), together with slash height (cm), cover (%) and access impedance, sapling impedance, and tree canopy cover (%) across habitats.

	Habitat				
Response	Clear Cut	Uncut Forest	Partial Harvest	Skid Road	SE
			Forage Biomass (kg/ha)		
Forb	892	834	931	1096	188
Grass	1551	678	1386	1114	346
Shrub	384 ab[1]	234 bc	144 c	432 a	86
Total	2828 a	1746 b	2461 a	2642 a	317
			Forage Crude Protein (%)		
Forb	11.3	11.7	12.0	11.6	1.1
Grass	7.8	7.8	7.2	7.9	0.4
Shrub	10.6 ab	10.4 a	10.9 ab	9.7 b	[2] *
			Forage Acid Detergent Fibre (%)		
Forb	30.9	30.0	30.0	31.9	3.0
Grass	40.4	38.9	39.8	39.6	1.6
Shrub	25.0	25.8	25.7	24.7	4.3
			Logging Slash		
Average Height (cm) [3]	13 c	19 ab	15 bc	21 a	2
Maximum Height (cm) [4]	64	88	86	76	9
Slash Cover (%) [3]	27 b	15 b	23 b	74 a	[2] **
Slash Impedance (0-10) [4]	3 b	3 b	3 b	8 a	1
Sapling Impedance (0-3)[4]	2.1 a	1.4 c	1.7 b	1.4 c	0.1
Tree Canopy Cover (%) [4]	14 a	27 ab	21 ab	3 b	[2] ***

[1] Within a row, means with different letters differ, $p<0.05$.

[2] Standard errors vary between habitats due to heterogeneous variances:

*SE clear cut: 0.4, SE uncut forest: 0.2, SE partial harvest: 0.5, SE skid road: 0.1.

**SE clear cut: 5, SE uncut forest: 2, SE partial harvest: 4, SE skid road: 12.

***SE clear cut: 2, SE uncut forest: 9, SE partial harvest: 6, SE skid road: 1.

[3] Data collected in 2008.

[4] Data collected in 2009.

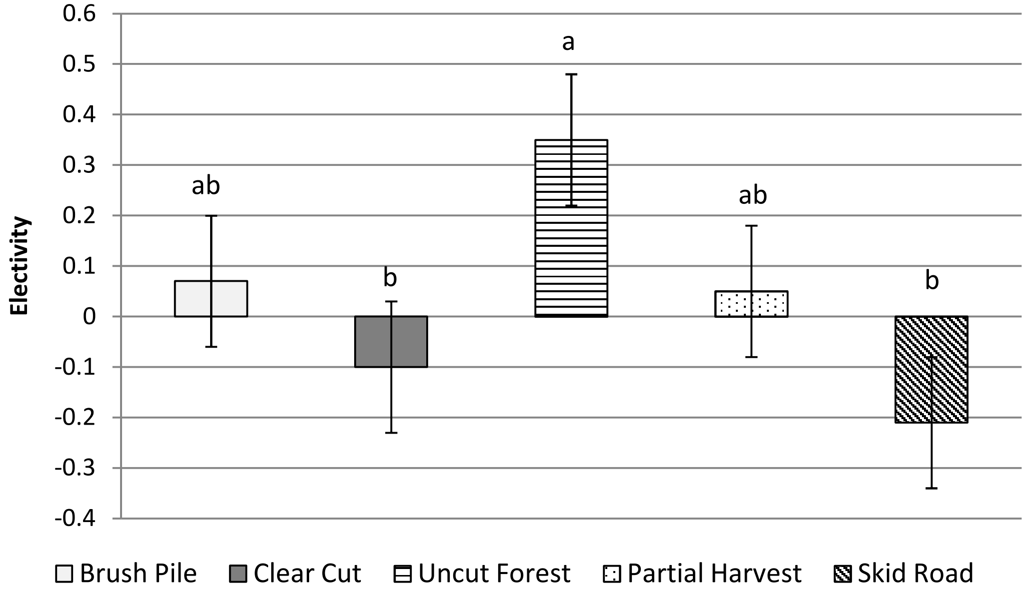

Figure 3.1: Mean (±0.13) cattle habitat preference based on Ivlev's electivity index resulting from a high stocking rate treatment in 2008 and 2009. Means with different letters differ, $p<0.05$. Uncut forest electivity is greater ($p<0.01$) than zero and indicates preference, while clear cut and skid road electivities are less ($p<0.10$) than zero and signifies avoidance.

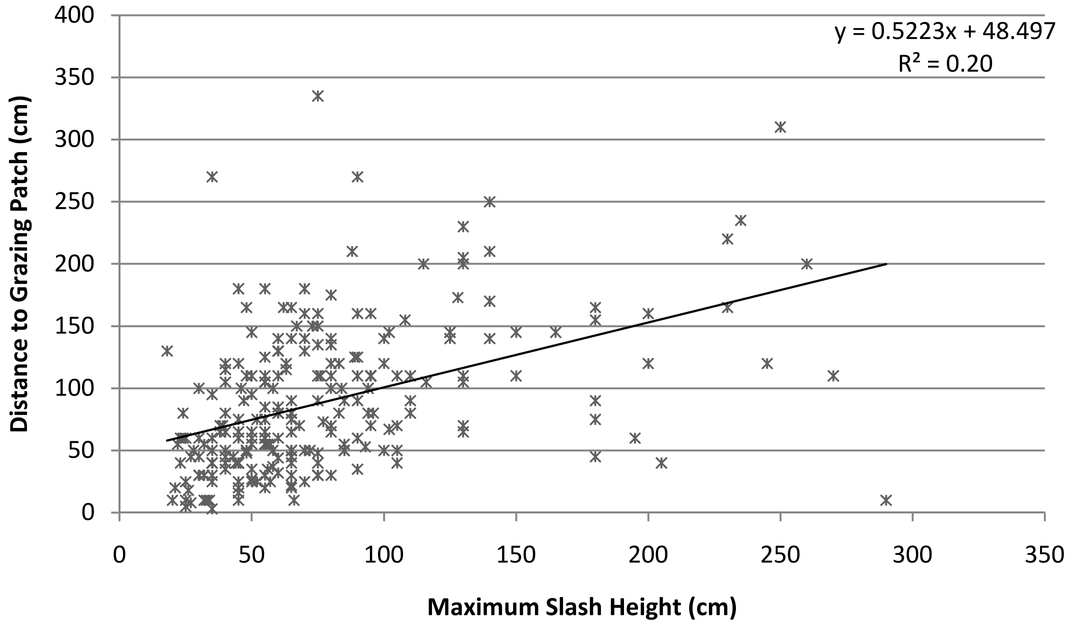

Figure 3.2: Relationship between maximum slash height (cm) within a plot and minimum distance to the nearest grazed patch ($p<0.0001$; $R^2 = 0.20$).

3.6. *Literature Cited*

Alberta Sustainable Resource Development. 2008. Alberta regeneration survey manual. Forest Management Branch, Edmonton, Alberta, Canada. Publication No. T/181. ISBN No. 978-0-7785-7039-4 (On-line Edition).

Alexander. M.J. 1995. The response of mature decadent and healthy sapling aspen forest communities to prescribed burning and controlled livestock grazing. M.Sc. Thesis, University of Alberta, Edmonton, Alberta, Canada.

Asamoah, S.A., E.W. Bork, B.D. Irving, M.A. Price, and R.J. Hudson. 2003. Cattle herbage utilization patterns under high-density rotational grazing in the aspen parkland. Canadian Journal of Animal Science 83: 541-550.

Bailey, A.W. 1970. Barrier effect of the shrub *Elaeagnus commutata* on grazing cattle and forage production in central Alberta. Journal of Range Management 23(4): 248-251.

Bailey, A.W., B.D. Irving, and R.J. Fitzgerald. 1990. Regeneration of woody species following burning and grazing in aspen parkland. Journal of Range Management 43(3): 212-215.

Bailey, D.W., L.R. Rittenhouse, R.H. Hart, D.M. Swift, and R.W. Richards. 1989. Association of relative food availabilities and locations by cattle. Journal of Range Management 42(6): 480-482.

Bailey, D.W., J.E. Gross, E.A. Laca, L.R. Rittenhouse, M.B. Coughenour, D.M. Swift, and P.L Sims. 1996. Mechanisms that result in large herbivore grazing distribution patterns. Journal of Range Management 49 (5): 386-400.

Bartos, D.L. and W.F. Mueggler. 1982. Early succession following clearcutting of aspen communities in northern Utah. Journal of Range Management 35(6): 764-768.

Beaver, J.M. and B.E. Olson. 1997. Winter range use by cattle of different ages in southwestern Montana. Applied Animal Behaviour Science 51:1-13.

Bella, I.E. 1986. Logging practices and subsequent development of aspen stands in east-central Saskatchewan. The Forestry Chronicle 62: 81-83.

Belsley, D.A., E. Kuh, and R.E. Welsch. 1980. Regression Diagnostics. John Wiley and Sons Inc, New York, USA.

Clary, W.P., P.F. Ffolliott, and F.R. Larson. 1978. Factors affecting forage consumption by cattle in Arizona ponderosa pine forests. Journal of Range Management 31(1): 9-10.

de Chantal, M. and A. Granström. 2007. Aggregations of dead wood after wildfire act as browsing refugia for seedlings of *Populus tremula* and *Salix caprea*. Forest Ecology and Management 250: 3-8.

Dockrill, C.W.M., P.V. Blenis, A.W. Bailey, and J.R. King. 2004. Effect of summer cattle grazing on aspen stem injury, mortality and growth. The Forestry Chronicle 80(2): 257-261.

Dockrill, C.W.M., A.W. Bailey, P.V. Blenis, and J.R. King. 2006. Seasonal variation in resistance of aspen stems to shearing force. Rangeland Ecology and Management 59(2): 212-215.

Dumas, J.B.A. 1831. Procedes de l'analyse organique. Ann. Chim. Phys. 247-213.

Fitzgerald, R.D. and A.W. Bailey. 1984. Control of aspen regrowth by grazing with cattle. Journal of Range Management 37(2): 156-158.

Fitzgerald, R.D., R.J. Hudson, and A.W. Bailey. 1986. Grazing preferences of cattle in regenerating aspen forest. Journal of Range Management 39(1): 13-18.

Forester, J.D., A.R. Ives, M.G. Turner, D.P. Anderson, D. Fortin, H.L. Beyer, D.W. Smith, and M.S. Boyce. 2007a. State-space models link elk movement patterns to landscape characteristics in Yellowstone National Park. Ecological Monographs 77(2): 285-299.

Forester, J.D., D.P. Anderson, and M.G. Turner. 2007b. Do high-density patches of coarse wood and regenerating saplings create browsing refugia for aspen (*Populus tremuloides* Michx.) in Yellowstone National Park (USA)? Forest Ecology and Management 253: 211-219.

Ganskopp, D., R. Cruz, and D.E. Johnson. 2000. Least-effort pathways?: a GIS analysis of livestock trails in rugged terrain. Applied Animal Behaviour Science 68: 179-190.

Ganskopp, D.C. and D.W. Bohnert. 2009. Landscape nutritional patterns and cattle distribution in rangeland pastures. Applied Animal Behaviour Science 116: 110-119.

Gillen, R.L., W.C. Krueger, and R.F. Miller. 1984. Cattle distribution on mountain rangeland in northeastern Oregon. Journal of Range Management 37(6): 549-553.

Grisez. T.J. 1960. Slash helps protect seedlings from deer browsing. Journal of Forestry 58: 385-387.

Hart, R.H., K.W. Hepworth, M.A. Smith, and J.W. Waggoner, Jr. 1991. Cattle grazing behavior on a foothill elk winter range in southeastern Wyoming. Journal of Range Mangement 44(3): 262-266.

Holechek, J.L. and M. Vavra. 1982. Forage intake by cattle on forest and grassland ranges. Journal of Range Management 35(6): 737-741.

Ivlev, V.S. 1961. Experimental ecology of the feeding of fishes. Yale University Press, New Haven, Connecticut.

Jones, K.L. 1983. Current knowledge of the effects of cattle grazing on aspen in the Alberta parkland. Rangelands 5(2): 59-60.

Jung, S., D.A. Rickert, N.A. Deak, E.D. Aldin, J. Recknor, L.A. Johnson, and P.A. Murphy. 2003. Comparison of Kjeldahl and Dumas methods for determining protein contents of soybean products. Journal of American Oil Chemists 80(12):1169-1173.

Karki, U. and M.S. Goodman. 2010. Cattle distribution and behavior in southern-pine silvopasture versus open-pasture. Agroforest Syst 78: 159-168.

Kowalenko, C.G. 2001. Assessment of Leco CNS-2000 analyzer for simultaneously measuring total carbon, nitrogen, and sulphur in soil. Communications in Soil Science and Plant Analysis 32: 2065-2078.

Krzic, M., R.F. Newman, and K. Broersma. 2003. Plant species diversity and soil quality in harvested and grazed boreal aspen stands of northeastern British Columbia. Forest Ecology and Management 182: 315-325.

Krzic, M., H. Page, R.F. Newman, and K. Broersma. 2004. Aspen regeneration, forage production, and soil compaction on harvested and grazed boreal aspen stands. BC Journal of Ecosystems and Management 5(2): 30-38.

Launchbaugh, K.L and L.D. Howery. 2005. Understanding landscape use patterns of livestock as a consequence of foraging behaviour. Rangeland Ecology and Management 58(2): 99-108.

Lawrence, D., C.T. Lane, M.G. Willoughby, C. Hincz, D. Moisey, and C. Stone. 2005. Range plant community types and carrying capacity for the lower foothills subregion of Alberta. Fourth approximation. Alberta Sustainable Resource Development, Public Lands and Forest Division. Pub. No. T/083. ISBN. No. (On-line edition) 0-7785-4098-7.

Morgan, R.K. 1991. The role of protective understorey in the regeneration system of a heavily browsed woodland. Vegetation 92: 119-132.

Owens, M.K., K.L. Launchbaugh, and J.W. Holloway. 1991. Pasture characteristics affecting spatial distribution of utilization by cattle in mixed brush communities. Journal of Range Management 44(2): 118-123.

Parker, K.L., C.T. Robbins, and T.A. Hanley. 1984. Energy expenditures for locomotion by mule deer and elk. Journal of Wildlife Management 48(2): 474-488.

Pinchak, W.E., M.A. Smith, R.H. Hart, and J.W. Waggoner Jr. 1991. Beef cattle distribution patterns on foothill range. Journal of Range Management 44(3): 267-275.

Platts, P.J., C.J. McClean, J.C. Lovett, and R. Marchant. 2008. Predicting tree distributions in an east African biodiversity hotspot: model selection, data bias and envelope uncertainty. Ecological Modelling 218: 121-134.

Powell, G.W. and E.W. Bork. 2006. Aspen canopy removal and root trenching effects on understory vegetation. Forest Ecology and Management 230: 79-90.

Putfarken, D., J. Dengler, S. Lehmann, and W. Härdtle. 2008. Site use of grazing cattle and sheep in a large-scale pasture landscape: a GPS/GIS assessment. Applied Animal Behaviour Science 111: 54-67.

Ripple, W.J. and E.J. Larsen. 2001. The role of postfire coarse woody debris in aspen regeneration. Western Journal of Applied Forestry 16(2): 61-64.

Roath, L.R. and W.C. Krueger. 1982. Cattle grazing and behavior on a forested range. Journal of Range Management 35(3): 332-338.

Senft, R.L. 1989. Hierarchical foraging models: effects of stocking and landscape composition on simulated resource use by cattle. Ecological Modelling 46: 283-303.

Senft, R.L., L.R. Rittenhouse, and R.G. Woodmansee. 1983. The use of regression models to predict spatial patterns of cattle behavior. Journal of Range Management 36(5): 553-557.

Senft, R.L., M.B. Coughenour, D.W. Bailey, L.R. Rittenhouse, O.E. Sala, and D.M. Swift. 1987. Large herbivore foraging and ecological hierarchies. BioScience 37(11): 789-799.

Sheehy, D.P. and M. Vavra. 1996. Ungulate foraging areas on seasonal rangeland in northeastern Oregon. Journal of Range Management 49(1): 16-23.

Skinner, B.F. 1938. The behavior of organisms. New York, NY: Apleton-Century-Crofts. 457 p.

Vogel, K.P., J.F. Pedersen, S.D. Masterson, and J.J. Toy. 1999. Evaluation of a filter bag system for NDF, ADF and IVDMD forage analysis. Crop Science 39: 276-279.

Wallis de Vries, M.F. and P. Schippers. 1994. Foraging in a landscape mosaic: selection for energy and minerals in free-ranging cattle. Oecologia 100: 107-117.

West, B.T., K.B. Welch, and A.T. Gałecki. 2007. Linear mixed models: practical guide using statistical software. Chapman & Hall/CRC, Taylor & Francis Group, Boca Raton, Florida, USA.

White, H. 1980. A heteroskedasticity-consistent covariance matrix estimator and a direct test for heteroskedasticity. Econometrica 48: 817-838.

Wollis, H. 1991. Wildlife and aspen management: a government perspective. In S. Navratil and P.B. Chapman, editors. Aspen management for the 21st century. Proceedings of a symposium held November 20-21, 1990, Edmonton, Alberta. For. Can., Northwest Reg., North. For. Cent. and Poplar Counc. Can., Edmonton, Alberta.

4. Effects of Cattle Grazing on Deciduous Regeneration Following Logging

4.1. Introduction

Public lands in Western Canada are important for supporting multiple uses, which include cattle grazing and commercial timber production. Balancing multiple uses provides the basis for public land management and is fundamental to maintaining the ecological integrity of deciduous forests. Successful integration of cattle grazing and timber production on a common land base requires cooperation and collaboration among ranching and forest industries. Careless pursuit of independent resource objectives has the potential to create conflict and animosity between timber and grazing disposition holders, thereby complicating the process of integrated resource management.

In the case of aspen (*Populus tremuloides* Michx.) forests, cattle grazing of regenerating cut blocks has been associated with increased mortality and poorer growth of aspen saplings (Bailey et al. 1990; Dockrill et al. 2004), resulting from browsing, trampling, soil compaction, and hoof shear damage to shallow aspen roots. Provincial regeneration assessments require that aspen saplings be undamaged in order to be accepted in the determination of adequate tree stocking densities (ASRD 2008). As timber companies operating in Alberta are ultimately responsible for sufficient regeneration of cut blocks, any factor causing substandard regeneration increases reforestation costs, reduces profit, and jeopardizes future timber harvesting opportunities.

Logging of aspen creates a mosaic of habitats based on harvest regime and often includes areas of clear cut, partial harvest, uncut forest, and slash accumulated skid roads whereon fallen trees are removed during logging. Following logging, aspen clear cuts naturally re-establish high density stands with up to 100,000 stems/ha (Bella 1986), and experience a pronounced increase in herb growth following understory release from shading and competition (Wollis 1991). The ensuing increase in forage may attract cattle to utilize harvested areas, leading to greater potential for regeneration damage and mortality.

Although aspen typically comprises a relatively small portion of cattle diets (Fitzgerald et al. 1986), the likelihood of browsing is greatest during spring and early summer due to limited understory herbage availability and the favourable quality (i.e. high crude protein) of young succulent saplings (Dockrill et al. 2004). Defoliation just after leaf emergence may increase aspen mortality resulting from decreased photosynthetic capabilities and exhausted carbohydrate reserves (Fitzgerald and Bailey 1984; Bailey et al. 1990). Aspen stem mortality from June grazing was 50% greater compared to ungrazed young aspen stands (Dockrill et al. 2004). Additionally, intense late season aspen browsing has been shown to negatively impact aspen survival due to inadequate carbohydrate storage and winter preparedness following the initiation of regrowth (Fitzgerald and Bailey 1984; Jones et al. 2009). Regardless of season of use, repeated foraging by cattle reduces the long-term probability of aspen survival by depleting root carbohydrate reserves within 6 to 8 years of grazing exposure (Bailey et al. 1990; Dockrill et al. 2004).

While defoliation may damage aspen suckers, this process may not be as strongly associated with sucker mortality as stem trampling (Dockrill et al. 2004). Densely crowded aspen saplings impede animal accessibility, resulting in stem scarring, vertical displacement and breakage when cattle attempt to travel through cut blocks. Damaged saplings do not qualify as healthy and are omitted from provincial regeneration assessments. As aspen sapling phenology advances throughout the summer growing season, aspen stem strength and resistance to hoof shearing increases by 200 to 2000% due to the development of thicker cell walls during lignification (Dockrill et al. 2006). Sustainable livestock grazing during late summer may therefore result in less trampling damage due to improved stem strength and durability.

The extent of cattle induced damage to regenerating saplings is dependent on the presence of alternative forages and livestock stocking rate. Forage depletion resulting from high stocking rates can motivate cattle to occupy dense sapling stands that are typically avoided and consume aspen (Chapter 3). Successful aspen growth and regeneration is hindered by high levels of leader and branch biomass removal, along with episodes of repeated browsing (Jones et al. 2009). Longer periods of cattle grazing (i.e. 2 months vs. 1 month) within cut blocks have resulted in greater damage to aspen saplings (Dockrill et al. 2004). Grazing intensity and duration, as influenced by stocking rate and livestock distribution, need to be managed accordingly to limit the detrimental effects of cattle on tree regeneration (Krzic et al. 2003, 2004; Jones et al. 2009).

The goal of this study was to quantify the effects of growing season (i.e. July) cattle grazing on aspen regeneration 2 and 3 years after timber harvest. Specific research objectives included to:

1. Determine how cattle grazing at two stocking rates affects the extent and type of damage to regenerating deciduous trees.
2. Quantify the effects of cattle grazing on subsequent tree regeneration densities, height and diameter growth, as well as survival.

Ultimately, this research should lead to improved livestock grazing practices consistent with optimizing aspen regeneration and sustaining commercial forestry on multiple use public lands, while also minimizing conflict between livestock and timber industries.

4.2. Materials and Methods

4.2.1. Study Area

This study was conducted within two commercial cut blocks (Fig. A.1, see Appendix A) situated within a pair of cattle grazing leases approximately 5 km northwest of the town of Lodgepole in west central Alberta, from 2008 through 2009. The area is located along the easternmost extent of the Lower Foothills Natural Subregion. Forests in the region are dominated by deciduous tree species including aspen, balsam poplar (*Populus balsamifera* L.) and paper birch (*Betula papyrifera* Marsh.), with secondary succession to white spruce [*Picea glauca* (Moench)]. Soils under forests in the area are

Dark Gray Chernozems and Gray to Dark Gray Luvisols. Other ecosite characteristics include predominantly east to southern aspects, slopes from 0 to 16%, soils with medium to rich nutrient status, and mesic to sub-hygric moisture regimes, with drainage varying from well to imperfect on upper to mid slope positions (Lawrence et al. 2005).

During 2008 and 2009, a temporary weather station erected at the study site recorded a maximum temperature of 33.3^{o}C and a minimum temperature of -39.9^{o}C, while the average annual temperature was 3.8^{o}C. Average monthly temperatures closely resembled the 30 year norm (1971-2000) from Environment Canada’s nearby weather station located at Shining Bank, 94 km northwest of the study site (Fig. B.1, see Appendix B). As precipitation data were not available for the study period from Shining Bank, data for 2008-09 were obtained from Environment Canada’s Violet Grove weather station, 23 km northeast of the study area: total precipitation during 2008 was 375 mm (Fig. B.2), 70% of normal for the region (Environment Canada Shining Bank Normal, 1971 – 2000). Similarly, during 2009 total precipitation was 381 mm, 72% of normal (Environment Canada Shining Bank Normal, 1971-2000). Thirty year weather normals were not available for the Violet Grove station.

The specific study site for this research included deciduous cut blocks 1086 and 1021 (Fig. A.1), located within provincial grazing leases 920022 (legal location: SE 8 – Twnshp 48 – Rge 10 – West 5, 53^{o} 7’43.70$^{''}$N 115^{o} 22’18.65$^{''}$W) and 39275 (NE 4 - Twnshp 48 - Rge 10 – West 5, 53^{o} 7’15.46$^{''}$N 115^{o} 22’55.03$^{''}$W), respectively. Cut blocks were established in January 2006 using standard selective harvesting procedures by Weyerhaeuser Ltd., and led to a mixture of habitat types including clear cut (47% of area), partial harvest (24%), slash accumulated skid road (8%), and uncut forest (19%). Cut blocks also contained brush piles (1%), which were burned during the winter of 2007 and remained as ash pits during grazing trials.

4.2.2. Cattle Grazing Trials

In 2006, two experimental paddocks were constructed within each cut block for a total of four paddocks, each 2.5 to 3 ha in size (Fig A.2). Paddocks 1 and 3 were located within cut block 1021, while paddocks 4 and 5 were established within cut block 1086. Paddocks were laid out to include representative areas of all habitat types (Fig A.3). Additionally, 40 by 40 m exclosures containing all habitat types (where possible) were established within paddocks in 2007 to measure regeneration density and growth in the absence of cattle grazing. However, exclosures likely did not deter wildlife entry and browsing. Grazing trials within paddocks were initiated in early July of 2008 and 2009 using two herds of four mature red angus cross cows obtained from the local grazing lease holder.

In 2008, we tested the effect of two stocking rates: low (0.27 to 0.33 AUM/ha) and high (0.55-0.69 AUM/ha) (Table 4.1). The low stocking rate was in the range of that recommended by Alberta Sustainable Resource Development for mesic and moderately nutrient rich aspen communities within the Lower Foothills Natural Subregion (Lawrence et al. 2005), while the high stocking rate was twice that of the former. In 2009, only a high stocking rate (0.55-0.69 AUM/ha) was implemented due to limited expression of foraging responses resulting from the low stocking rate in year 1. Final stocking rates varied slightly within the low and high treatments due to variability within individual cattle weights and paddock areas. Herd 1 was rotated between paddocks 1 and 3 with the first rotation representing a low stocking rate, while the second rotation throughout the paddocks represented a high accumulative stocking rate (i.e. paddocks were grazed twice to simulate a high stocking rate). Each grazing period was approximately 5 days long. As a result, the low stocking rate was achieved by grazing four cows for 5 days, while the high stocking rate was attained by grazing four cows for 10 days.

Prior to commencing trials in 2008, four mature cows grazed all paddocks at a low stocking rate (0.27 to 0.33 AUM/ha) during August 2007 in order to allow for a 2 year comparison of regeneration inside and outside exclosures.

4.2.3. Regeneration Growth and Damage Assessment

In each of the four paddocks, 60 to 70 permanently marked plots were established in a systematic manner (30 to 40 m spacing) to achieve adequate representation of all habitat types (Fig. A.3). Regeneration assessments followed similar methodology as outlined in the *Alberta Regeneration Survey Manual* (ASRD 2008): each of the 233 plots was circular, 10 m^2 in area, and permanently marked at the centre. Plots were sampled twice in 2008: once after the low stocking treatment, and again after the high stocking treatment. During 2009, data were collected once following the high stocking rate treatment.

Within each plot, tree regeneration assessments were conducted to quantify the number of saplings, along with the height and basal diameter of the tallest saplings of each species. In addition, all saplings were assessed for damage, including browsing, leader breakage, basal scarring, vertical displacement, and mortality. Injured trees were tagged during the first sampling period in 2008 to differentiate between injuries occurring under low versus high stocking rates.

In order to conduct a comparative assessment of regeneration growth in the absence of cattle grazing, sapling counts of each tree species were recorded for up to 5 plots per harvest type within 40 x 40 m cattle-proof exclosures. Finally, height and basal diameter measurements of the tallest sapling of each tree species were measured. Saplings measured for maximum height and basal diameter were marked inside and outside exclosures to ensure that the same trees were visited each year.

4.2.4. Statistical Analysis

All data were checked for normality and equality of variances by assessing histograms and scatter plots of the residuals, in addition to output from Shapiro-Wilk and Levene's tests using Proc UNIVARIATE and Proc GLM (SAS Institute Inc. 2009, Cary, NC, USA), respectively. Although all data were normally distributed, some variables had heterogeneous variances. For these data, log likelihood ratio tests (LRT) were employed to determine whether models accounting for heterogeneous variances provided a better fit over homogeneous models (West et al. 2007). Where the resulting statistic (p-value) was larger than 0.05, the homogenous variance model was considered to provide a better fit. Models accounting for heterogeneous variances offered a superior fit over homogeneous variance models for balsam poplar and white birch height and basal diameter, and the proportion of damaged saplings following grazing in 2009. All other variables were analyzed using homogeneous variance models.

Data were statistically analyzed using an analysis of variance (ANOVA) in Proc MIXED (SAS Institute Inc. 2009). Analyses of the regeneration damage data, along with the comparative assessment of sapling growth inside vs. outside exclosures, were considered strip-plot designs (2 fixed factors: harvest regime and stocking rate or grazing exclusion). Regeneration densities and growth outside exclosures were analyzed using a randomized complete block design (1 fixed factor: habitat). Year was tested as a fixed factor to determine if sapling growth increased from 2008 to 2009. Paddock (i.e. block) was considered random in data sets from both years, and LRTs were employed to determine if the inclusion of a random block by habitat interaction improved model fit. All ANOVA analyses included the calculation of least-squares means for each variable, with main effects and interactions considered significant at $p<0.10$. Differences of least-squares means ($p<0.05$) were computed for all pairwise comparisons using Fisher's least significant difference test (i.e. no multiple comparison adjustment).

4.3. Results

4.3.1. Sapling Density and Growth

Total tree regeneration (including all deciduous species) differed ($p<0.01$) among habitats in both years (Table 4.2). At the end of the study in 2009, clear cuts had the greatest density of saplings at 33,100 ± 4900 stems/ha, while uncut forests and skid roads had lower regeneration densities of 11,600 ± 4900 stems/ha. Regeneration also was lower ($p<0.05$) within partially harvested areas compared to clear cuts at 21,700 ± 4900 stems/ha, but remained greater ($p<0.05$) than uncut forests and skid roads.

Differences in regeneration among habitats were similar during 2008 (Table 4.2), and although regeneration densities tended to be greater in 2009, no difference (p=0.19) was found between years. Within both logged habitats, the average number of trees per plot was 23 in 2008 and 26 in 2009, representing a 13% increase.

Among tree species, aspen (p<0.001) and balsam poplar (p<0.10) stem densities differed among habitats, while white birch regeneration did not (p>0.10). Aspen comprised 80% of total regeneration in 2008, while balsam poplar and white birch contributed 19 and 1%, respectively. Aspen continued to dominate stands in 2009 with 73% of total regeneration, followed by balsam poplar (16%) and white birch (11%). No difference (p=0.98) in regeneration densities was found between years for aspen and balsam poplar, but birch regeneration increased (p<0.01) by 2216 stems/ha in 2009.

Maximum aspen (p<0.05) and balsam poplar (p<0.10) height differed among habitats. Although saplings of aspen and poplar tended to be tallest in clear cuts during both years, they remained similar in height to those in uncut forest (p>0.05) (Table 4.2). However, both aspen and poplar saplings were shorter within skid roads compared to most other habitats, particularly clear cut and partial harvest areas (p<0.05). White birch maximum sapling height did not differ among habitats (p>0.10), although the greatest birch heights were typically found in clear cut and partial harvests. Maximum aspen height increased (p<0.10) by 30 ± 13 cm from 2008 to 2009, while no difference in balsam poplar (p=0.13) or white birch (p=0.54) height was detected between years. Within logged habitats, the average maximum height across all species was 213 cm in 2008 and 237 cm in 2009, representing an 11% increase.

Sapling basal diameters differed (p<0.05) among habitats only for balsam poplar during 2008, with the greatest diameters in clear cuts, followed by partially harvested areas (Table 4.2). Diameter of aspen and white birch remained similar (p>0.10) among habitats in both 2008 and 2009. Stems of all species growing on skid roads typically had the smallest basal diameter. No difference in aspen (p=0.12), poplar (p=0.13), or birch (0.58) diameter was found between years. Within logged habitats, the average basal diameter across all species was 2.4 cm in 2008 and 2.7 cm in 2009, representing a 13% increase.

4.3.2. Effect of Grazing on Sapling Growth

Although total sapling densities tended to be greater in the absence of grazing (Table 4.3), densities did not differ between exclosures compared to outside in either 2008 (p=0.20) or 2009 (p=0.25). A habitat effect was evident (p<0.0001) in both years on sapling density, with clear cuts greater (p<0.05) compared to all other habitats (Table 4.3). Skid roads and uncut forests had the lowest regeneration densities.

Maximum aspen height also failed to differ between the inside and outside of cattle exclosures in 2008 (p=0.12) and 2009 (p=0.83) (Table 4.3). Although no habitat by grazing interaction was detected (p=0.22 in 2008, p=0.53 in 2009), maximum aspen height within clear cuts tended to be taller in the presence of cattle (i.e. outside exclosures). Aspen height also varied among habitats (p<0.001 in 2008, p<0.01 in 2009), with skid roads having the shortest saplings (p<0.05) compared to other habitats (Table 4.3).

Similarly, aspen basal diameter remained unchanged inside and outside of exclosures (p=0.45 in 2008, p=0.90 in 2009), with a habitat effect evident (p<0.05) once again (Table 4.3). The diameter of aspen within skid roads generally remained smaller compared to other habitats. While no habitat by grazing interaction was evident (p=0.21 in 2008, p=0.26 in 2009), aspen basal diameter tended to be larger in the presence of cattle within clear cuts and skid roads (Table 4.3). Across all habitats, regeneration densities exposed to 2 years of grazing were 14% lower compared to that within exclosures, while aspen heights and diameters decreased by 6 and 4%, respectively.

4.3.3. Damage to Regeneration

During the 2008 trials, grazing at a high stocking rate resulted in greater ($p<0.01$) average damage (9.3 ± 1.9%) of all types to saplings compared to the low stocking rate (5.1 ± 1.9%). Damage did not vary ($p=0.26$) across habitats in 2008, with no interaction ($p=0.40$) between stocking rate and habitat (Fig. 4.1). Low and high stocking led to 2.3% and 7.3% of all saplings being damaged by cattle.

Damage to saplings did vary ($p<0.10$) among habitats in 2009; with uncut forests having a greater ($p<0.05$) proportion of damaged trees than within clear cuts and skid roads (Fig. 4.2). Partial harvests sustained intermediate damage and did not differ ($p>0.05$) from other habitats. In 2009, 4.7% of total saplings assessed had some type of damage from cattle following high stocking.

In 2008, browsing was the most common form of stem damage inflicted by cattle (4.7% of all saplings), followed by vertical displacement (1.4%), leader breakage (0.7%), and basal scarring (0.4%). During 2009, vertical displacement was slightly more frequent than browsing (2.0% vs. 1.8%) and basal scarring damage (1.0%) exceeded leader breakage (0.5%). In 2008, 6.8% of all damaged saplings had more than 1 type of damage. In 2009, 23.5% of all damaged saplings showed multiple forms of damage.

While the proportion of saplings with browsing did not differ among habitats in 2008 ($p=0.18$), more saplings were browsed within uncut forests ($p<0.05$) compared to all other habitats during 2009. Also of note was that cattle exhibited a decided affinity for balsam poplar following the high stocking rate treatment in 2008, with 25% of all poplar saplings browsed by cattle (Table 4.4). However, this trend did not continue in 2009, when only 0.5% of balsam poplar was browsed. Similarly, birch saplings were not readily browsed in 2009, with only 1.8% of these saplings experiencing browsing compared to 11% the year before. Aspen saplings generally had low levels of all forms of damage during the high stocking rate treatments in 2008 and 2009, with damage not exceeding 2.3%.

In 2009, saplings growing on skid roads had no vertical displacement ($p<0.05$), while all other habitats sustained less than or equal to 2.6 ± 0.8% vertical displacement.

During 2008, the proportion of saplings vertically displaced did not differ (p=0.65) among habitats. Similarly, the proportion of saplings with leader breakage (p=0.54 in 2008, p=0.27 in 2009) and basal scarring (p=0.75 in 2008, p=0.11 in 2009) remained similar among habitats.

Following the 2008 grazing trials, 13.3% of damaged saplings experienced mortality. Most mortality occurred due to leader breakage and vertical displacement, sometimes in conjunction with basal scarring. In comparison, 15.2% of saplings damaged in 2009 died. Most of this mortality was associated with leader breakage or basal scarring affecting 75% or more of the stem circumference; this damage appeared to be inflicted due to trampling.

4.4. Discussion

Aspen naturally regenerates through root suckering following overstory removal, root damage, or defoliation (David et al. 2001; Frey et al. 2003). Due to the tendency of aspen to proliferate asexually, site preparation and planting are typically unnecessary following clear cutting. Any factor that limits or prevents regeneration through suckering may impair aspen forest re-establishment and therefore serve as an ecological or economic threat in forest management (David et al. 2001; Frey et al. 2003; MacIssac et al. 2006).

High aspen regeneration densities and leaf areas are generally considered advantageous due to greater stand growth rates, uniform tree distribution, and as added insurance in the event of sapling mortality caused by disease, insects or other damage (Frey et al. 2003). From a biological perspective, successful regeneration requires sufficient sapling leaf area development, leading to greater biomass production and total non-structural carbohydrate reserves within roots (Lieffers et al. 2002; Landhäusser and Lieffers 2002; Frey et al. 2003). Minimum acceptable regeneration densities required to ensure successful reforestation are difficult to quantify at a single point in time due to the dynamic nature and self-thinning of young stands during the first 8 years of growth (Navatril 1991). Although David et al. (2001) report that regeneration densities 8 to 10 years post harvest will naturally decline to 5,000 to 10,000 stems/ha, Graham et al. (1963) recommended stands have at least 15,000 aspen saplings per hectare (ha) following clear cut logging to guarantee reforestation, while 30,000 stems/ha was considered optimal. Stem densities observed within our partially harvested areas met minimal expectations, while sucker establishment within clear cuts exceeded optimal guidelines, suggesting that successful cut block reforestation is likely to occur in unison with conservative cattle grazing. The aspen regeneration densities found here following logging were generally similar to those reported elsewhere for the western U.S. (15,000 to 124,000 stems/ha; Bartos and Mueggler 1982), below those in east-central Saskatchewan (>200,000 stems/ha; Bella 1986), and above those found in the Peace region of northern British Columbia (11,626 stems/ha; Krzic et al. 2004).

The Government of Alberta (2009) requires that an establishment survey be completed 4 and 8 years after logging to determine if cut blocks are at least 80% stocked with aspen, balsam poplar or white birch. Cut blocks in our study exceeded this expectation by achieving 96% stocking in both years. Additionally, the Government of Alberta (2009) requires a minimum average sapling height of 80 cm, as well as a minimum average of 7 saplings per regeneration plot for cut blocks located within the Lower Foothills Natural Subregion. This study found sapling abundance and growth to be well in excess of these guidelines. Therefore, it is clear that the cut blocks in our study met the regeneration standards set out by the provincial government despite the presence of cattle grazing at conservative stocking rates.

Partially harvested areas also exhibited satisfactory regeneration, although the final sapling densities at the end of the study in 2009 remained below that of clear cuts. Lower sapling establishment under partial cutting is likely related to the remaining overstory; mature trees produce and transport auxin throughout the root system acting to inhibit sucker initiation (Frey et al. 2003). Residual trees have a competitive advantage for light and resources and the remaining canopy maintains lower soil temperatures through shading, causing reduced sapling ermergence and growth (Maini and Horton 1966; Perala 1991; Huffman et al. 1999; David et al. 2001; Frey 2003).

Similarly, saplings in uncut areas are subject to extensive shading and competition from mature trees. Despite this, observed regeneration densities within uncut forests of the present study were greater than those reported by others, including Bartos and Mueggler (1982) (pre-harvest sucker densities of 1,400 to 4,300 stems/ha) and Krzic et al. (2004) (702 saplings/ha). These studies both concluded that suckers within uncut areas remained small and contributed little to overall forest biomass production.

Skid roads had poorer regeneration and growth compared to clear cuts and partial harvested areas. Reduced regeneration has been attributed to slash accumulation and soil compaction resulting from heavy logging equipment (Bella 1986; Navatril 1991; Bates et al. 1993; Lane 1998; Corns and Maynard 1998; Stone and Elioff 1998; Frey et al. 2003; Berger et al. 2004; MacIssac et al. 2006; Renkema et al. 2009). Soil compaction, reduced soil aeration and associated oxygen levels caused by heavy traffic has been linked to reduced sucker initiation, decreased growth, delayed early stand development, a temporary reduction in tree stocking, and poorer site productivity (Bates et al. 1993; Stone and Elioff 1998). Logging equipment operation can also injure shallow aspen roots, thereby creating an entry point for pathogens and depleting overall carbohydrate reserves required for regeneration (Frey et al. 2003).

Cold soil temperatures and the physical barrier maintained by thick logging slash accumulations have been related to root death leading to poor or no sucker initiation (Bella 1986; Corns and Maynard 1998; David et al. 2001; Frey et al. 2003; Renkema et al. 2009). Logging residue insulates the ground, preventing soil temperatures from reaching the required 15^{o}C necessary for promoting aspen suckering (Maini and Horton 1966). Reduced aspen abundance and growth for up to 14 years has been observed in association with disturbances such as slash piles, landings, and haul roads (Lane 1998; MacIssac et al. 2006).

Removal of the tree canopy and associated shading and competition can also lead to a marked release of understory vegetation (e.g. up to a 69% increase; Krzic et al. 2004), and may impact aspen growth, both directly through modification of growing conditions and resource availability (Powell and Bork 2006), and indirectly by luring cattle into using regenerating cut blocks. Although trending higher in areas without grazing, we found no difference in aspen abundance and size in areas exposed and protected from cattle. However, it should be noted that sapling growth and development within exclosures may not have accurately represented the paddock as a whole. Additionally, other indicators of sapling productivity and health (i.e. leaf area) were not measured, and outcomes may have been different had grazing been implemented during the growing season immediately following timber harvest. Krzic et al. (2003, 2004) found no impact of long term cattle grazing on aspen densities or canopy cover; conversely, Lane (1998) determined that aspen density, height and diameter each declined by at least 27% during 2 years of grazing. Notably, we observed that aspen saplings within clear cuts tended to be larger when exposed to grazing, suggesting cattle may have had a beneficial effect. Following logging, the highly competitive plant marsh reed grass [*Calamagrostis canadensis* (Michx.) Beauv.] can colonize cut blocks, prevent soil warming, and subsequently inhibit or limit aspen suckering and growth (Landhausser and Lieffers 1998; Frey et al. 2003). Thus, cattle grazing at moderate stocking rates may provide a natural form of biological control of marsh reed grass.

Extreme grazing pressure resulting from high stocking rates (e.g. 9 AUM/ha) has been shown to nearly eliminate aspen saplings and prevent the development of a forest canopy in the Aspen Parkland (Fitzgerald and Bailey 1984; Fitzgerald et al. 1986; Bailey et al. 1990). It is important to note that the occurrence of successful regeneration in association with cattle grazing in the current study is due to the implementation of very conservative stocking rates nearly 20 to 30 times smaller than those used by the fore-mentioned studies to control aspen. Dockrill et al. (2004) found improved aspen growth and development when grazing was limited to 1 rather than 2 months, and may therefore account for the limited impact of cattle in the current study. Nevertheless, as the stocking rates used here are consistent with accepted cattle grazing practices on public land in the region, these results suggest that grazing can be consistent with maintaining aspen regeneration, with very low stocking rates more likely to minimize damage to aspen saplings, as the proportion of stems injured increased sharply when stocking rates were doubled.

Irrespective of stocking rate, proportional damage to saplings remained most pronounced within uncut forests, presumably in part because cattle preferred to spend their time within these habitats (see Chapter 3). In contrast, lower damage was observed within clear cuts due to cattle avoidance of these areas, coupled with high stem densities and the physical barrier they present to cattle access. Stem densities of 16,000 to 28,000 stems/ha, in addition to sapling diameters greater than 1.5 cm at breast height, provide an impassable obstruction for mature cows (Krzic et al. 2004). During 2009, skid roads sustained the least damage to aspen saplings, likely due to cattle avoidance caused by inaccessibility under heavy slash accumulation. Downed woody debris impedes herbivore movement and deters entry into foraging areas (Grisez 1960; Jones 1983; Parker et al. 1984; Morgan 1991; Long et al. 1998; Ripple and Larsen 2001; Casabon and Pothier 2007; and de Chantal and Ganström 2007).

When and where damage did occur, browsing was the most common form of damage inflicted by cattle. Dockrill et al. (2004) also found browsing damage to be more frequent than trampling. However, trampling showed a stronger association with stem mortality compared to browsing. Given the favourable forage quality of current year's aspen growth (e.g. crude protein concentration of 13.1%, see Chapter 3), cattle may have been attracted to consume young aspen leaves and twigs. Simulated browsing has shown that aspen growth is greatest when the terminal leader remains intact and less than 25% of axillary branch biomass is removed (Jones et al. 2009), while browsing of the leader had the greatest negative impact on stem growth. Most of the sapling apical leaders measured in our study were taller than the 1.5 m browse line for livestock (with the exception of those growing on skid roads), thereby minimizing the potential for extensive browsing damage. MacIssac et al. (2006) affirm that the threat of browsing is reduced once saplings reach 4 to 5 m height. Interestingly, Jones et al. (2009) observed a positive growth response to browsing of branches provided the terminal leader remained relatively intact (i.e. was browsed less than 20%).

The overall greater proportion of damage to regenerating stems in 2008 than 2009 can be attributed to the unexpected anomaly of targeted cattle browsing of young balsam poplar. We have yet to find a dietary or physiological explanation to corroborate cattle affinity for balsam poplar browse, and in fact other studies highlight the unpalatable nature of young balsam poplar and white birch twigs due to an abundance of anti-quality resins (Risenhoover et al. 1985; Jogia et al. 1989). These resins can be toxic to rumen microbes and negatively affect digestion, leading to decreased nutrient supply and energy for herbivores (Risenhoover et al. 1985). Alternatively, the toxic secondary metabolites present within young balsam poplar twigs may have been detoxified during digestion (Risenhoover et al. 1985).

4.5. Management Implications

Overall, successful aspen re-growth was achieved and forest regeneration standards were surpassed under the grazing practices examined here, with minimal injury to saplings. Stocking rate was a key factor determining the extent of cattle-induced damage to regeneration; an increase in stocking rate was accompanied by greater instance of sapling injury. Even at our high stocking rate, damage to regeneration did not compromise the ability of cut blocks to become adequately reforested. As cut blocks age and evolve, stocking rates should ideally be adjusted to reflect the change in plant communities and forage conditions over time.

Our findings support the notion that sapling damage can be minimized by implementing a grazing system that involves a single annual grazing period with a conservative stocking rate to ensure cattle are not forced to browse saplings or trample stems during their search for forage. Grazing of cut blocks during late summer allows time for greater forage accumulation, lignification of sapling twigs, and improved stem strength and resistance to damage (Lane 1998; Dockrill et al. 2004, 2006), thereby reducing the chance for stem injury and mortality. Given the results, the introduction of cattle grazing at 18 months post-harvest allowed cut blocks to vigorously regenerate and meet provincial reforestation expectations.

The implementation of sustainable grazing management techniques has allowed forest and ranching industries to achieve successful integration within aspen stands of the British Columbia Peace River region (Krzic et al. 2003, 2004), results which coincide with our study findings. Based on our observations, there may be some evidence for the beneficial effect of sustainable grazing in promoting the growth of saplings within dense stands. Research outcomes should lead to improved grazing practices that are consistent with optimizing aspen regeneration and sustaining commercial forestry on Alberta public lands, while also minimizing conflict between livestock and timber industries.

Table 4.1: Dates of cattle rotation for each herd through paddocks to achieve the low and high stocking rate treatments during the 2008 grazing trial. Only the high stocking rate treatment was implemented and tested during the 2009 grazing trial.

			Stocking Rate			
Year	**Herd**	**Paddock**	Low	Low	High	High
2008	1	1	Jul 8–12		Jul 17–23	
	1	3		Jul 12–17		Jul 23–27
	2	4		Jul 12–17		Jul 23–27
	2	5	Jul 8–12		Jul 17–23	
2009	1	1	-	-	Jul 6–16	
	1	3	-	-		Jul 16–26
	2	4	-	-		Jul 16–26
	2	5	-	-	Jul 6–16	

Table 4.2: Average regeneration densities, heights and basal diameters of each tree species throughout habitats and years.

	Habitat				
Year and Response	Clear Cut	Partial Harvest	Uncut Forest	Skid Road	SE
	Regeneration Density (stems/ha X 10,000)				
2008					
Aspen	2.40 a[1]	1.45 b	0.85 b	0.85 b	0.32
Balsam Poplar	0.52 a	0.35 ab	0.23 ab	0.07 b	0.12
White Birch	0.03	0.05	0.02	0.05	0.01
Total Regeneration	2.96 a	1.87 b	1.11 c	0.94 c	0.40
2009					
Aspen	2.45 a	1.46 b	0.82 c	0.83 c	0.30
Balsam Poplar	0.52	0.34	0.23	0.09	0.13
White Birch	0.35	0.35	0.09	0.22	0.16
Total Regeneration	3.31 a	2.17 b	1.16 c	1.16 c	0.49
	Sapling Height (m)				
2008					
Aspen	2.38 a	2.31 a	2.10 a	1.49 b	0.20
Balsam Poplar	2.12 a	2.11 a	1.56 ab	1.30 b	[2] *
White Birch	1.96	2.13	2.18	0.75	[2] **
2009					
Aspen	2.73 a	2.78 a	2.21 ab	1.74 b	0.25
Balsam Poplar	2.42	1.91	1.78	1.48	[2] ***
White Birch	2.27	2.20	1.98	2.16	[2] ****
	Sapling Basal Diameter (cm)				
2008					
Aspen	2.8	2.5	2.5	2.0	0.3
Balsam Poplar	2.6 a	2.4 a	2.0 ab	1.6 b	0.3
White Birch	1.9	2.1	2.6	1.1	[2]*****
2009					
Aspen	3.1	3.1	2.5	2.3	0.3
Balsam Poplar	2.9	2.4	2.2	1.8	[2] ~
White Birch	2.3	2.0	2.3	2.1	[2] ~~

[1] Within a row, means with different letters differ, $p<0.05$.

[2] Standard errors vary between habitats due to missing data points or heterogeneous variances:

* SE clear cut, uncut forest and skid road: 0.23, SE partial harvest: 0.27.

** SE clear cut: 0.38, SE uncut forest and partial harvest: 0.44, SE skid road: 0.76.

*** SE clear cut, uncut forest, and skid road: 0.28, SE partial harvest: 0.32.

**** SE clear cut: 0.32, SE uncut forest and partial harvest: 0.39, SE skid road: 0.46.

***** SE clear cut: 0.1, SE uncut forest: 0.8, SE partial harvest: 0.4, SE skid road: 0.9.

~ SE clear cut, uncut forest, and skid road: 0.3, SE partial harvest: 0.4.

~~ SE clear cut: 0.3, SE uncut forest and partial harvest: 0.4, SE skid road: 0.5.

Table 4.3: Comparison of sapling growth with and without (i.e. inside exclosures) cattle within each habitat during 2008 and 2009. No grazing or grazing by habitat effect was observed.

	Habitat				
Year and Response	Clear Cut	Partial Harvest	Uncut Forest	Skid Road	SE
	Regeneration Density (stems/ha X 10,000)				
2008					
Cattle Present	2.96 a[1]	1.87 b	1.11 bc	0.94 c	0.52
No Cattle	3.81 a	2.03 b	1.32 bc	1.11 c	*
2009					
Cattle Present	3.31 a	2.17 b	1.16 c	1.16 c	0.52
No Cattle	3.58 a	2.24 b	1.66 c	1.24 c	**
	Aspen Height (m)				
2008					
Cattle Present	2.38 a	2.31 a	2.10 a	1.49 b	0.21
No Cattle	2.17 a	2.75 a	2.78 a	1.57 b	***
2009					
Cattle Present	2.73 a	2.78 a	2.21 a	1.74 b	0.25
No Cattle	2.42 a	2.78 a	2.74 a	1.70 b	~
	Aspen Basal Diameter (cm)				
2008					
Cattle Present	2.8 a	2.5 a	2.5 a	2.0 b	0.3
No Cattle	2.4 a	3.0 a	3.4 a	1.8 b	~~
2009					
Cattle Present	3.1 a	3.2 a	2.6 a	2.3 b	0.3
No Cattle	2.6 a	3.2 a	3.4 a	2.0 b	~~~

[1] Within a row, means with different letters differ, $p<0.05$.

[2] Standard errors vary between habitats due to missing data points or heterogeneous variances:

* SE clear cut and skid road: 0.52, SE partial harvest: 0.57, SE uncut forest: 0.64.

** SE clear cut and skid road: 0.52, SE partial harvest: 0.54, SE uncut forest: 0.58.

*** SE clear cut and skid road: 0.21, SE partial harvest: 0.24, SE uncut forest: 0.30.

~ SE clear cut and skid road: 0.25, SE partial harvest: 0.29, SE uncut forest: 0.36.

~~ SE clear cut, partial harvest and skid road: 0.3, SE uncut forest: 0.4.

~~~ SE cear cut and skid road: 0.3, SE partial harvest and uncut forest: 0.4.
~~~

Table 4.4: Proportion of total tree saplings by species damaged through browsing, leader breakage, vertical displacement and basal scarring. All data are from the high stocking rate treatment.

	2008			**2009**		
Type of Damage	Aspen	Balsam Poplar	White Birch	Aspen	Balsam Poplar	White Birch
	% of Saplings Damaged					
Browsing	0.6	25.1	11.4	1.9	0.5	1.8
Leader Breakage	0.6	0.8	0	0.6	0.5	0.4
Vertical Displacement	1.1	2.7	0	2.3	2.3	0
Basal Scarring	0.4	0.4	0	1.2	0.8	0
Total Stem Count	3717	864	70	3803	855	562

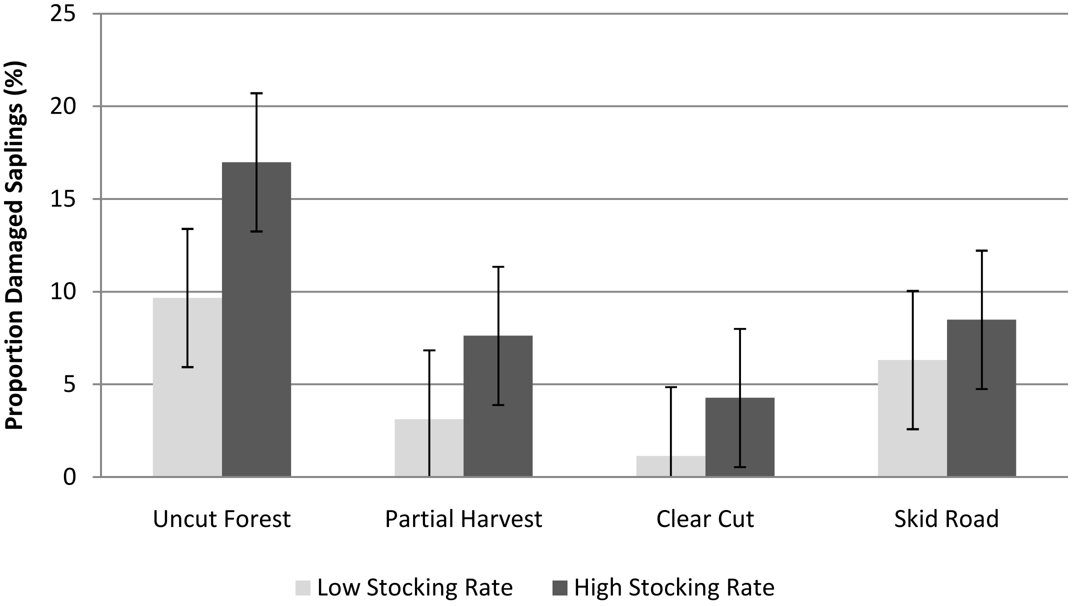

Figure 4.1: Mean (±3.7) proportion of saplings damaged following grazing under low and high stocking rates in 2008. Proportion of damaged saplings was greater under (p<0.01) the high stocking rate, but did not vary (p=0.26) among habitats.

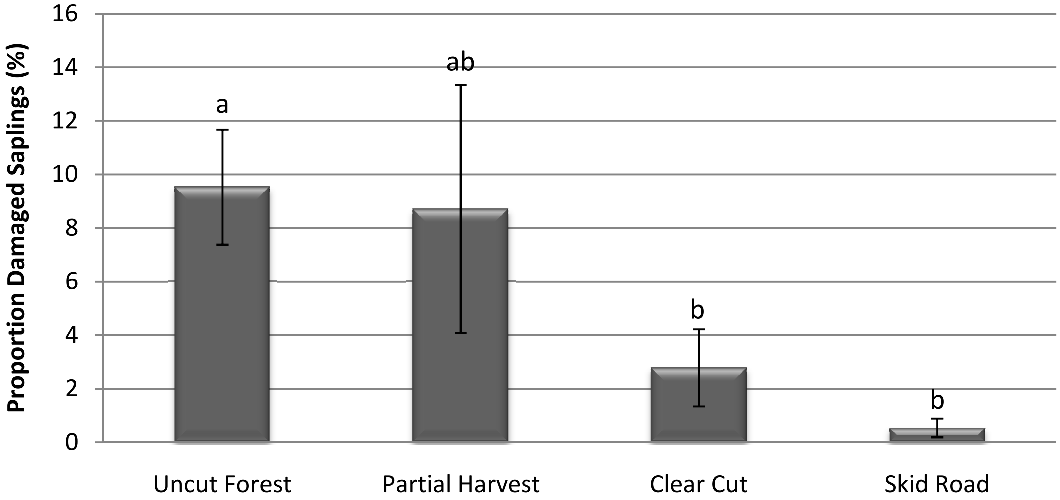

Figure 4.2: Average proportion of saplings damaged following grazing under the high stocking rate treatment in 2009, p<0.10. Standard errors vary among habitats due to heterogeneous variances: uncut forest (±2.2), partial harvest (±4.6), clear cut (±1.4), skid road (±0.4).

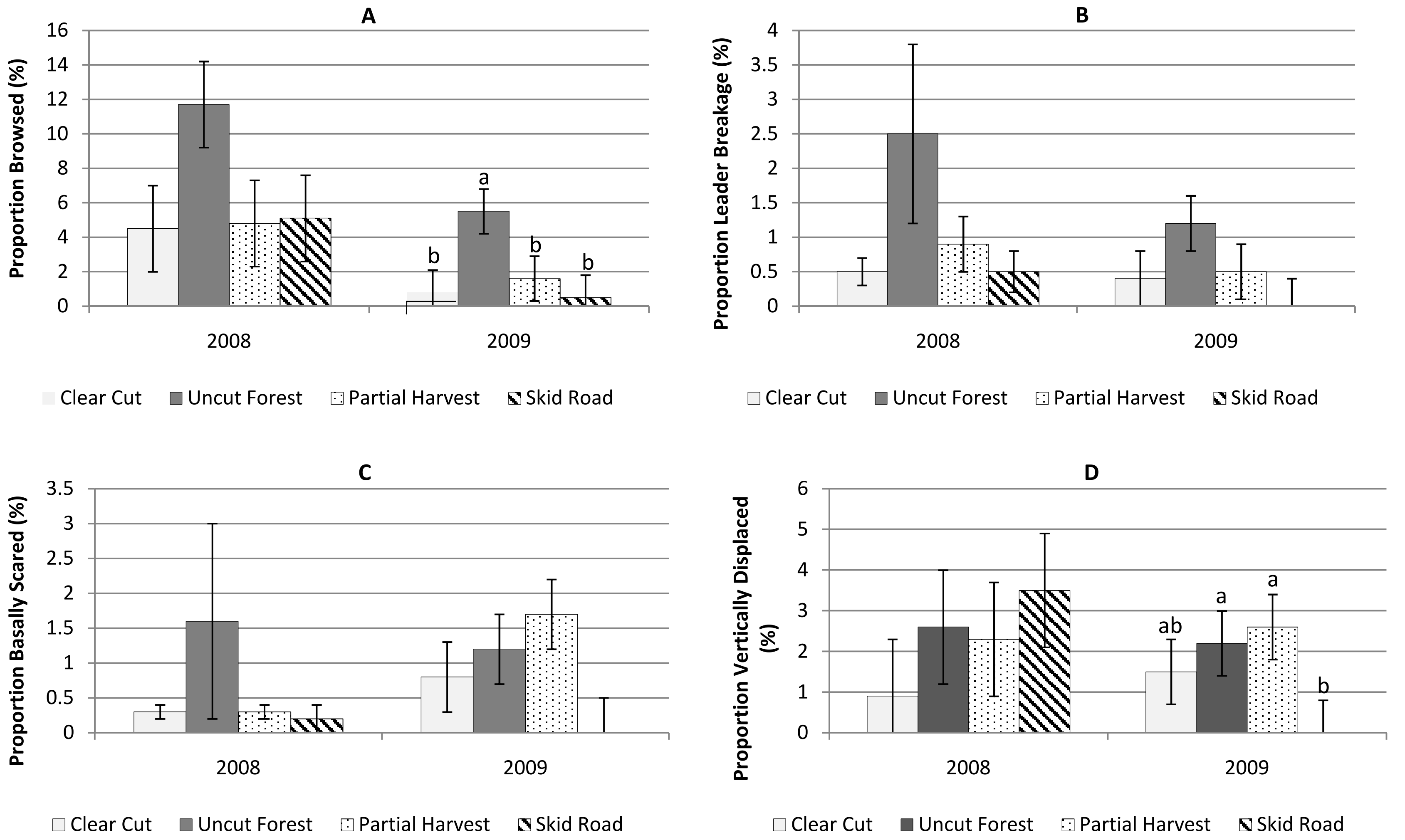

Figure 4.3: Average proportion of saplings injured by A) browsing, B) leader breakage, C) basal scarring, and D) vertical displacement, during the high stocking rate treatments in 2008 and 2009.

4.6. Literature Cited

Alberta Sustainable Resource Development. 2008. Alberta regeneration survey manual. Forest Management Branch, Edmonton, Alberta, Canada. Publication No. T/181. ISBN No. 978-0-7785-7039-4 (On-line Edition).

Bailey, A.W., B.D. Irving, and R.J. Fitzgerald. 1990. Regeneration of woody species following burning and grazing in aspen parkland. Journal of Range Management 43(3): 212-215.

Bartos, D.L. and W.F. Mueggler. 1982. Early succession following clearcutting of aspen communities in northern Utah. Journal of Range Management 35(6): 764-768.

Bates, P.C., C.R. Blinn, and A.A. Alm. 1993. Harvesting impacts on quaking aspen regeneration in northern Minnesota. Canadian Journal of Forest Resources 23: 2403-2412.

Bella, I.E. 1986. Logging practices and subsequent development of aspen stands in east-central Saskatchewan. The Forestry Chronicle 62: 81-83.

Berger, A.L, K.J. Puettmann, and G.E. Host. 2004. Harvesting impacts on soil and understory vegetation: the influence of season of harvest and within-site disturbance patterns on clear-cut aspen stands in Minnesota. Canadian Journal of Forest Resources 34: 2159-2168.

Casabon, C. and D. Pothier. 2007. Browsing of tree regeneration by white-tailed deer in large clearcuts on Anticosti Island, Quebec. Forest Ecology and Management 253: 112-119.

Corns, I.G.W. and D.G. Maynard. 1998. Effects of soil compaction and chipped aspen residue on aspen regeneration and soil nutrients. Canadian Journal of Soil Science 78: 85-92.

David, A.J., J.C. Zasada, D.W. Gilmore, and S.M. Landhäusser. 2001. Current trends in the management of aspen and mixed aspen forests for sustainable production. The Forestry Chronicle 77(3): 525-532.

de Chantal, M. and A. Granström. 2007. Aggregations of dead wood after wildfire act as browsing refugia for seedlings of *Populus tremula* and *Salix caprea*. Forest Ecology and Management 250: 3-8.

Dockrill, C.W.M., P.V. Blenis, A.W. Bailey, and J.R. King. 2004. Effect of summer cattle grazing on aspen stem injury, mortality and growth. The Forestry Chronicle 80(2): 257-261.

Dockrill, C.W.M., A.W. Bailey, P.V. Blenis, and J.R. King. 2006. Seasonal variation in resistance of aspen stems to shearing force. Rangeland Ecology and Management 59(2): 212-215.

Fitzgerald, R.D. and A.W. Bailey. 1984. Control of aspen regrowth by grazing with cattle. Journal of Range Management 37(2): 156-158.

Fitzgerald, R.D., R.J. Hudson, and A.W. Bailey. 1986. Grazing preferences of cattle in regenerating aspen forest. Journal of Range Management 39(1): 13-18.

Frey, B.R., V.J. Lieffers, S.M. Landhäusser, P.G. Comeau, and K.J. Greenway. 2003. An analysis of sucker regeneration of trembling aspen. Canadian Journal of Forest Resources 33: 1169-1179.

Government of Alberta. 2009. Alternative regeneration standards manual: establishment survey standard. Online edition: http://www.srd.alberta.ca/managingprograms/ForestManagement/documents/ARS_Establishment_Survey_Standard_May_09.pdf

Graham, S.A., R.P. Harrison, Jr., and C.E. Westell, Jr. 1963. Aspens: Phoenix trees of the Great Lakes Region. The University of Michigan Press, Ann Arbor, Michigan, USA.

Grisez. T.J. 1960. Slash helps protect seedlings from deer browsing. Journal of Forestry 58: 385-387.

Huffman, R.D., M.A. Fajvan, and P.B. Wood. 1999. Effects of residual overstory on aspen development in Minnesota. Canadian Journal of Forest Resources 29: 284-289.

Jogia, M.K., A.R.E. Sinclair, and R.J. Andersen. 1989. An antifeedant in balsam poplar inhibits browsing by snowshoe hares. Oecologia 79: 189-192.

Jones, K.L. 1983. Current knowledge of the effects of cattle grazing on aspen in the Alberta parkland. Rangelands 5(2): 59-60.

Jones, B.E., D.F. Lile, and K.W. Tate. 2009. Effect of simulated browsing on aspen regeneration: implications for restoration. Rangeland Ecology and Management 62(6): 557-563.

Krzic, M., R.F. Newman, and K. Broersma. 2003. Plant species diversity and soil quality in harvested and grazed boreal aspen stands of northeastern British Columbia. Forest Ecology and Management 182: 315-325.

Krzic, M., H. Page, R.F. Newman, and K. Broersma. 2004. Aspen regeneration, forage production, and soil compaction on harvested and grazed boreal aspen stands. BC Journal of Ecosystems and Management 5(2): 30-38.

Landhäusser, S.M. and V.J. Lieffers. 1998. Growth of Populus tremuloides in association with Calamagrostis Canadensis. Canadian Journal of Forest Resources 28: 396-401.

Landhäusser, S.M. and V.J. Lieffers. 2002. Leaf area renewal, root retention and carbohydrate reserves in a clonal tree species following aboveground disturbance. J. Ecol. 90: 658-665.

Lane, C.T.P. 1998. Effects of full-tree skidding and livestock grazing on aspen regeneration. M.Sc. Thesis, University of Alberta, Edmonton, Alberta, Canada.

Lawrence, D., C.T. Lane, M.G. Willoughby, C. Hincz, D. Moisey, and C. Stone. 2005. Range plant community types and carrying capacity for the lower foothills subregion of Alberta. Fourth approximation. Alberta Sustainable Resource Development, Public Lands and Forest Division. Pub. No. T/083. ISBN. No. (On-line edition) 0-7785-4098-7.

Liffers, V.J., B.D. Pinno, and K.J. Stadt. 2002. Light dynamics and free-to-grow standards in aspen-dominated mixedwood forests. The Forestry Chronicle 78: 137-145.

Long, Z.T., W.P. Carson, and C.J. Peterson. 1998. Can disturbance create refugia from herbivores: an example with hemlock regeneration on treefall mounds. Journal of the Torrey Botanical Society 125(2): 165-168.

MacIsaac, D.A., P.G. Comeau, and S.E. Macdonald. 2006. Dynamics of regeneration gaps following harvest of aspen stands. Canadian Journal of Forest Resources 36: 1818-1833.

Maini, J.S. and K.W. Horton. 1966. Vegetative propagation of Populus spp. I. Influence of temperature on formation and initial growth of aspen suckers. Can. J. Bot. 44: 1183-1189.

Morgan, R.K. 1991. The role of protective understorey in the regeneration system of a heavily browsed woodland. Vegetation 92: 119-132.

Navatril, S. 1991. Regeneration challenges. In S. Navratil and P.B. Chapman, editors. Aspen management for the 21st century. Proceedings of a symposium held

November 20-21, 1990, Edmonton, Alberta. For. Can., Northwest Reg., North. For. Cent. and Poplar Counc. Can., Edmonton, Alberta.

Parker, K.L., C.T. Robbins, and T.A. Hanley. 1984. Energy expenditures for locomotion by mule deer and elk. Journal of Wildlife Management 48(2): 474-488.

Perala, D.A. 1991. Renewing decadent aspen stands. In S. Navratil and P.B. Chapman, editors. Aspen management for the 21st century. Proceedings of a symposium held November 20-21, 1990, Edmonton, Alberta. For. Can., Northwest Reg., North. For. Cent. and Poplar Counc. Can., Edmonton, Alberta.

Powell, G.W. and E.W. Bork. 2006. Aspen canopy removal and root trenching effects on understory vegetation. Forest Ecology and Management 230: 79-90.

Renkema, K.N., V.J. Lieffers, and S.M. Landhäusser. 2009. Aspen regeneration on log decking areas as influenced by season and duration of log storage. New Forests 38(3): 323-335.

Ripple, W.J. and E.J. Larsen. 2001. The role of postfire coarse woody debris in aspen regeneration. Western Journal of Applied Forestry 16(2): 61-64.

Risenhoover, K.L., L.A. Renecker, and L.E. Morgantini. 1985. Effects of secondary metabolites from balsam poplar and paper birch on cellulose digestion. Journal of Range Management 38(4): 370-372.

Sharrow, S.H. 2007. Soil compaction by grazing livestock in silvopastures as evidenced by changes in soil physical properties. Agroforesty Systems 71: 215-223.

Stone, D.M. and J.D. Elioff. 1998. Soil properties and aspen development five years after compaction and forest floor removal. Canadian Journal of Soil Science 78: 51-58.

West, B.T., K.B. Welch, and A.T. Gałecki. 2007. Linear mixed models: practical guide using statistical software. Chapman & Hall/CRC, Taylor & Francis Group, Boca Raton, Florida, USA.

Wollis, H. 1991. Wildlife and aspen management: a government perspective. In S. Navratil and P.B. Chapman, editors. Aspen management for the 21st century. Proceedings of a symposium held November 20-21, 1990, Edmonton, Alberta. For. Can., Northwest Reg., North. For. Cent. and Poplar Counc. Can., Edmonton, Alberta.

5. Cattle Habitat Selection and Foraging Behaviour Within Montane Rangelands

5.1. Introduction

Public lands in Western Canada are important for supporting multiple uses, including cattle grazing and timber harvest. Balancing multiple uses provides the basis for public land management and is fundamental to maintaining the ecological integrity of forested rangelands. However, lack of cooperation between forest and cattle industries as they pursue independent resource goals on a common land base can create conflict, thereby complicating the process of integrated resource management (Mitchell et al. 1982). In order to mitigate disagreement between the forest and ranching industries, a greater understanding is required of how cattle utilize the landscape and the underlying factors that may influence their site selection within heterogeneous montane rangelands containing recently harvested cut blocks.

Mountainous forested landscapes are comprised of a mosaic of habitats including interspersed grasslands and scattered aspen stands, among widespread conifer and mixed wood forests. Most research into cattle grazing on conifer rangelands concludes that cattle spend a relatively small proportion of their time within forested areas (Roath and Krueger 1982; Zimmerman and Neuenschwander 1984; Kie and Boroski 1996) and prefer to graze low lying (and typically more productive) range sites instead (Hart et al. 1991). Cattle grazing within forested areas of the Sierra Nevada Mountains of California exhibited greatest preference for riparian areas, followed by clear cuts, second-growth forest, and lastly, burned areas (Kie and Boroski 1996).

Aside from accessibility, the primary factors influencing habitat preference by cattle are forage quantity and quality, as animals generally strive to optimize nutrient intake at minimal energetic cost (Senft et al. 1987). Roath and Krueger (1982) found that cattle distribution and use across forested ranges could be related to vegetation type and forage quality. Elements affecting forage quantity and quality include community composition, plant morphology, the presence of secondary compounds and associated palatability, as well as growing conditions (Senft et al. 1987; Senft 1989; Chapman et al. 2007). On a ponderosa pine (*Pinus ponderosa* Douglas ex C.Lawson) rangeland in Arizona, forage consumption by cattle was positively influenced by increasing grass biomass and decreasing tree density (Clary et al. 1978). Those habitats that provide the most favourable forage attributes are likely to experience greater cattle occupancy compared to those areas with less desirable vegetation.

Cattle distribution across the landscape and associated use of vegetation is further affected by habitat accessibility, temperature, shelter from the elements, and protection from pests (Owens et al. 1991; Beaver and Olson 1997; Launchbaugh and Howery 2005). Distance to low elevation free standing water is known to strongly influence cattle locations and habitat preference (Roath and Krueger 1982; Kie and Boroski 1996). Livestock avoid areas within mountainous forested landscapes associated with steep slopes, closed overstory canopies, north and west-facing aspects, as well as sparse vegetation (Roath and Krueger 1982; Kie and Boroski 1996).

Following timber harvest, large quantities of slash and wood residue may be left on and above the soil surface, and act as a physical or visual barrier to grazing. Accumulated logging slash presents a challenge for livestock in that it physically prevents cattle from accessing forage, or cattle may become injured when attempting to walk over it (Jones 1983; Morgan 1991). Over time livestock may associate areas of high slash accumulation with high energy costs and low forage availability, leading them to continually avoid these areas (Parker et al. 1984; Forester et al. 2007).

Livestock producers can alter cattle foraging behaviour by managing the timing, intensity and duration of grazing (McLean and Clark 1980; Eissenstat et al. 1982; Newman et al. 1994; Pitt et al. 1998). Range use by cattle varies with season as a result of altered forage quality and quantity. Forage depletion resulting from high stocking rates can motivate cattle to access less favourable grazing sites that are unproductive, nutrient poor, or less accessible (Senft et al. 1983; Hart et al. 1991). In this situation, stocking rates need to be reduced and livestock distribution adjusted accordingly in order to limit the detrimental effects of cattle grazing on tree regeneration (Newman et al. 1994; Pitt et al. 1998; Krzic et al. 2003, 2004). When stocking rates are properly matched to available forage resources within primary ranges, specifically grasslands and deciduous forest, damage to conifer seedlings can be minimized (McLean and Clark 1980; Cutter et al. 1999). However, this is also based on the assumption that cattle demonstrate a decided preference for these habitats over that of cut blocks.

The goal of this study was to assess cattle selection of various Montane habitats including conifer cut blocks, aspen, conifer, and mixed wood forests, and lowland modified and upland native grasslands. Additionally, we wanted to quantify the factors influencing forage use by cattle within all habitats with the exception of cut blocks; an in depth and detailed analysis of the mechanisms affecting cattle occupancy within cut blocks is provided in Chapter 6. Specific research objectives included to:

1. Determine cattle preferences for various habitats within heterogeneous montane rangelands,
2. Identify mechanisms regulating cattle forage use at the patch and landscape levels, including forage quantity and quality, accessibility (i.e. proximity to roads) and environmental characteristics (i.e. topography and distance to water).

5.2. Materials and Methods

5.2.1.Study Area

This study was conducted within two provincial grazing allotments of the Rocky Mountain Forest Reserve of south western Alberta, from June 2008 through October 2009. The area, known as the Porcupine Hills, is situated within the Montane Natural Subregion. The specific study site for this research was located approximately 46 km north of the town of Pincher Creek and included three distribution units (Damon-836 ha, North Sharples-364 ha, and Prong Coulee-1035 ha) (Fig. A.4, see Appendix A) within the Sharples Creek and Skyline public grazing allotments (49^{o}53’46.89”N, 114^{o}01’41.20”W) (legal location: Twnshps 10 & 11-Rge 1-West 5) administered by Alberta Sustainable Resource Development.

The area is characterized by rolling topography with dramatic relief, slopes ranging from 6 to 30 %, and elevations of 1400 to 1700 m above sea level. Different plant communities and soils are present across the landscape as a result of variation in topographic relief, aspect and resultant moisture availability. Native upland grasslands occupy south to south west facing slopes with rapid drainage, and are comprised of primarily foothills rough fescue (*Festuca campestris* Rydb.), Parry's oat grass (*Danthonia parryi* Scribn.), Richardson's needle grass (*Stipa richardsonii* Link), and Idaho fescue (*Festuca idahoensis* Elmer). Modified lowland grasslands occur near water sources where livestock grazing has been historically concentrated (Willoughby et al. 2005), and are dominated by introduced and invasive species including bluegrasses (*Poa spp.*), timothy (*Phleum pratense* L.), and smooth brome (*Bromus inermis* Leyss.). Trembling aspen stands (*Populus tremuloides* Michx.) are found on well drained mesic sites and represent transitional plant communities between grasslands and conifer forests. Dense stands of lodgepole pine (*Pinus contorta* Loudon) occupy mesic sites, while Douglas fir [*Pseudotsuga menziesii* (Mirb.)] forests are the climax vegetation on steep south facing slopes with shallow, rocky soils and rapid drainage (Willoughby et al. 2005). Limber pine (*Pinus flexilis* James) is found on exposed sandstone outcrops and xeric hillcrests with shallow and poorly developed soils (Willoughby et al. 2005). Mixed wood forests comprised of aspen and coniferous species represent successional communities that transition to pure conifer stands at climax. Mesic to submesic grassland and aspen plant communities are associated with Black Chernozemic soils, while steep, south facing, or exposed sites are characterised by Regosolic and Brunisolic soils.

The Montane experiences two precipitation peaks annually: May-June and August-September (Willoughby et al. 2005). Environment Canada's Connelly Creek (49^{o}36'58.030"N 114^{o}12'54.080"W) weather station recorded total precipitation during 2008 at 378.5 mm (Fig. B.3, see Appendix B), only 65% of normal (Environment Canada Connelly Creek Normal, 1971 – 2000). Greater precipitation occurred during 2009 at 521.7 mm, representing 90% of normal (Environment Canada Connelly Creek Normal, 1971-2000). Average annual temperatures at the Connelly Creek weather station during

2008 and 2009 were 5.1°C and 4.1°C, respectively (Fig. B.4). Environment Canada reports the 30 yr average annual temperature at 4.8°C (Environment Canada Connelly Creek Normal, 1971-2000), with temperature extremes ranging from > 35°C during summer to approximately -45°C in winter.

For the purposes of this study, six main habitat types were identified across the landscape: native upland grassland (19% of total area), modified lowland grassland (3%), aspen (11%), conifer forest (51%), mixed wood forest (10%) and conifer cut block (5%). Commercial timber harvest was conducted by Spray Lakes Sawmills during December 2005, and January and March 2006. Following logging, cut blocks were scarified during October and December of 2006 using skidder machines with ripper teeth mounted on the blades. Cut blocks were planted with lodgepole pine and white spruce (*Picea glauca* (Moench)) seedlings during July 2007.

5.2.2. Cattle Grazing Trials and Spatial Assessment

A herd of approximately 311 mature black angus cross cow-calf pairs and 10 bulls grazed the Damon, North Sharples, and Prong Coulee distribution units sequentially during July, August and September of 2008 and 2009, although the sequence of grazing varied from year to year (Table 5.1). Resulting stocking rates were 0.35 to 0.59 AUM/ha (Table 5.1). Lotek Wireless Inc. (Newmarket, ON) 3300LR GPS collars were placed on eleven randomly selected cows to track animal locations and study spatial patterns of habitat selection. Collars were correctly fitted to each cow by Alberta Sustainable Resource Development (ASRD) staff to ensure safety and comfort. Prior to releasing cattle into the distribution unit and commencing grazing, cattle were given a period of time to become accustomed to collars, which weighed approximately 0.95 kg. Collars remained on animals for the duration of the grazing period in each year and were programmed to record GPS locations of each animal every 10 minutes. Data recorded during every GPS fix included animal location (latitude, longitude, and elevation), date and time, the dilution of precision value, fix status (2D or 3D) and ambient temperature.

A detailed description of dilution of precision (DOP) and the difference between 2D and 3D fixes is provided in Section 2.6 of Chapter 2.

At the end of the grazing periods in each year, collars were removed from cattle and location data downloaded. In order to improve spatial data accuracy, data were converted to RINEX format using Lotek's N4 computer program and differentially corrected using Pleiades Data Corp. (Calgary, AB) reference station data from Lethbridge, AB. Accuracy of GPS locations using Lotek 3300LR collars is within 5 m or less following differential correction, and can be influenced by atmospheric, satellite and receiver errors. Once corrected, all GPS fixes with a DOP value greater than 6 were removed to improve data quality, resulting in 73,064 locations remaining from 2008 and 87,486 from 2009.

Locations were converted to Universal Transverse Mercator (UTM) values and intersected with spatial files of habitats using ArcGIS 9.2 (ESRI®, Redlands, CA, USA). Three dimensional figures were created in ArcScene (ESRI®) to show cattle locations within distribution units (see Figures D.1 – D.6 in Appendix D). Prior to initiation of the study, a detailed rangeland inventory was conducted of the grazing allotments, and plant communities mapped by Alberta Sustainable Resource Development, Pincher Creek. Ivlev's electivity index (Ivlev 1961) (see Equation [1]) was used to determine cattle habitat preference by comparing habitat use (proportion of time spent in each habitat) in relation to habitat availability (proportion of total habitat consisting of a given habitat).

$$\text{Electivity}_{\text{habitat}} = (\%\ \text{time spent}_{\text{habitat}} - \%\ \text{area}_{\text{habitat}})/(\%\ \text{time spent}_{\text{habitat}} + \%\ \text{area}_{\text{habitat}}) \qquad [1]$$

Electivity data range from +1 to -1, with +1 indicating perfect habitat preference or selection, while -1 indicates complete habitat avoidance. Values at or near zero indicate random selection (i.e. habitat use in direct proportion to habitat availability).

5.2.3. Cattle Use and Vegetation Measures

Collection of field data served to support cattle GPS locations and explain patterns of habitat use. Data collection occurred immediately following each period of grazing within each distribution unit. Permanent sample plots laid out in a coarse grid (i.e. minimum of 50 m apart) across the study area were used to sample habitat types in a systematic manner, with each habitat type (excluding cut blocks) containing at least eleven plots per distribution unit (Fig. A.5). The same plots were visited each year, with the exception of additional plots established in 2009. All plots were circular and 10 m^2 in area. Within each distribution unit and habitat type, two range cages, 1.5 x 1.5 m in size, were paired with randomly selected plots for the assessment of ungrazed biomass and quantification of forage utilization. Additionally, range cage data were used to calibrate ocular estimations of standing biomass in all plots. In order to complement GPS data and gather information on the factors potentially responsible for cattle habitat preference, the following data were collected at each plot:

1. Evidence of cattle visitation in the form of tracks, grazing, or defecation (presence/absence per plot),
2. Ocular estimates of standing biomass by growth form, to the nearest 250 kg/ha,
3. Biomass clippings within a 0.5 m^2 quadrat from within those plots where range cages were present: two cages per habitat type per distribution unit. Biomass clippings were taken inside and outside cages and separated into grass, forb and shrub (current annual growth only) components. Biomass clippings were used to validate and adjust (if needed) biomass estimates. Simple linear regressions showing the relationship between actual and estimated biomass values (i.e. the ability to recognize incremental changes in production) for each year are shown in Figures C.3 through C.5 in Appendix C. Biomass samples were retained for quality analysis at a later date.
4. Ocular assessment of forage utilization (%). Where range cages were present, actual utilization was calculated by comparing dry matter biomass (kg/ha) inside and outside of cages using Equation [2]. Simple regressions summarizing the relationship between actual biomass removal and estimated utilization values (i.e. the ability to distinguish incremental use) for each year are provided in Figure C.6. These relationships should be interpreted with care, as actual field biomass determination

is prone to experimental error due to vegetation heterogeneity (Bork and Werner 1999). While ocular estimates can account and compensate for variation, small field samples are generally less able to do so.

Forage utilization (%) = (inside cage kg/ha – outside cage kg/ha)/inside cage kg/ha * 100 [2]

5. Biophysical attributes within each plot were assessed, including plant species composition (i.e. foliar cover of 3 dominant herbs and 3 dominant shrubs, see Appendix E), canopy cover (%) of trees, slope gradient (%) using a clinometer, aspect (^{o}) using a compass, and elevation using a handheld GPS unit.

Finally, distance to the nearest water source from each permanent sample plot was calculated using ArcGIS 9.2 (ESRI®) software.

5.2.4. Forage Quality Analysis

Plant biomass samples were dried at 45^{o}C for 48 hrs to constant mass, and weighed. Samples were then ground to 1 mm using a Thomas® Scientific (Swedesboro, NJ, USA) Wiley Mill in preparation for proximate analysis. Crude protein (CP) and acid detergent fibre (ADF) concentrations were determined for grass, forb and shrub samples. Where sample quantity was limited, protein analysis was prioritized over ADF due to the relative greater importance of protein intake over digestible energy for herbivores (Senft et al. 1987). Crude protein content was estimated by measuring the nitrogen concentration of forage using the Dumas (1831) method in association with a LECO® (St. Joseph, MI, USA) TruSpec FP-428 analyzer. The Dumas method employs high temperature (800 to 1000^{o}C) combustion to convert all forms of nitrogen within the sample first to nitrogen oxides, followed by reduction to N_2, which is subsequently measured by thermal conductivity detection (Kowalenko 2001, Jung et al. 2003). Nitrogen values were subsequently converted to CP concentration by multiplying nitrogen values by 6.25. Concentrations of CP were calculated separately for forb, grass and shrub components.

The ANKOM 200 (ANKOM Technology, Macedon, NY, USA) filter bag technique was used to determine ADF concentrations, which uses a sulphuric acid and cetyl trimethylammonium bromide solution to digest all plant matter except cellulose and lignin residues (Vogel et al. 1999). The portion of sample lost through the process is considered to be available digestible energy for herbivores. Following digestion, samples are cleansed with acetone to remove any remaining impurities and dried at 100°C for 2 hrs. Upon removal from the drying oven, samples are placed in a desiccator to prevent moisture uptake prior to weighing to the nearest 0.0001 gram.

5.2.5. Statistical Analysis

To assess forage characteristics, cattle electivity, and the extent of cattle utilization among habitats, all data were first checked for normality and equality of variances by assessing histograms and scatter plots of the residuals, in addition to output from the Shapiro-Wilk and Levene's tests using Proc UNIVARIATE and Proc GLM (SAS Institute Inc. 2009, Cary, NC, USA), respectively. Although all data were normally distributed, some variables had heterogeneous variances. For these data, log likelihood ratio tests (LRT) were employed to determine whether models accounting for heterogeneous variances provided a better fit over homogeneous models (West et al. 2007). Where the resulting statistic (p-value) was larger than 0.05, the homogenous variance model was considered to provide a better fit. Models accounting for heterogeneous variances offered a superior fit over homogeneous variance models for cattle electivity, shrub biomass, and grass ADF data sets.

Differences in forage characteristics, cattle electivity, forage use by cattle, and the proportion of plots showing cattle occupancy were each analyzed using an analysis of variance (ANOVA) in Proc MIXED (SAS Institute Inc. 2009). Analyses were considered to be randomized complete block designs with habitat as a fixed factor. Distribution unit (i.e. block) and year were considered random in all data sets and LRTs were employed to determine if including random interactions (i.e. block*year, block*habitat, habitat*year) improved model fit. All ANOVA analyses included the calculation of least-squares means for each variable, with main effects and interactions considered significant at $p<0.10$. Differences of least-squares means ($p<0.05$) were computed for all pairwise comparisons using Fisher's least significant difference test (i.e. no multiple comparison adjustment). Electivity values were further tested to determine significant ($p<0.10$) deviation from zero using a one-sample t-test (PROC TTEST) with a two-tailed hypothesis (SAS Institute Inc. 2009).

Multiple regression (Proc REG) with stepwise model selection (SAS Institute Inc. 2009) was used to identify the environmental factors associated with cattle forage use at the patch (i.e. plot) and landscape (i.e. distribution unit) levels, with model entry and stay levels set at $p\leq0.10$ for predictor variables. For multiple regressions at the landscape scale, response and independent variables were averaged among plots for each habitat within each distribution unit and year. Prior to regression, residuals were checked for normality by examining residual plots of observed vs. expected values. Additionally, data were assessed for collinearity among variables by applying variance inflation factor (VIF) and tolerance (TOL) options; VIF values less than 10 and TOL values greater than 0.1 indicated no collinearity (Belsley et al. 1980). Correlations were also conducted to identify variables associated with a correlation coefficient (r) greater than or equal to 0.6. As a result of strong correlation between forage CP and ADF, the ADF variable was removed from the model. White's test was employed to test the assumption of homogeneous variances (White 1980).

Ocular estimations of forage utilization (%) (dependent variable) were related to several independent variables including forage biomass estimates, forage protein, slope, elevation, aspect (cosine transformed (Platts et al. 2008)), canopy cover, and distance to nearest water source and gravel road. Biomass estimates were adjusted using forage utilization estimates to determine the available forage prior to grazing (see Equation [3]). At the patch scale, habitats and distribution units were not included as independent variables because prior exploratory analysis revealed a low proportion of variation (i.e. 3% combined) related to these regressors.

$$\text{Forage biomass} = \text{post grazing biomass estimate} / (1 - \text{estimate of proportion forage used}) \quad [3]$$

CP concentration data for all forage at the plot level were obtained using the mean contribution of CP from each of the three growth forms, weighted by their estimated biomass contribution (see Equation [4]).

$$\text{Total plot CP concentration} = \frac{\text{biomass}_{\text{grass}} * \text{CP}_{\text{grass}} + \text{biomass}_{\text{forb}} * \text{CP}_{\text{forb}} + \text{biomass}_{\text{shrub}} * \text{CP}_{\text{shrub}}}{\text{biomass}_{\text{grass}} + \text{biomass}_{\text{forb}} + \text{biomass}_{\text{shrub}}} \quad [4]$$

Models were considered significant at $p<0.05$, with the proportion of variance explained assessed using goodness-of-fit (R^2) values. Standardized beta coefficients were calculated to assess the relative strength of each predictor, while partial R^2 values provided the proportional variance accounted for by each individual variable (i.e. contribution to R^2).

5.3. Results

5.3.1. Cattle Habitat Preference and Foraging Behaviour

Electivity values differed ($p<0.001$) among habitats (Fig 5.1). Cattle showed the greatest preference for lowland modified grasslands, followed by upland native grasslands, with electivity values greater ($p<0.001$) than zero. In contrast, habitats avoided by cattle included conifer forest and cut blocks, with electivity values smaller ($p<0.01$) than zero. Electivity for mixed wood and aspen stands did not differ from zero ($p=0.88$, 0.13), suggesting that these habitats were chosen at random (i.e. neither preferred nor avoided).

The proportion of field sample plots exhibiting cattle use differed ($p<0.0001$) between habitat types (Table 5.2) and supported electivity results. Lowland and upland grassland, in addition to aspen and mixed wood forest plots, showed greater than 90% cattle visitation and differed ($p<0.05$) from conifer and cut block, with 60% or less of plots showing any sign of cattle presence. Cut block plots showed the lowest proportion of cattle visitation (i.e. 44%).

Forage utilization by cattle also varied ($p<0.0001$) among habitats (Table 5.2), with the greatest ($p<0.05$) level of use (i.e. 43%) observed within lowland grasslands. Upland grasslands, aspen and mixed wood forests experienced light forage use (16 to 19%), but remained greater ($p<0.05$) than that observed within cut blocks and conifer forest at just 3 to 6% utilization, respectively.

Stepwise multiple regression at the patch (plot) scale revealed a significant model ($p<0.0001$, $R^2=0.49$) with 49% of the variation in forage use explained by forage biomass and water distance ($p<0.0001$), slope, distance to gravel road, and forage protein ($p<0.001$), and lastly aspect ($p=0.05$) (Table 5.4). The majority of the variance in forage use was attributed to forage biomass, which had the greatest positive relationship with levels of forage consumption by cattle. With each additional 100 kg/ha of forage provided, utilization increased by 1.0%. Forage CP concentration and distance to gravel road also had positive associations with forage use, with each variable accounting for 2% of the variation. Forage consumption by cattle increased by 1.4% when CP increased by 1%. As for the effect of road proximity, each additional 100 m away from gravel roads resulted in a 0.4% increase forage use. Distance to nearest water source, slope gradient and aspect had negative relationships with forage utilization, with water distance accounting for 4% variation, while slope and aspect explained 1 to 2%. Distance to water had the greatest negative influence, with forage use declining by 4.2% for each additional 100 m distance from water. Similarly, as slope gradient increased by 1%, forage consumption by cattle diminished by 0.6%. A one unit increase in aspect (radians cosine transformed) also resulted in a decline in forage use by 3%, which equates to less forage use associated with northern as compared to southern aspects.

Stepwise multiple regression of forage use at the landscape (distribution unit) scale revealed a significant model ($p<0.0001$, $R^2=0.70$), with 70% of variation accounted for by slope ($p<0.0001$), distance to water ($p<0.01$) and distance to gravel road ($p=0.06$) (Table 5.5). Slope gradient alone explained 56% of the variance in forage use, with consumption decreasing by 4% as slope increased by 1%. Distance to nearest water source also had a negative, yet smaller, influence on forage utilization, which diminished by 9.4% as distance to water increased by 100 m. Lastly, distance to nearest gravel road had a small positive effect on forage use, with consumption increasing by 0.5% with each additional 100 m distance away from roads.

5.3.2. Environmental Attributes of Habitats

Total forage biomass differed ($p<0.01$) among habitats, with grasslands and cut blocks being the most productive, followed by aspen, mixed wood, and conifer forests (Table 5.3). Among respective vegetation components, grass biomass varied among habitats ($p<0.0001$), with production ranks resembling that of total biomass (Table 5.3). Forb biomass also differed among habitats ($p<0.01$), with conifer stands producing less ($p<0.05$) than other habitats (Table 5.3). Finally, aspen forests had greater ($p<0.05$) shrub biomass than grasslands or conifer habitats (Table 5.3). Due to heterogeneous variances, shrub biomass within cut blocks and mixed wood forests did not differ ($p<0.05$) from that within other habitats (Table 5.3).

Grass CP concentration (%) varied among habitats ($p<0.0001$); grass underneath conifer stands had greater protein content ($p<0.05$) compared to other habitats (Table 5.3). Additionally, mixed wood stands provided greater ($p<0.05$) grass CP concentration than cut blocks and lowland grasslands. Similarly, forb CP content differed ($p<0.05$) among habitats, with mixed wood stands offering greater ($p<0.05$) forb CP than grasslands (Table 5.3). Shrub CP was similar ($p=0.76$) among habitats.

Grass ADF concentrations (%) varied ($p<0.05$) among habitats, with cut blocks providing the least digestible ($p<0.05$) grass compared to other habitats (Table 5.3). Grasses growing within conifer habitats were more ($p<0.05$) digestible than that within all other habitats with the exception of lowland grasslands (Table 5.3). Forb ADF concentrations were similar ($p=0.19$) among habitats, while shrub ADF differed ($p<0.01$); shrubs within grassland and aspen habitats were more digestible ($p<0.05$) than those growing in conifer stands and cut blocks.

5.4. Discussion

Herbivore foraging behaviour and habitat selection involve several complex processes including experiential learning, genetic predispositions, interaction with surrounding environmental characteristics, and the social dynamics of a herd (Senft et al. 1983; Bailey et al. 1989; Launchbaugh and Howery 2005). Skinner (1938) originally coined the term 'operant conditioning' to describe how animals will search for and actively choose habitats that provide optimal opportunities for satiation, safety, and comfort. Herbivores employ all physical senses to judge the suitability or desirability of habitats, and have the ability to associate certain environmental features with positive or negative consequences (Bailey et al. 1996; Launchbaugh and Howery 2005).

Habitat preference by herbivores has been related to abundant forage of high nutritional quality, ample water supply, safety from predators, and shelter from harsh weather conditions and insects (Bailey et al. 1996; Launchbaugh and Howery 2005; Karki and Goodman 2010). Forage availability and associated dietary preferences are deemed the primary factors influencing habitat selection and spatial distribution of herbivores (Senft et al. 1983; Bailey et al. 1989, 1996; Owens et al. 1991; Wallis de Vries and Schippers 1994; Asamoah et al. 2003; Launchbaugh and Howery 2005). In the present study, cattle exhibited the greatest preference for lowland grasslands, followed by upland grasslands, and lastly aspen. The strong affinity cattle showed for lowland grasslands is likely due to the large amount of forage offered by productive tame grass species including smooth brome (*Bromus inermis* Leyss.) and timothy (*Pleum pratense* L.). Although productive, these introduced grass species did not maintain nutritional quality well, resulting in lowland grasslands offering relatively low crude protein concentrations. Therefore, cattle habitat preference was likely driven by forage availability rather than nutrient maximization (Senft 1989). Preference for lowland grasslands could also be attributed to the close proximity to streams that offered a source of water and a cool, shady environment.

Cattle showed the next greatest preference for native upland grasslands that also provided abundant forage, but at further distances and upslope from water. Moreover, native grasses of upland ranges are hard, rough and more fibrous in nature, making them potentially less palatable to cattle than the introduced species found within lowland habitats. The majority of forage available for grazing within preferred habitats was in the form of grass, which is the primary component of cattle diets as bulk roughage feeders (Hofmann 1989).

Although conifer forests provided high quality forage, these habitats were likely avoided by cattle due to low forage production and availability beneath a dense and closed tree canopy. Mixed wood stands, characterized by both deciduous and coniferous habitat features, in addition to aspen forests, were neither preferred nor avoided, but chosen at random likely due to lesser amounts of forage compared to grassland habitats.

Despite providing substantial forage biomass, cut blocks were strongly avoided by cattle potentially due to the inhospitable environment created by dense logging slash accumulation and soil scarification windrows and furrows (Chapter 6). Additionally, a considerable portion of the forage production within cut blocks included unpalatable weeds such as Canada thistle [*Cirsium arvense* (L.) Scop.] that established within cut blocks following soil disturbance. Grasses colonizing logged areas, primarily pine grass (*Calamagrostis rubescens* Buckley), senesce by midsummer (Hedrick et al. 1969) and subsequently offer little nutritional benefit. Accumulated logging slash presents a challenge for livestock in that it physically prevents cattle from accessing forage, or cattle may become injured when attempting to walk over it (Grisez 1960; Jones 1983; Morgan 1991). Over time livestock may associate areas of high slash accumulation with high energy costs, leading them to continually avoid these areas (Parker et al. 1984; Forester et al. 2007). Increased dead wood aggregation has been shown to provide a greater obstruction to wildlife seeking to browse deciduous seedlings (de Chantal and Ganstrom 2007).

Cattle behaviour research conducted within large mountainous allotments reveals supporting results, with the exception of cut block preference outcomes. On rangelands of north eastern Oregon, cattle preference of riparian meadows and logged areas was attributed to high forage production (Gillen et al. 1984). Cattle use of these Oregon cut blocks was greatest early in the season, while use declined once grasses matured and became unpalatable later in the season. Cattle grazing on Sierra Nevada ranges of California also showed a strong affinity for riparian habitats and clear cuts (Kie and Boroski 1996).

The discrepancy in cut block preference may be related to the age of logged areas, as cattle use of advanced cut blocks is more likely given establishment of abundant feed and the breakdown of woody debris. The logged areas in the present study were relatively young, with just 2 to 3 years elapsed following timber harvest. Similar to our findings, cattle avoided heavily forested habitats in Oregon and California due to limited forage availability. Within the foothills of south eastern Wyoming, cattle similarly favoured lowland sites when low stocking rates were employed (Hart et al. 1991). Ultimately, the interpretation of animal selection responses must be tempered by the collective availability of habitats.

The use of sustainable stocking rates allowed cattle to clearly exhibit habitat preferences and maintain moderate forage use levels (i.e. < 43%). Forage utilization among habitats and the percentage of plots showing cattle use support the electivity results. While the greatest forage use was in lowland grasslands, observed levels of use were within the range considered sustainable for these grasslands (i.e. < 50%). Upland grasslands, aspen stands and mixed wood forests experienced particularly light use ranging from 16 to 19%. Forage consumption was very limited within conifer forests and cut blocks, at just 6 and 3% respectively. The low level of use in conifer stands is consistent with McLean (1972), who observed light utilization where trees formed a near complete canopy. Similarly, Clary et al. (1978) found increased forage consumption associated with decreasing tree density.

With the exception of cut blocks and conifer forests, all habitats had greater than 90% plot occupancy, suggesting that cattle travelled extensively through grasslands, aspen and mixed wood forests, but limited exploration of conifer stands and cut blocks.

Cattle may begin to use these less desirable habitats to obtain feed if stocking rates were increased and primary ranges (grasslands) became depleted (Hart et al. 1991).

The relative strength and importance of mechanisms influencing cattle forage use differed at the patch and landscape scales. Grazing at the patch level was affected by a combination of biotic and abiotic factors, with forage biomass as the primary patch characteristic related to increased forage use by cattle. Forage crude protein concentration and distance from roads also showed positive relationships with forage use, albeit much weaker than that of forage biomass. The positive influence of forage quantity and quality on forage consumption is consistent with Clary et al. (1978), Pinchak et al. (1991), and Ganskopp and Bohnert (2009). Greater forage use by cattle at further distances from roads suggests that vehicle traffic may have deterred animals from grazing near roads. Distance to nearest water source had the greatest negative influence on forage consumption, followed by slope gradient and aspect. Cattle use was greater when associated with southerly rather than northerly aspects, likely due to the presence of preferred habitats in the form of productive grasslands at this location.

Conversely, at the landscape level, only abiotic factors influenced forage use; slope gradient was the primary deterrent of forage use, while increasing distance to water had a weaker negative impact. Preference by cattle for areas near water has been found by numerous previous studies, as has the detrimental impact of increasing slope on degree of use (Mueggler 1965; Roath and Krueger 1982; Gillen et al. 1984; Pinchak et al. 1991; Kie and Boroski 1996; Ganskopp and Bohnert 2009). However, it is notable that the nature of slope impacts on cattle use was unlike those suggested by previous studies, as even small reductions in slope served to sharply decrease cattle use. Frequently used guidelines suggest expected cattle use should be progressively reduced until slopes reach 10% (Campbell and Bawtree 1998), which in our study, would already have resulted in a progressive decline of cattle use by 40%. These results therefore shed further light on the impact of topography in altering cattle distribution and corresponding grazing capacity on public land.

Distance to roads showed a weak positive relationship with forage use, which is contrary to the assumption that cattle would use roads as easy routes for traversing the landscape. On rangelands within the Blue Mountains of Oregon, cattle used roads extensively as primary travel routes (Roath and Krueger 1982). Although cattle may still use roads for travel, our results suggest cattle promptly move off roads and into less disturbed areas of the landscape.

The differences in foraging patterns observed at patch and landscape scales can be related to herbivore objectives. At the patch level, cattle strive to maximize nutrient intake (Senft et al. 1987; Bailey et al. 1996), thus explaining the important role of forage biomass and crude protein concentration in regulating utilization. When feeding at the patch level, cattle make specific decisions regarding what plants and plant parts to consume. This behaviour is referred to as ‘overmatching’, and is described as a disproportionally large response resulting from a change in forage characteristics (Senft et al. 1987; Bailey et al. 1996). In contrast, herbivore grazing at the landscape level typically occurs in proportion to changes in forage conditions, which is known as a ‘matching’ response (Senft et al. 1987; Bailey et al. 1996). When deciding where in the landscape to forage, cattle must choose areas that are most efficient for feeding, while also meeting their water and shelter needs (Senft et al. 1987). Therefore, it is the abiotic factors including slope, distance to water and road proximity that play the primary role in affecting grazing effectiveness at the landscape scale (Bailey et al. 1996). Ultimately, of greater consequence and significance to the herbivore is where in the landscape to concentrate grazing as opposed to the specific plant-related decisions made at the patch scale (Senft et al. 1987). This is supported by the findings of Owens et al. (1991), who observed that plant characteristics were the main factors affecting utilization when forage biomass was plentiful, while road and water proximity were primarily responsible for grazing patterns when forage was limited. Overall, the strength of the relationship between forage use and abiotic factors was much stronger at the landscape than patch scale, a result shared by Wallis de Vries and Schippers (1994).

As with any field study focusing on habitat selection and herbivore foraging behaviour, it is important to remember that these study outcomes represent only a snapshot in time and space, and are continually subject to change (Launchbaugh and Howery 2005). Thus, the value of certain habitats to herbivores will vary with grazing management practices and environmental conditions; previously avoided habitats may experience greater use in cases of limited forage availability or relief from obstruction. For example, cattle use of aging and evolving cut blocks may be difficult to predict into the future, as animals respond to changes in forage availability and accessibility as influenced by logging debris and tree regeneration, or ongoing changes to vegetation in other habitats of the area. Additionally, care must be taken when extrapolating foraging behaviour results from one region to another, as use is likely to be strongly influenced by landscape composition (Senft 1989). Finally, other factors may have played a role in regulating cattle foraging behaviour and habitat preference, but were not assessed here, including animal genetics, social dynamics, individual learning experiences, and the effect of daily or hourly weather conditions.

5.5. Management Implications

By satisfying the study objectives, we are able to better understand cattle habitat selection and foraging patterns within heterogeneous montane rangelands containing recently harvested and regenerating coniferous cut blocks. Given the implementation of moderate stocking rates associated with 50% forage use or less, cattle exhibited clear preference for grassland habitats and aspen stands. Productive lowland grasslands in close proximity to streams provided primary ranges for cattle. Without the need to seek out sufficient forage and meet intake requirements, cattle showed a clear avoidance for cut blocks despite abundant forage availability. Although cut blocks offer an increased supply of forage, maintaining stocking rates at pre-harvest levels may provide added insurance against overuse by cattle. Conifer forests were also avoided by cattle, likely due to the lack of forage they provided.

Grazing management of rangelands containing cut blocks should take into account the landscape level factors driving forage consumption by cattle in order to minimize overuse of regenerating cut blocks. Given the outcomes of this research, slope gradient and distance to water had the greatest negative influence on forage use, suggesting that cattle concentrate their foraging at more productive sites near streams and on easily accessible slopes. Watering sites for cattle would ideally be located away from regenerating cut blocks, so as to not encourage use of logged sites. Future planning and development of cut blocks within Alberta's Montane landscapes could consider, where possible, the influence of slope gradient and stream proximity on large scale cattle foraging patterns in order to successfully achieve independent resource goals on multiple use lands. From a grazing management perspective, more uniform cattle use and distribution across the landscape may be achieved through the use of attractants including watering and salting sites, in addition to fence construction. However, these alterations present an increased operating and capital cost to the rancher.

This research supports the use of sustainable stocking rates and responsible grazing management to prevent overuse of regenerating clear cuts, thereby creating a cooperative and integrative environment for forestry and ranching industries to work together. Based on our findings, successful regeneration of these cut blocks should be attainable provided moderate stocking rates are maintained and re-evaluated as forage conditions and plant communities change over time. Study outcomes should lead to improved grazing practices that are consistent with optimizing conifer regeneration and sustaining commercial forestry on multiple use lands, while also minimizing conflict between livestock and timber industries.

Table 5.1: Grazing periods and stocking rates within each of the 3 distribution units of the Sharples Creek and Skyline grazing allotments.

	2008		**2009**	
Distribution Unit	Grazing Period	Stocking Rate (AUM/ha)	Grazing Period	Stocking Rate (AUM/ha)
Damon	July 1 - Aug. 6	0.44	July 31 - Aug. 28	0.42
North Sharples	Aug. 25 - Sept. 8	0.59	Sept. 16 - Oct. 2	0.56
Prong Coulee	Sept. 9 - Oct. 5	0.35	June 29 - July 30	0.39

Table 5.2: Proportion (%) of plots with evidence of cattle occupation and measured forage utilization (%) by cattle.

			Habitat				
Use Parameter	Lowland Grass	Upland Grass	Aspen	Mixed Wood	Conifer	Cut Block	SE
% Occupied Plots	100 a[1]	93 a	100 a	94 a	60 b	44 b	6
% Forage Utilization	43 a	19 b	17 b	16 b	6 c	3 c	3

[1] Within a row, means with different letters differ, $p<0.05$.

Table 5.3: Measured forage biomass (kg/ha), crude protein and acid detergent fibre concentrations (%) among habitats at time of grazing.

			Habitat				
Response	Lowland Grass	Upland Grass	Aspen	Mixed Wood	Conifer	Cut Block	SE
			Forage Biomass (kg/ha)				
Grass	2306 a[1]	2092 a	1307 b	617 c	105 d	1303 b	238
Forb	873 a	787 a	591 a	563 a	132 b	760 a	175
Shrub	10 b	42 b	182 a	106 ab	38 b	246 ab	[2]*
Total	3188 a	2921 ab	2080 bc	1286 cd	276 d	2310 abc	387
			Forage Crude Protein (%)				
Grass	6.0 c	6.4 bc	6.8 bc	7.5 b	9.0 a	5.9 c	0.7
Forb	8.8 bc	8.0 c	9.6 ab	10.2 a	9.4 ab	10.0 ab	1.1
Shrub	8.3	8.3	9.2	8.7	8.7	8.0	[3]*
			Forage Acid Detergent Fibre (%)				
Grass	39.6 bc	40.8 b	40.5 b	39.7 b	38.3 c	43.6 a	[2]**
Forb	33.1	32.2	31.7	31.3	29.6	29.7	1.7
Shrub	15.4 c	20.7 c	24.8 c	25.5 bc	34.3 a	32.6 ab	[3]**

[1] Within a row, means with different letters differ, $p<0.05$.

[2] Standard errors vary due to heterogeneous variances or missing data points:

* SE Lowland Grass: 18, SE Upland Grass: 17, SE Aspen: 48, SE Mixed Wood: 52, SE Conifer: 23, SE Cut Block: 120.

** SE Lowland and Upland Grass, Aspen, Mixed Wood and Conifer: 1.3, SE Cut Block: 1.6.

[3] Standard errors vary among habitats due to missing values resulting from no or inadequate shrub material available for analyses.

* SE Lowland Grass: 1.5, SE for all other habitats: 0.8.

** SE Lowland Grass: 6.4, SE Upland Grass, Cut Block and Conifer: 2.8, SE Aspen and Mixed Wood: 2.5.

Table 5.4: Stepwise regression summary of the relationship between forage utilization at the patch (plot) scale and significant predictor variables.

Dependent Variable	**Independent Variable**	**Partial R^2**	**Model R^2**	**β [1]**	**Regressor P-value**
Forage Utilization (%)	Forage Biomass	0.38	0.38	0.58	<0.0001
	Water Distance	0.04	0.43	-0.17	<0.0001
$R^2 = 0.49$	Slope	0.02	0.44	-0.15	<0.001
Adj $R^2 = 0.48$	Road Distance	0.02	0.46	0.15	<0.001
$p<0.0001$	Forage Protein	0.02	0.48	0.16	<0.001
	Aspect	0.01	0.49	-0.08	0.05

[1] Standardized beta coefficients.

Table 5.5: Stepwise regression summary of the relationship between forage utilization at the landscape (distribution unit) scale and significant predictor variables.

Dependent Variable	**Independent Variable**	**Partial R^2**	**Model R^2**	**β [1]**	**Regressor P-value**
Forage Utilization (%)					
$R^2 = 0.73$	Slope	0.56	0.56	-0.70	<0.0001
Adj $R^2 = 0.70$	Water Distance	0.13	0.69	-0.34	<0.01
$p<0.0001$	Road Distance	0.04	0.73	0.21	0.06

[1] Standardized beta coefficients.

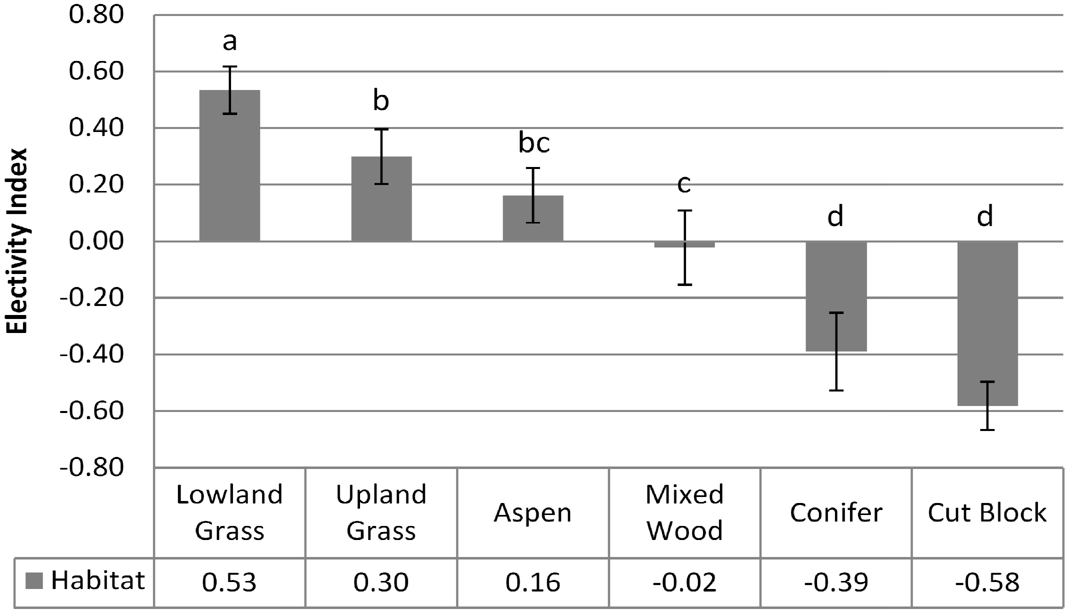

Figure 5.1: Mean cattle electivity values for each of 6 habitats based on GPS cattle locations in 2008 and 2009. Habitats with different letters differ, $p<0.0001$. Standard errors of electivities vary due to heterogeneous variances among habitats. Habitats with electivities that differ from zero (random) include lowland grass, upland grass, conifer and cut block ($p<0.05$).

5.6. Literature Cited

Akaike, H. 1973. Information theory and an extension of the maximum likelihood principle. In: Petrov, B.N., Csaki, F. (Eds.), 2nd International Symposium of Information Theory, Akademiai Kiado, Budapest, pp. 267-281.

Anderson, D.R. 2008. Model Based Inference in the Life Sciences. Springer Science + Business Media, LLC, New York, New York, USA.

Asamoah, S.A., E.W. Bork, B.D. Irving, M.A. Price, and R.J. Hudson. 2003. Cattle herbage utilization patterns under high-density rotational grazing in the aspen parkland. Canadian Journal of Animal Science 83: 541-550.

Bailey, D.W., L.R. Rittenhouse, R.H. Hart, D.M. Swift, and R.W. Richards. 1989. Association of relative food availabilities and locations by cattle. Journal of Range Management 42(6): 480-482.

Bailey, D.W., J.E. Gross, E.A. Laca, L.R. Rittenhouse, M.B. Coughenour, D.M. Swift, and P.L Sims. 1996. Mechanisms that result in large herbivore grazing distribution patterns. Journal of Range Management 49 (5): 386-400.

Beaver, J.M. and B.E. Olson. 1997. Winter range use by cattle of different ages in southwestern Montana. Applied Animal Behaviour Science 51:1-13.

Belsley, D.A., E. Kuh, and R.E. Welsch. 1980. Regression Diagnostics. John Wiley and Sons Inc, New York, USA.

Bork, E.W. and S.J. Werner. 1999. Viewpoint: implications of spatial variability for estimating forage use. Journal of Range Management 52(2): 151-156.

Campbell, C.W. and A.H. Bawtree. 1998. Rangeland handbook for B.C. British Columbia Cattlemen's Association, Kamloops, British Columbia, Canada.

Chapman, D.F., A.J. Parsons, G.P. Cosgrove, D.J. Barker, D.M. Marotti, K.J. Venning, S.M. Rutter, J. Hill, and A.N. Thompson. 2007. Impacts of spatial patterns in pasture on animal grazing behaviour, intake, and performance. Crop Science 47: 399-415.

Clary, W.P., P.F. Ffolliott, and F.R. Larson. 1978. Factors affecting forage consumption by cattle in Arizona ponderosa pine forests. Journal of Range Management 31(1): 9-10.

Cutter, B.E., K. Hunt, and J.D. Haywood. 1999. Tree/wood quality in slash pine following longterm cattle grazing. Agroforestry Systems 44: 305-312.

de Chantal, M. and A. Granström. 2007. Aggregations of dead wood after wildfire act as browsing refugia for seedlings of *Populus tremula* and *Salix caprea*. Forest Ecology and Management 250: 3-8.

Dumas, J.B.A. 1831. Procedes de l'analyse organique. Ann. Chim. Phys. 247-213.

Eissenstat, D.M., J.E. Mitchell, and W.W. Pope. 1982. Trampling damage by cattle on northern Idaho forest plantations. Journal of Range Management 35(6): 715-716.

Forester, J.D., A.R. Ives, M.G. Turner, D.P. Anderson, D. Fortin, H.L. Beyer, D.W. Smith, and M.S. Boyce. 2007. State-space models link elk movement patterns to landscape characteristics in Yellowstone National Park. Ecological Monographs 77(2): 285-299.

Ganskopp, D.C. and D.W. Bohnert. 2009. Landscape nutritional patterns and cattle distribution in rangeland pastures. Applied Animal Behaviour Science 116: 110-119.

Gillen, R.L., W.C. Krueger, and R.F. Miller. 1984. Cattle distribution on mountain rangeland in northeastern Oregon. Journal of Range Management 37(6): 549-553.

Grisez. T.J. 1960. Slash helps protect seedlings from deer browsing. Journal of Forestry 58: 385-387.

Hart, R.H., K.W. Hepworth, M.A. Smith, and J.W. Waggoner, Jr. 1991. Cattle grazing behavior on a foothill elk winter range in southeastern Wyoming. Journal of Range Mangement 44(3): 262-266.

Hedrick, D.W., B.R. Eller, J.A.B. McArthur, and R.D. Pettit. 1969. Steer grazing on mixed coniferous forest ranges in northeastern Oregon. Journal of Range Management 22(5): 322-325.

Hofmann, R.R. 1989. Evolutionary steps of ecophysiological adaptation and diversification of ruminants: a comparative view of their digestive system. Oecologia 78: 443-457.

Ivlev, V.S. 1961. Experimental ecology of the feeding of fishes. Yale University Press, New Haven, Connecticut, USA.

Jones, K.L. 1983. Current knowledge of the effects of cattle grazing on aspen in the Alberta parkland. Rangelands 5(2): 59-60.

Jung, S., D.A. Rickert, N.A. Deak, E.D. Aldin, J. Recknor, L.A. Johnson, and P.A. Murphy. 2003. Comparison of Kjeldahl and Dumas methods for determining protein contents of soybean products. Journal of American Oil Chemists 80(12):1169-1173.

Karki, U. and M.S. Goodman. 2010. Cattle distribution and behavior in southern-pine silvopasture versus open-pasture. Agroforest Syst 78: 159-168.

Kie, J.G. and B.B. Boroski. 1996. Cattle distribution, habitats, and diets in the Sierra Nevada of California. Journal of Range Management 49(6): 482-488.

Kowalenko, C.G. 2001. Assessment of Leco CNS-2000 analyzer for simultaneously measuring total carbon, nitrogen, and sulphur in soil. Communications in Soil Science and Plant Analysis 32: 2065-2078.

Krzic, M., R.F. Newman, and K. Broersma. 2003. Plant species diversity and soil quality in harvested and grazed boreal aspen stands of northeastern British Columbia. Forest Ecology and Management 182: 315-325.

Krzic, M., H. Page, R.F. Newman, and K. Broersma. 2004. Aspen regeneration, forage production, and soil compaction on harvested and grazed boreal aspen stands. BC Journal of Ecosystems and Management 5(2): 30-38.

Launchbaugh, K.L and L.D. Howery. 2005. Understanding landscape use patterns of livestock as a consequence of foraging behaviour. Rangeland Ecology and Management 58(2): 99-108.

Manly, B.F.J., L.L. McDonald, D.L. Thomas, T.L. McDonald, and W.P. Erickson. 2002. Resource selection by animals: statistical analysis and design for field studies. Second Edition. Kluwer, Boston, Massachusetts, USA.

McLean, A. 1972. Beef production on lodgepole pine-pinegrass range in the caribou region of British Columbia. Journal of Range Management 25(1): 10-11.

McLean, A. and M.B. Clark. 1980. Grass, trees, and cattle on clearcut-logged areas. Journal of Range Management 33(3): 213-217.

Mitchell, J.E., D.M. Eissenstat, and A.J. Irby. 1982. Forest grazing – an opportunity for diplomacy. Rangelands 4(4): 172-174.

Morgan, R.K. 1991. The role of protective understorey in the regeneration system of a heavily browsed woodland. Vegetation 92: 119-132.

Mueggler, W.F. 1965. Cattle distribution on steep slopes. Journal of Range Mangement 18(5): 255-257.

Newman, R.F., B.M. Wikeem, M.D. Pitt, D. Quinton, P. Youwe, and G.W. Powell. 1994 Grass/tree/cattle research on forest range in British Columbia, Canada. Managing

Canadian Rangelands for Sustainability & Profitability: Proceedings of the First Interprovincial Range Conference in Western Canada. Pgs. 175-181.

Owens, M.K., K.L. Launchbaugh, and J.W. Holloway. 1991. Pasture characteristics affecting spatial distribution of utilization by cattle in mixed brush communities. Journal of Range Management 44(2): 118-123.

Parker, K.L., C.T. Robbins, and T.A. Hanley. 1984. Energy expenditures for locomotion by mule deer and elk. Journal of Wildlife Management 48(2): 474-488.

Pinchak, W.E., M.A. Smith, R.H. Hart, and J.W. Waggoner Jr. 1991. Beef cattle distribution patterns on foothill range. Journal of Range Management 44(3): 267-275.

Pitt, M.D., R.F. Newman, P.L. Youwe, B.M. Wikeem, and D.A. Quinton. 1998. Using a grazing pressure index to predict cattle damage of regenerating seedlings. Journal of Range Management 51(2): 152-157.

Platts, P.J., C.J. McClean, J.C. Lovett, and R. Marchant. 2008. Predicting tree distributions in an east African biodiversity hotspot: model selection, data bias and envelope uncertainty. Ecological Modelling 218: 121-134.

Roath, L.R. and W.C. Krueger. 1982. Cattle grazing and behavior on a forested range. Journal of Range Management 35(3): 332-338.

Senft, R.L. 1989. Hierarchical foraging models: effects of stocking and landscape composition on simulated resource use by cattle. Ecological Modelling 46: 283-303.

Senft, R.L., M.B. Coughenour, D.W. Bailey, L.R. Rittenhouse, O.E. Sala, and D.M. Swift. 1987. Large herbivore foraging and ecological hierarchies. BioScience 37(11): 789-799.

Senft, R.L., L.R. Rittenhouse, and R.G. Woodmansee. 1983. The use of regression models to predict spatial patterns of cattle behavior. Journal of Range Management 36(5): 553-557.

Skinner, B.F. 1938. The behavior of organisms. New York, NY: Apleton-Century-Crofts. 457 p.

Vogel, K.P., J.F. Pedersen, S.D. Masterson, and J.J. Toy. 1999. Evaluation of a filter bag system for NDF, ADF and IVDMD forage analysis. Crop Science 39: 276-279.

Wallis de Vries, M.F. and P. Schippers. 1994. Foraging in a landscape mosaic: selection for energy and minerals in free-ranging cattle. Oecologia 100: 107-117.

West, B.T., K.B. Welch, and A.T. Gałecki. 2007. Linear mixed models: practical guide using statistical software. Chapman & Hall/CRC, Taylor & Francis Group, Boca Raton, Florida, USA.

Willoughby, M.G., M.J. Alexander, and B.W. Adams. 2005. Range plant community types and carrying capacity for the montane subregion. Sixth approximation. Alberta Sustainable Resource Development, Public Lands and Forest Division. Pub. no.: T/071. ISBN: 0-7785-4062-4 (On-line edition).

White, H. 1980. A heteroskedasticity-consistent covariance matrix estimator and a direct test for heteroskedasticity. Econometrica 48: 817-838.

Zimmerman, G.T. and L.F. Neuenschwander. 1984. Livestock grazing influences on community structure, fire intensity, and fire frequency within the Douglas-fir/ninebark habitat type. Journal of Range Management 37(2): 104-110.

6. Cattle Use of Coniferous Cut Blocks and Associated Damage to Regeneration

6.1. *Introduction*

Public lands in Western Canada are important for supporting multiple uses, including cattle grazing and timber harvest. Balancing multiple uses provides the basis for public land management and is fundamental to maintaining the ecological integrity of forested rangelands. However, lack of cooperation between forest and cattle industries as they pursue independent resource goals on a common land base can create conflict, thereby complicating the process of integrated resource management (Mitchell et al. 1982).

Cattle grazing of coniferous cut blocks have been associated with poor tree regeneration, survival and growth (Zimmerman and Neuenshwander 1984). When livestock stocking rates are too high to be supported by a regenerating forested range, tree seedlings may be affected by grazing (Newman et al. 1994; Pitt et al. 1998). Although cattle typically do not browse coniferous trees due to their low palatability (Lewis 1980a), damage to seedlings could still occur from trampling (McLean and Clark 1980; Newman et al. 1994), leading to increases in the likelihood of conifer seedling mortality (Eissenstat et al. 1982). Physical damage to the tree's cambium layer not only hinders tree physiological processes and associated growth (Lewis 1980b), but increases tree susceptibility to environmental stresses, including attack by harmful pathogens and insects (Frey et al. 2003). Timber companies operating in Alberta are ultimately responsible for regeneration of cut blocks (ASRD 2009). Provincial regeneration assessments require that coniferous seedlings be undamaged in order to be accepted in the determination of adequate tree stocking densities (ASRD 2008). Any factor causing substandard regeneration increases reforestation costs, reduces profit, and jeopardizes future timber harvesting opportunities.

In order to mitigate cattle-induced damage to regenerating trees and minimize conflict between the forest and ranching industries, a greater understanding is required of the extent to which cattle utilize cut blocks, the level of damage associated with cut block use, and the underlying factors that may influence cattle occupancy of cut blocks.

Aside from accessibility, the primary factors influencing site selection by cattle during feeding are forage quantity and quality, as animals generally strive to optimize nutrient intake at minimal energetic cost (Senft et al. 1987). Roath and Krueger (1982) found that cattle distribution and use across forested ranges could be related to vegetation type and forage quality. Elements affecting forage quantity and quality include community composition, plant morphology, the presence of secondary compounds and associated palatability, as well as growing conditions (Senft et al. 1987; Senft 1989; Chapman et al. 2007). Those locations that provide the most favourable forage attributes are likely to experience greater cattle occupancy compared to areas with less desirable vegetation.

Cattle distribution across the landscape and associated use of vegetation is further affected by accessibility, temperature, shelter from the elements, and protection from pests (Owens et al. 1991; Beaver and Olson 1997; Launchbaugh and Howery 2005). Distance to free standing water is known to strongly influence cattle locations and grazing preference (Roath and Krueger 1982; Kie and Boroski 1996). Livestock avoid areas within mountainous forested landscapes associated with steep slopes, north and west-facing aspects, as well as sparse vegetation (Roath and Krueger 1982; Kie and Boroski 1996).

Following timber harvest, large quantities of slash and wood residue may be left on and above the soil surface, and may act as a physical or visual barrier to grazing. Accumulated logging slash presents a challenge for livestock in that it physically prevents cattle from accessing forage, or cattle may become injured when attempting to walk over it (Jones 1983; Morgan 1991). Over time livestock may associate areas of high slash accumulation with high energy costs and low forage availability, leading them to continually avoid these areas (Parker et al. 1984; Forester et al. 2007a). Factors that generally influence the outcome of cattle grazing on conifer plantations include stocking rate, tree species, topography and habitat type (Lewis 1980b; Pitt et al. 1998).

Livestock producers can alter cattle foraging behaviour, including the extent of use of young trees, by managing the timing, intensity and duration of grazing (McLean and Clark 1980; Eissenstat et al. 1982; Newman et al. 1994; Pitt et al. 1998). Range use by cattle is also influenced by season of grazing, as a result of altered forage quality and quantity. Forage depletion resulting from high stocking rates can motivate cattle to access sites that are relatively unproductive, nutrient poor, or less accessible (Senft et al. 1983; Hart et al. 1991). In this situation stocking rates need to be reduced and livestock distribution adjusted accordingly in order to limit the detrimental effects of cattle grazing on tree regeneration (Newman et al. 1994; Pitt et al. 1998; Krzic et al. 2003; Krzic et al. 2004). When stocking rates are properly matched to available forage resources within primary ranges, damage to conifer seedlings can be minimized (McLean and Clark 1980; Cutter et al. 1999).

The goal of this study was to assess cattle distribution patterns within cut blocks of SW Alberta, and evaluate potential mechanisms influencing cattle occupancy of cut blocks. An additional research objective was to quantify levels of cattle-induced damage to regenerating conifer seedlings. Specific research objectives included to:

1. Identify mechanisms regulating cattle site selection within cut blocks including forage quantity and quality, accessibility (i.e. slash obstruction) and environmental characteristics (i.e. topography and distance to water),
2. Quantify damage to coniferous seedlings due to cattle.

6.2. Materials and Methods

6.2.1. Study Area

This study was conducted within two provincial grazing allotments of the Rocky Mountain Forest Reserve of south western Alberta, from June 2008 through October 2009. The area, known as the Porcupine Hills, is situated within the Montane Natural Subregion. The specific study site for this research was located approximately 46 km north of the town of Pincher Creek and included three distribution units (DU) (Damon-

836 ha, North Sharples-364 ha, and Prong Coulee-1035 ha) (Fig. A.4, see Appendix A) within the Sharples Creek and Skyline public grazing allotments (49°53’46.89”N, 114°01’41.20”W) (legal location: Twnshps 10 & 11-Rge 1-West 5) administered by Alberta Sustainable Resource Development.

The area is characterized by rolling topography containing large-scale relief, with slopes ranging from 6 to 30 %, and elevations of 1400 to 1700 m above sea level. Different plant communities, including conifer, mixed wood and aspen forests among interspersed grasslands, are present across the landscape as a result of variation in topographic relief, aspect and resultant moisture availability. Dense stands of lodgepole pine (*Pinus contorta* Loudon) occupying mesic north-facing sites are the primary reference vegetation for the Montane, with succession to Douglas fir [*Pseudotsuga menziesii* (Mirb.)] and white spruce [*Picea glauca* (Moench)] (Willoughby et al. 2005). Douglas fir forests are the climax vegetation on south-facing slopes with shallow, rocky soils and rapid drainage, while white spruce stands develop in areas with greater moisture (Willoughby et al. 2005). Within cut blocks, frequently occurring grass species include pinegrass (*Calamagrostis rubescens* Buckley), hairy wild rye (*Elymus innovatus* Beal), and bluegrasses (*Poa* spp.). Common native forbs include heart leaved arnica (*Arnica cordifolia* Hook.), showy aster (*Aster conspicuus* Lindl.), and bunchberry (*Cornus canadensis* L.), while Canada thistle [*Cirsium arvense* (L.) Scop.] is invasive within severely disturbed sites. Widespread shrub species in cut blocks include common wild rose (*Rosa woodsii* Lindl.), wild red raspberry (*Rubus idaeus* L.), thimbleberry (*Rubus parviflorus* Nutt.), and white meadowsweet (*Spiraea betulifolia* Pallas). Typical soil types associated with conifer forests are Gray Luvisols and Eutric Brunisols (Willoughby et al. 2005).

The Montane experiences two precipitation peaks annually: May-June and August-September (Willoughby et al. 2005). Environment Canada’s Connelly Creek (49°36’58.030”N 114°12’54.080”W) weather station recorded total precipitation during 2008 at 378.5 mm (Fig. B.3, see Appendix B), 65% of normal (Environment Canada Connelly Creek Normal, 1971 – 2000). Greater precipitation occurred during 2009 at

521.7 mm, representing 90% of normal (Environment Canada Connelly Creek Normal, 1971-2000). Average annual temperatures at the Connelly Creek weather station during 2008 and 2009 were 5.1^{o}C and 4.1^{o}C, respectively (Fig. B.4). Environment Canada reports the 30 yr average annual temperature to be 4.8^{o}C (Environment Canada Connelly Creek Normal, 1971-2000), with temperature extremes ranging from > 35^{o}C during summer to approximately -45^{o}C in winter.

Conifer cut blocks represent 5% of the total area of the grazing allotment, with a total of five cut blocks assessed in this investigation (i.e. one to two per DU), ranging from 2.1 to 18.6 ha in size. Commercial timber harvest was conducted by Spray Lakes Sawmills during December 2005, and January and March 2006. Following logging, cut blocks were scarified during October and December of 2006 using skidder machines outfitted with ripper teeth on the blades. Cut blocks were planted with lodgepole pine and white spruce seedlings in July 2007.

6.2.2. Cattle Use and Vegetation Measures

Approximately 311 mature black Angus cross cow-calf pairs and 10 bulls grazed the Damon, North Sharples, and Prong Coulee distribution units sequentially during July, August and September of 2008 and 2009, although the sequence of grazing varied from year to year (Table 6.1). Resultant stocking rates were 0.35 to 0.59 AUM/ha (Table 6.1). Data collection occurred immediately following each grazing period within each distribution unit. One large cut block or two smaller cut blocks within each distribution unit were selected in order to collect detailed data on cattle use of cut blocks, cattle damage to tree seedlings, levels of slash loading, and environmental characteristics. A fine-scale systematic sampling grid was created within each cut block consisting of permanent sample plots situated 50 to 60 m apart (Fig. A.5). Regeneration assessments followed methodology similar to that outlined in the *Alberta Regeneration Survey Manual* (ASRD 2008): each plot was circular, 10 m^2 in area, and permanently marked at the centre. Within each cut block and distribution unit, two range cages, 1.5 x 1.5 m in size, were paired with randomly selected plots for the assessment of ungrazed biomass.

Additionally, range cage data were used to calibrate ocular estimations of standing biomass in all plots. To gather information on the factors potentially responsible for cattle site selection within cut blocks and the effect of grazing on regeneration, the following data were collected at each plot:

1. Evidence of cattle visitation in the form of tracks, grazing, or defecation (presence/absence per plot),
2. Ocular estimates of standing biomass by growth form (kg/ha),
3. Biomass clippings within a 0.5 m^2 quadrat from within those plots where range cages were present: two cages per cut block per distribution unit. Biomass clippings were taken inside and outside cages and separated into grass, forb and shrub (current annual growth only) components. Biomass clippings were used to validate and adjust (if needed) biomass estimates. Simple linear regressions showing the relationship between actual and estimated biomass values (i.e. the ability to recognize incremental changes in production) for each year are shown in Figure C.5 (see Appendix C). Biomass samples were retained for quality analysis at a later date.
4. Ocular assessment of forage utilization (%). Where range cages were present, actual utilization was calculated by comparing dry matter biomass (kg/ha) inside and outside of cages using Equation [1]. Simple regressions summarizing the relationship between actual biomass removal and estimated utilization values (i.e. the ability to distinguish incremental use) for each year are provided in Figure C.6. These relationships should be interpreted with care, as actual field biomass determination is prone to experimental error due to vegetation heterogeneity (Bork and Werner 1999). While ocular estimates can account and compensate for variation, small field samples are generally less able to do so.

   Forage utilization (%) = (inside cage kg/ha – outside cage kg/ha)/inside cage kg/ha * 100 [1]
5. Biophysical attributes within each plot were assessed, including plant species composition (i.e. foliar cover of 3 dominant herbs and 3 dominant shrubs, see Appendix E), slope gradient (%) using a clinometer, aspect (^{o}) using a compass, and elevation using a handheld GPS unit.

6. Quantification of slash (i.e. woody debris) abundance, including ocular assessment of the proportion (%) of ground covered by slash, and measurements of maximum slash height (cm) per plot. Additionally, from the point of greatest slash height within the plot, the distance to the nearest grazing patch (cm) was measured.
7. Number, height, and basal diameter of seedlings for each tree species,
8. Damage to trees including browsing, leader breakage, basal scarring, and vertical displacement.

Finally, distance to the nearest water source from each permanent sample plot was calculated using ArcGIS 9.2 (ESRI®) software.

6.2.3. Forage Quality Analysis

Plant biomass samples were dried at 45°C for 48 hrs to constant mass, and weighed. Samples were then ground to 1 mm using a Thomas® Scientific (Swedesboro, NJ, USA) Wiley Mill in preparation for proximate analysis. Crude protein (CP) concentrations were determined separately for grass, forb and shrub samples, using estimates of nitrogen concentration of forage using the Dumas (1831) method in association with a LECO® (St. Joseph, MI, USA) TruSpec FP-428 analyzer. The Dumas method employs high temperature (800 to 1000°C) combustion to convert all forms of nitrogen within the sample first to nitrogen oxides, followed by reduction to N_2, which is subsequently measured by thermal conductivity detection (Kowalenko 2001; Jung et al. 2003). Nitrogen values were subsequently converted to CP concentration by multiplying nitrogen values by 6.25.

6.2.4. Statistical Analysis

Simple linear regression (Proc REG; SAS Institute Inc. 2009) was used to determine the relationship between cattle accessibility in the form of distance to the nearest grazing patch (dependent variable) and maximum slash height (independent variable). Prior to regression, data were checked for normality by examining plots of the residuals between observed vs. expected values, while White's test was employed to test the assumption of homogeneous variances (White 1980). The regression model was considered significant at $p<0.05$, and the R^2 used to assess the proportion of variance explained.

An information-theoretic approach (Akaike 1973, Anderson 2008) was used to evaluate models describing the probability of cattle occupancy of cut block plots during 2008 and 2009, given measured independent variables. Cattle occupancy of cut block plots (dependent variable) was characterized using binary values of 1 (presence) and 0 (absence), and was related to 4 main independent parameters (see Table 6.2): forage [biomass (kg/ha) and crude protein concentration (%)], topography [elevation (m), slope (%) and aspect (degrees) cosine transformed (Platts et al. 2008)], logging slash accumulation [maximum height (cm) and cover (%)], and lastly distance to the nearest water source (m). Correlations were conducted to identify collinearity and eliminate variables associated with a correlation coefficient (r) greater than 0.6. Biomass values were adjusted using forage utilization estimates to determine the forage biomass available prior to grazing (see Equation [2]). Crude protein concentration data for all forage at the plot level were obtained using the mean contribution of CP from each of the three growth forms, weighted by their estimated biomass contribution (see Equation [3]).

$$\text{Forage biomass} = \text{post grazing biomass estimate} / (1 - \text{estimate of proportion forage used}) \qquad [2]$$

$$\text{Total plot CP concentration} = \qquad [3]$$

$$(\text{biomass}_{\text{grass}} * \text{CP}_{\text{grass}} + \text{biomass}_{\text{forb}} * \text{CP}_{\text{forb}} + \text{biomass}_{\text{shrub}} * \text{CP}_{\text{shrub}}) /$$

$$(\text{biomass}_{\text{grass}} + \text{biomass}_{\text{forb}} + \text{biomass}_{\text{shrub}})$$

To aid in the development of hypotheses, we compared the relative strength of each of the four main parameters using an information theoretic approach. Our initial analysis showed topography to have the chief influence on cattle occupancy within cut blocks, while the other three parameters contributed very little explanatory power. Based on preliminary findings, we developed the following eight candidate models for comparison to determine if water, forage or slash provided any additive effect over topography:

1. Null model with no predictive parameters
2. Topography (elevation, slope and aspect)
3. Topography + forage (biomass and CP concentration)
4. Topography + distance to water
5. Topography + slash accumulation (slash maximum height and ground cover)
6. Topography + distance to water + forage
7. Topography + distance to water + slash accumulation
8. Topography + distance to water + slash accumulation + forage

Given determination of the best primary model, sub-models were also developed to assess the strength and relative contribution of each sub-parameter within the topography and forage categories.

Topography sub-models:

a. Elevation + distance to water + forage
b. Slope + distance to water + forage
c. Aspect + distance to water + forage

Forage sub-models:

a. Topography + distance to water + forage biomass
b. Topography + distance to water + forage CP concentration

Topography sub-models were only compared against each other, as was the same for forage sub-models.

To identify models providing the closest representation of reality, Akaike's Information Criterion, corrected for small sample size (AIC_c), was calculated for each candidate model using Equation [4].

$$AIC_c = - 2 \text{ log likelihood} + 2K + (2K (K + 1)) / (n - K - 1) \qquad [4]$$

General linear mixed model analysis (PROC GLIMMIX with LAPLACE estimation technique) (SAS Institute Inc. 2009) was employed to acquire -2 log likelihood values for each model, with K representing the number of parameters and n the sample size (i.e.

number of observations). The leading model with the greatest amount of support was characterized by the lowest AIC_c value. Ranking of models was based on differences in AIC_c scores among candidate models (*i*) and the minimum AIC_c, with the best model having a difference (i.e. ΔAICc) of 0 (See equation [5]).

$$\Delta AICc = AICc_i - AICc_{min} \quad [5]$$

Furthermore, model probabilities (ω_i) were calculated to determine the probability of each candidate model (*i*) being the best model among those tested (see Equation [6]).

$$\omega_i = \exp(-0.5\Delta_i) / \sum_{r=1}^{R} \exp(-0.5\Delta_r) \quad [6]$$

A resource selection probability function (RSPF) (Manly et al. 2002) for the best model was developed using beta coefficients (β) obtained from general linear mixed analyses (SAS Institute Inc. 2009). The RSPFs relate the probability of cattle occupancy of cut blocks to all measured independent variables (X) (see Equation [7]). Calculation of McFadden's pseudo R^2 (Windmeijer 1995) provided insight regarding the goodness of fit for each model (See Equation [8]).

$$RSPF = \exp(\beta_o + \beta_1 X_1 + \ldots + \beta_p X_p) / 1 + \exp(\beta_o + \beta_1 X_1 + \ldots + \beta_p X_p) \quad [7]$$

$$\text{McFadden's pseudo } R^2 = 1 - (\text{log likelihood}_{\text{candidate model}} / \text{log likelihood}_{\text{null model}}) \quad [8]$$

6.3. Results

6.3.1. Factors Affecting Cut Block Occupancy by Cattle

Comparison of the four main parameters (topography, forage, water distance, and slash accumulation) thought to influence cattle occupancy within cut blocks reveals that topography played the chief role, as substantiated by a model probability of 100% (Table 6.3). Water distance, forage and slash model probabilities were virtually zero. However, ranking these three relatively insignificant factors based on their model probabilities resulted in distance to water ranked at a very distant second, followed by forage characteristics, and last, slash accumulation.

Analysis of competing hypotheses (i.e. candidate models) identified the additive topography, water distance, and forage model as the best, as supported by a model probability of 66% (Table 6.4). The second best model associated with a model probability of 26% was that combining the influence of topography with distance to water (Table 6.4). The model accounting for topography alone provided a low model probability of just 0.04%, thus confirming the importance of water distance and forage attributes, in association with topography, in explaining cattle site selection within cut blocks. The best model accounting for topography, forage and water distance effects resulted in a weak pseudo R^2 of 21% (Table 6.4), indicating that much of the variance surrounding cattle occupancy within cut blocks was not explained through the parameters we measured.

Comparison of topography sub-models revealed elevation as virtually the sole topological factor affecting cattle occupancy within cut blocks, as evidenced by a model probability of 100% (Table 6.5). Aspect and slope effects were insignificant, with model probabilities near zero (Table 6.5). General linear mixed analysis revealed elevation to have a highly significant effect ($p<0.0001$), while beta coefficients showed a 4.5% decrease in the probability of cattle occupancy relating to a 100 m increase in elevation (Table 6.6, Fig. 6.1). Three dimensional figures (Fig. D1 to D6, see Appendix D) show cattle GPS locations concentrated at low elevation positions within cut blocks, in addition to very limited cattle use of cut blocks in general compared to other available rangeland habitats. Slope was an insignificant factor ($p=0.89$), while aspect ($p<0.05$) caused a 2.36% decrease in the probability of cattle occupancy relating to a 1 unit increase in aspect cosine transformed. In practical terms, this relationship equates to a greater probability of cattle occupying sites with a north-west rather than northerly aspect.

Comparative analysis of forage sub-models reveals forage CP concentration to have a greater influence than forage biomass, with competing model probabilities of 68 versus 32% (Table 6.5). General linear mixed analysis finds both forage CP and biomass significant at $p<0.05$, and $p<0.0001$, respectively (Table 6.6). Biomass was associated with a small positive beta coefficient of 0.0004, indicating a slight increase in the probability of cattle occupancy associated with 1 kg/ha increase in biomass (Table 6.6). Protein however was associated with a negative beta coefficient of -0.35, indicating a 0.35% decrease in the probability of cattle occupancy associated with a 1% increase in CP concentration (Table 6.6). Further investigation of the unexpected negative influence of increased forage CP content revealed that cut block forbs were greater in CP concentration than grasses ($p<0.001$), and that plots used by cattle had on average 162 kg/ha more grass biomass than forb. In contrast, plots without cattle use produced on average equal amounts of grass and forb biomass, accounting for the greater protein level of plots with lower use.

General linear mixed model analysis found water distance as a significant factor ($p<0.001$), while the beta coefficient revealed that with each 100 m increase in distance to water, the probability of cattle occupancy decreased by 0.6% (Fig. 6.1).

Information theoretic analysis found logging slash accumulation to have an insignificant influence on cattle site selection within cut blocks, as evidenced by the drop in model probability from 26% to 7% when the slash parameter was added to the topography and water distance model (Table 6.4). Simple linear regression of distance to nearest grazed patch, as affected by maximum slash height, showed a weak but significant negative relationship ($R^2=0.09$; $p<0.05$) (Fig 6.2). In general, greater slash ground cover negatively affected cattle use of plots, with the proportion of plots exhibiting cattle occupancy declining with increasing slash cover (Fig. 6.3).

6.3.2. Damage to Regeneration

Observed damage to coniferous regeneration was very limited, and confined to the vertical displacement of two naturally regenerating Douglas fir seedlings within the Damon distribution unit grazed during August of 2009. Total coniferous regeneration densities showed an increasing trend within each distribution unit from 2008 to 2009 (Table 6.7), with these increases tied to the abundance of lodgepole pine and Douglas fir seedlings rather than white spruce, the latter of which declined in density. Dead and browned spruce seedlings were frequently observed despite no apparent damage. Most Douglas fir seedlings were a result of natural regeneration.

Seedling growth, as measured by height and diameter, showed an increase despite cattle grazing over the study (Table 6.7). Average measurements of seedlings indicated they will likely meet the minimum 30 cm height requirement for conifer regeneration standards in establishment surveys for the Montane region (ASRD 2008) conducted no sooner than 4 years and no later than 5 years following harvest (i.e. 2010 – 2011). Additionally, a minimum of 80% stocking is required within regenerating cut blocks at the time of the establishment survey. At the end of the study in 2009, overall tree stocking rates were 77, 69 and 68% in cut blocks assessed within the Prong Coulee, North Sharples and Damon distribution units.

6.4. Discussion

Cattle use of cut blocks likely involves several complex processes including experiential learning, genetic predispositions, interaction with surrounding environmental characteristics, and the social dynamics of a herd (Senft et al. 1983; Bailey et al. 1989; Launchbaugh and Howery 2005). Herbivores employ all physical senses to judge the suitability or desirability of sites, and have the ability to associate certain environmental features with positive or negative consequences (Bailey et al. 1996; Launchbaugh and Howery 2005).

The relative ranking and importance of mechanisms regulating cattle use of cut blocks will vary for different environments based on variation in soils, elevation, topography, precipitation, temperature, logging method, post-harvest site treatment, distance to water, accessibility, and herd management (McLean and Clark 1980; Eissenstat et al. 1982; Allen and Bartolome 1989; Pitt et al. 1998). When comparing the relative significance of topography, forage, water availability, and accessibility as influenced by logging slash accumulation, topography was the principal factor regulating cattle site selection within cut blocks. However, herbivore responses are rarely driven by a single environmental feature and are more typically influenced by multifaceted and interacting factors. Therefore, it is fitting that we determined the additive effects of topography, distance to water, and forage characteristics to provide the best description and representation of cattle site selection within cut blocks. From a holistic perspective, topographical and forage conditions, paired with water availability, acted in unison to influence cattle site selection within the coniferous cut blocks studied, given the grazing management applied.

Among topographical features measured, elevation played the chief role in affecting cattle occupancy of cut blocks, with the probability of cattle presence diminishing with increasing elevation. Low elevation sites within cut blocks were likely more accessible to cattle, in addition to being situated closer to water sources and productive grassland habitats within valley bottoms. At the landscape level, cattle showed a strong affinity for low-lying grassland habitats situated near streams and riparian areas (see Chapter 5). While spending the majority of their time within lowland grasslands, cattle may have crossed steams and wandered into nearby cut blocks to investigate this novel habitat, thereby concentrating their presence to low elevation sites near water. Our speculation is supported by Kie and Boroski (1996), who hypothesized that cattle use of logged areas within California ranges may be related to the proximity of clear cuts to riparian habitats. Vertical distance above water, a modified measure of elevation, was determined to be the key factor affecting cattle use on moderately steep slopes within the Blue Mountains of Oregon (Holechek et al. 1982). Similarly, Ganskopp and Bohnert (2009) found that cattle distribution had a negative association with elevation of stock water. The significant role of water availability in affecting spatial distribution of cattle is well documented (Mueggler 1965; Roath and Krueger 1982; Pinchak et al. 1991; Ganskopp 2001; Putfarken et al. 2008; Ganskopp and Bohnert 2009).

Although an interaction between elevation and slope was not tested, it too could explain limited cattle use of high elevation positions within cut blocks. With slopes ranging from 6 to 26% within cut blocks of the present study, cattle may be less inclined to expend energy travelling to uphill locations. Research has shown that cattle are more likely to remain at or near foot-slope positions as slope gradient increases (Mueggler 1965; Chapter 5). Our observations agree with those of Eissenstat et al. (1982) who noted cattle prefer bottom slope locations within cut blocks in Idaho.

Although cattle are known to concentrate use on slopes of 10% or less (Pinchak et al. 1991; Bailey et al. 1996), we found slope gradient alone did not alter cattle site selection within cut blocks. This outcome contrasts that of Gillen et al. (1984) who concluded slope was the only physical factor consistently associated with cattle distribution within north-eastern Oregon rangelands. Similarly, the role of aspect was relatively unimportant given competing model hypotheses. The limited role of aspect may be explained by the limited variation of this parameter within or between cut blocks, as aspect was typically limited to north and north-west facing slopes. However, resource selection functions suggest that greater probability of cattle occurrence was associated with north-western aspects that potentially offer more productive forage benefiting from increased solar radiation, and prior to logging may have been more typical of low density 'Montane' forest conditions.

In addition to the effects of elevation and water availability, forage attributes also governed site selection within cut blocks. Given competing hypotheses, forage CP concentration appeared slightly more important in predicting cattle occupancy than biomass. However, contrary to our assumption that cattle would actively choose sites with greater CP content, RSPFs revealed a negative relationship with increased forage CP levels. A possible explanation for this unexpected herbivore response is that highly nutritional yet unpalatable plants such as Canada thistle (*Cirsium arvense* (L.) Scop.) and other weeds that colonized disturbed soils were likely avoided by cattle. While thistle may be high in protein content, it often deters herbivory by cattle (De Bruijn and Bork 2006). Thus, despite providing lower nutritive content, in general cattle tended to occupy sites with more abundant grass than forb biomass, suggesting that low quality yet productive grasses were targeted by cattle. Despite this, forage characteristics alone offered limited explanation relating to cattle occupancy within cut blocks, which suggests that hunger and satiation were not major factors motivating cattle to enter cut blocks. These results contrast the notion that forage availability and quality are primary factors influencing the spatial distribution of herbivores (Clary et al. 1978; Senft et al. 1983; Bailey et al. 1989, 1996; Owens et al. 1991; Wallis de Vries and Schippers 1994; Asamoah et al. 2003; Launchbaugh and Howery 2005).

Contrary to our prediction that cattle would avoid sites characterized by expansive and vertically elevated logging debris, slash accumulation had a limited affect on cattle occupancy within cut blocks. The best models with the greatest probability of accurately identifying factors influencing cattle occupancy never included slash parameters. Given that cattle typically travel least effort pathways to traverse the landscape (Ganskopp et al. 2000), one would expect increasing slash accumulation to deter cattle occupancy (Parker et al. 1984; Forester et al. 2007a). Downed woody debris has been shown to obstruct herbivore movement or prevent entry into potential foraging sites (Grisez 1960; Jones 1983; Fredericksen et al. 1998; Bergquist and Örlander 1998; Ripple and Larson 2001; Kupferschmid and Bugmann 2005; Casabon and Pothier 2007; de Chantal and Granström 2007; Forester et al. 2007b). Nevertheless, we did observe a weak relationship indicating cattle foraging may be impeded as slash height increases. Additionally, cattle use declined as the amount of ground covered by slash increased. Wildlife studies have shown that the predicted energy cost of travel through woody debris increases in relation to obstacle density and depth (Parker et al. 1984). Parker et al. (1984) determined slash depths in excess of 0.5 m substantially suppressed elk and deer use, while Ripple and Larson (2001) suggested woody debris greater than 0.8 m deterred ungulates. Maximum slash height within the cut blocks used for our research averaged 0.85 m. As slash breaks down over subsequent years, any detrimental effect it has on cattle movement will likely diminish (Casabon and Pothier 2007).

Our study supports the compatibility of forestry and cattle grazing on a common land base given that we observed just two instances of cattle-induced damage to conifer seedlings, in addition to increased regeneration establishment and growth throughout the study. Final conifer seedling densities within our study were slightly greater than those of Zimmerman and Neuenschwander (1984), who reported approximately 1,330 Douglas fir and ponderosa pine stems/ha within cut blocks of Idaho. However, McLean and Clark (1980) found greater seedling densities in British Columbia, ranging from 1,700 to 6,100 stems/ha. Research suggests that Douglas fir regeneration responds better to grazing than some pine species (Zimmerman and Neuenschwander 1984), which may explain the increase in naturally occurring Douglas fir seedlings. Moreover, should regeneration continue to increase in the future, with or without the assistance of grazing to control competing herbs, there is the potential for cut blocks to meet provincial regeneration requirements during 2010 or 2011 when establishment surveys are conducted. Natural recruitment of conifer species supplements planted stock, leading to increased total seedling densities.

Regeneration damage and mortality can be expected as livestock stocking rate increases (Lewis 1980a; Newman et al. 1994; Pitt et al. 1998). The limited occurrence of tree seedling damage in the present study can be attributed to the sustainable pairing of cattle stocking rates with available forage resources. The implementation of moderate forage use levels (i.e. 50%) could potentially be beneficial to seedling growth and establishment through the control of competing vegetation, as well as the creation of microsites (i.e. exposed soil) required for seedling recruitment (Zimmerman and Neuenschwander 1984; Allen and Bartolome 1989; Newman et al. 1994; Kie and Boroski 1996). Substantial seedling death from non-cattle related causes has been attributed to weather conditions during planting, poor condition of planting stock, and even rodent damage (McLean and Clark 1980, Allen and Bartolome 1989, Newman et al. 1994). Many spruce seedlings in cut blocks examined here demonstrated significant chlorosis despite no livestock presence or damage, and could be related to drought conditions, particularly during 2008 when rainfall was 35% below normal.

Cases of successful assimilation of timber and cattle industries have been documented in British Columbia (McLean and Clark 1980; Newman et al. 1994), the Sierra Nevada forests of California (Allen and Bartolome 1989), slash pine stands in Louisiana (Cutter et al. 1999), and Douglas fir/ponderosa pine woodlands of Idaho

(Eissenstat et al. 1982; Zimmerman and Neuenschwander 1984). These researchers attribute negligible seedling damage and sufficient tree stocking and performance to well managed grazing practices that take into account an appropriate timing, duration, and intensity of forage use, which apprears to be the case for the current study as well.

6.5. Management Implications

Livestock producers, timber companies, and public land managers can work together to lay out future cut blocks in the landscape, implement appropriate grazing systems, monitor cattle activity and impacts within cut blocks, and determine what level of regeneration damage is acceptable (Mitchell et al. 1982; Allen and Bartolome 1989). Based on the findings of the present study, cattle use of cut blocks may be less likely if timber harvests are planned for high elevation areas at further distances from streams, riparian areas and primary (i.e. grassland) ranges. Additionally, the implementation of a conservative to moderate stocking rate should allow cattle to concentrate their use at preferred sites rather than traversing slopes to uphill sites in search of forage. Overuse of regenerating cut blocks, resulting in increased occurrence of tree seedling damage by cattle, can be prevented by employing moderate stocking rates corresponding to 50% forage utilization or less on primary ranges (Newman et al. 1994), which was never attained in the current study (max use = 43% in lowland grasslands; see Chapter 5).

Increased forage use within cut blocks may be possible once seedlings are well established, resilient to damage, and can effectively provide a visual and physical barrier to cattle (Lewis 1980c; Eissenstat et al. 1982; Mitchell et al. 1982; Newman et al. 1994). In addition to grazing management, several factors need to be taken into consideration in order to achieve successful integration of forestry and livestock grazing, including weather conditions causing altered forage availability and herbivore behaviour, and the physical characteristics and location of cut blocks. The findings of this study garner support for the successful coexistence of cattle grazing and commercial forestry on multiple use lands so as to minimize conflict between livestock and timber industries.

Table 6.1: Grazing periods and stocking rates within each of the 3 distribution units in the Sharples Creek and Skyline grazing allotments.

	2008		**2009**	
Distribution Unit	Grazing Period	Stocking Rate (AUM/ha)	Grazing Period	Stocking Rate (AUM/ha)
Damon	July 1 – Aug. 6	0.44	July 31 – Aug. 28	0.42
North Sharples	Aug. 25 – Sept. 8	0.59	Sept. 16 – Oct. 2	0.56
Prong Coulee	Sept. 9 – Oct. 5	0.35	June 29 – July 30	0.39

Table 6.2: Summary of model parameters used to explain cattle occupancy of cut block plots.

Model Parameters
Distance to nearest water source (m)
Topography:
Elevation (m)
Slope gradient (%)
Aspect (degrees, cosine transformed)
Logging slash accumulation:
Slash ground cover (%)
Slash maximum height (cm)
Forage characteristics:
Forage biomass (kg/ha)
Forage crude protein concentration (%)

Table 6.3: Comparison of the four main model parameters in their affect on cattle occupancy within cut blocks.

Model Parameters	**R^2** [1]	***k*** [2]	**-2 LL** [3]	**AIC_c** [4]	**ΔAIC_c** [5]	**ω_i** [6]
Null [7]		2	379.97	384.01	53.66	2.23 E-12
Topography	0.16	5	320.15	330.35	0	1
Water Distance	0.04	3	366.28	372.36	42.01	7.55 E-10
Forage	0.03	4	368.47	376.60	46.25	9.04 E-11
Slash	0.01	4	375.91	384.04	53.69	2.19 E-12

Table 6.4: Comparison of RSPF hypothesis models explaining cattle occupancy within cut blocks.

Candidate Models	**R^2** [1]	***k*** [2]	**-2 LL** [3]	**AIC_c** [4]	**ΔAIC_c** [5]	**ω_i** [6]
Null [7]		2	379.97	384.01	68.53	0
Topography	0.16	5	320.15	330.35	14.88	0.0004
Topography + Forage	0.18	7	312.58	326.96	11.48	0.002
Topography + Water Distance	0.20	6	305.08	317.36	1.89	0.26
Topography + Slash	0.16	7	318.71	333.09	17.61	0
Topography + Water Distance +Forage	0.21	8	298.99	315.47	0	0.66
Topography + Water Distance + Slash	0.20	8	303.42	319.20	4.43	0.07
Topography + Water Distance + Forage + Slash [8]	0.19	10	307.41	328.16	12.68	0.001

[1] McFadden's pseudo R^2 goodness of fit measure

[2] Number of model parameters

[3] -2 log likelihood value

[4] AIC adjusted for a sample size of 306 observations

[5] Difference between each AIC_c and lowest AIC_c score

[6] Model probability

[7] Null model includes intercept only and is used for comparative purposes

[8] Global model (includes all model parameters)

Table 6.5: Comparison of RSPF topography and forage sub-models explaining cattle occupancy within cut blocks, based on the best model from Table 6.4.

Candidate Sub-Models	**R^2**	***k***	**-2 LL**	**AIC_c**	**ΔAIC_c**	**ω_i**
Topography						
Null		2	379.97	384.01	68.09	0
Elevation + Water Distance + Forage	0.20	6	303.64	315.92	0	1
Slope + Water Distance + Forage	0.07	6	355.26	367.54	51.62	0
Aspect + Water Distance +Forage	0.08	6	350.55	362.83	46.91	0
Forage						
Null		2	379.97	384.01	68.70	0
Topography + Water Distance + Forage Biomass	0.20	7	302.47	316.85	1.54	0.32
Topography + Water Distance + Forage Protein	0.21	7	300.93	315.31	0	0.68

Table 6.6: Relative influence of each parameter included in the best RSPF model explaining cattle use within cut blocks.

Parameter	**β^1**	**SE**	***P* value**
Intercept	74.16	11.78	<0.05
Elevation	-0.04	0.007	<0.0001
Slope	0.005	0.04	0.89
Aspect	-2.36	1.11	<0.05
Water Distance	-0.006	0.002	<0.001
Forage Biomass	0.0004	0	<0.0001
Forage Protein	-0.35	0.17	<0.05

[1] Beta coefficient

Table 6.7: Regeneration densities, heights and basal diameters of coniferous tree seedlings within cut blocks of each of three distribution units (Damon, North Sharples and Prong Coulee), during each of 2008 and 2009.

	2008			**2009**		
Response & Tree Species	Damon	North Sharples	Prong Coulee	Damon	North Sharples	Prong Coulee
Regeneration Density (stems/ha)						
White Spruce	260±527	143±521	1323±2023	360±722	71±261	1194±2488
Lodgepole Pine	460±930	1310±1070	661±829	1140±1443	1500±1384	871±1274
Douglas Fir	0	0	32±178	20±141	95±484	65±248
Total Regeneration	720±1031	1453±1194	2016±2154	1520±1568	1666±1509	2130±2796
Seedling Height (cm)*						
White Spruce	24.3±5.9	14.3±6.5	26.4±16.8	26.9±7.1	28.3±3.2	58.3±55.5
Lodgepole Pine	16.2±6.7	16.2±5.1	17.8±6.9	16.7±10.0	26.9±11.4	20.2±10.8
Douglas Fir	-	-	12.5±3.5	22.0±0	13.3±2.6	16.0±3.9
Basal Diameter (cm)						
White Spruce	0.6±0.2	0.6±0.2	0.6±0.5	0.8±0.2	1±0	1.3±1.0
Lodgepole Pine	0.4±0.1	0.5±0.1	0.4±0.2	0.5±0.3	0.7±0.3	0.6±0.2
Douglas Fir	-	-	0.4±0.1	0.9±0	0.5±0.2	0.5±0.1

* In 2008, seedling heights were measured to the tip of the terminal needles. In 2009, seedling heights were recorded to the tip of the stem and excluded terminal needle length.

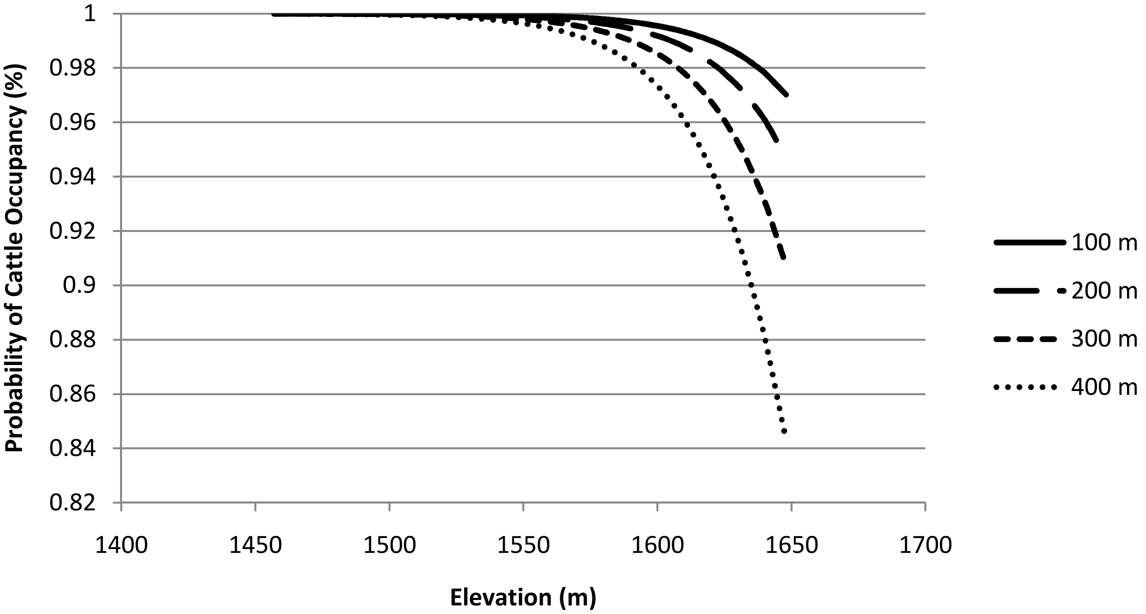

Figure 6.1: Resource selection probability functions showing the relationship between cattle occupancy within cut blocks and elevation, as influenced by distance to water at 100, 200, 300, and 400 m. Functions are based on the beta coefficients of the best model which includes the effects of topography, water distance and forage, with undepicted parameters held constant.

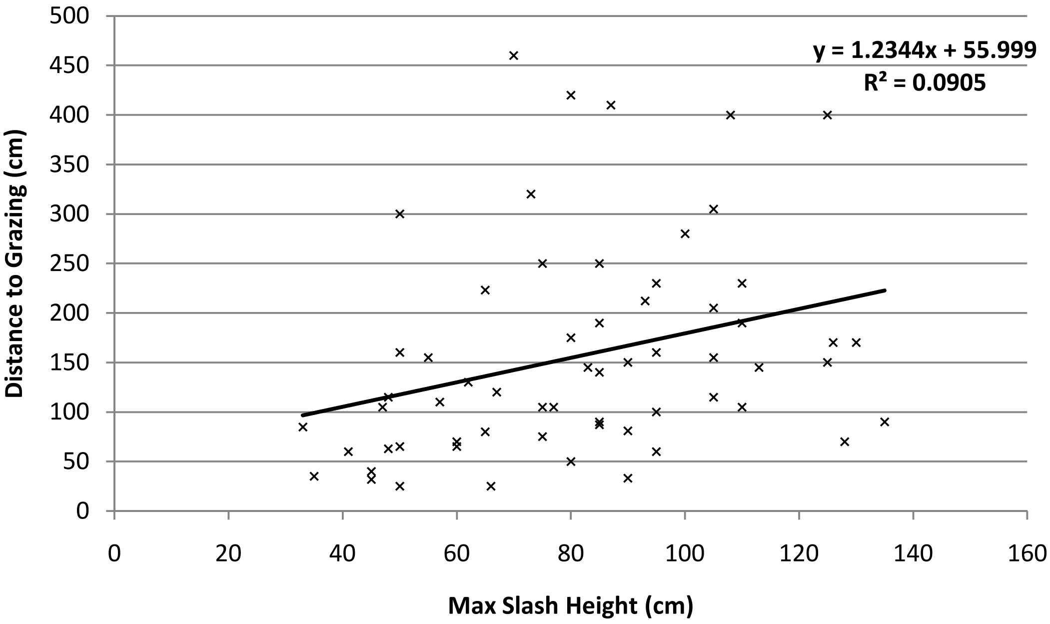

Figure 6.2: Relationship between maximum slash height and cattle accessibility in the form of distance to the nearest grazing patch (R^2 = 0.09; p<0.05).

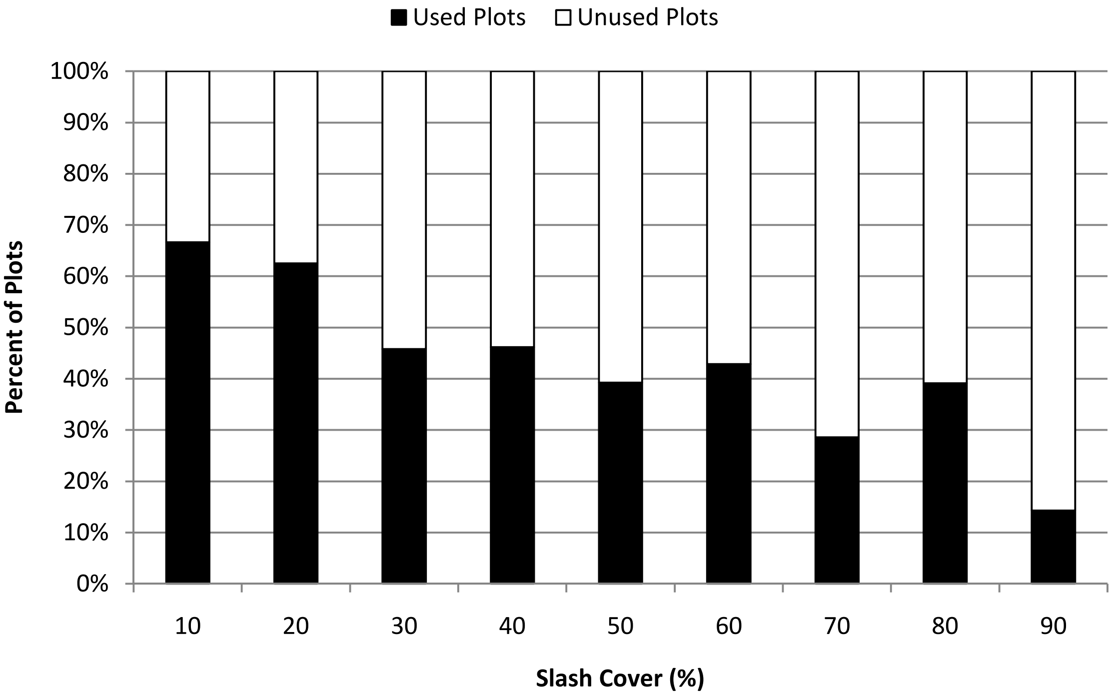

Figure 6.3: Proportion of cut block plots during 2008 and 2009 with signs of cattle occupancy across increasing slash cover (%) classes.

6.6. *Literature Cited*

Akaike, H. 1973. Information theory and an extension of the maximum likelihood principle. In: Petrov, B.N., Csaki, F. (Eds.), 2nd International Symposium of Information Theory, Akademiai Kiado, Budapest, pp. 267-281.

Alberta Sustainable Resource Development. 2008. Alberta regeneration survey manual. Forest Management Branch, Edmonton, Alberta, Canada. Publication No. T/181. ISBN No. 978-0-7785-7039-4 (On-line Edition).

Alberta Sustainable Resource Development. 2009. 2009 annual status of reforestation in Alberta. Forest Management Branch, Forestry Division.

Allen, B.H. and J.W. Bartolome. 1989. Cattle grazing effects on understory cover and tree growth in mixed conifer clearcuts. Northwest Science 63(5): 214-220.

Anderson, D.R. 2008. Model Based Inference in the Life Sciences. Springer Science + Business Media, LLC, New York, New York, USA.

Asamoah, S.A., E.W. Bork, B.D. Irving, M.A. Price, and R.J. Hudson. 2003. Cattle herbage utilization patterns under high-density rotational grazing in the aspen parkland. Canadian Journal of Animal Science 83: 541-550.

Bailey, D.W., L.R. Rittenhouse, R.H. Hart, D.M. Swift, and R.W. Richards. 1989. Association of relative food availabilities and locations by cattle. Journal of Range Management 42(6): 480-482.

Bailey, D.W., J.E. Gross, E.A. Laca, L.R. Rittenhouse, M.B. Coughenour, D.M. Swift, and P.L Sims. 1996. Mechanisms that result in large herbivore grazing distribution patterns. Journal of Range Management 49 (5): 386-400.

Beaver, J.M. and B.E. Olson. 1997. Winter range use by cattle of different ages in southwestern Montana. Applied Animal Behaviour Science 51:1-13.

Bergquist, J., G. Örlander, and U. Nilsson. 1999. Deer browsing and slash removal affect field vegetation on south Swedish clearcuts. Forest Ecology and Management 115: 171-182.

Bork, E.W. and S.J. Werner. 1999. Viewpoint: implications of spatial variability for estimating forage use. Journal of Range Management 52(2): 151-156.

Casabon, C. and D. Pothier. 2007. Browsing of tree regeneration by white-tailed deer in large clearcuts on Anticosti Island, Quebec. Forest Ecology and Management 253: 112-119.

Chapman, D.F., A.J. Parsons, G.P. Cosgrove, D.J. Barker, D.M. Marotti, K.J. Venning, S.M. Rutter, J. Hill, and A.N. Thompson. 2007. Impacts of spatial patterns in pasture on animal grazing behaviour, intake, and performance. Crop Science 47: 399-415.

Clary, W.P., P.F. Ffolliott, and F.R. Larson. 1978. Factors affecting forage consumption by cattle in Arizona ponderosa pine forests. Journal of Range Management 31(1): 9-10.

Cutter, B.E., K. Hunt, and J.D. Haywood. 1999. Tree/wood quality in slash pine following longterm cattle grazing. Agroforestry Systems 44: 305-312.

De Bruijn, S.L. and E.W. Bork. 2006. Biological control of Canada thistle in temperate pastures using high density rotational cattle grazing. Biological Control 36: 305-315.

de Chantal, M. and A. Granström. 2007. Aggregations of dead wood after wildfire act as browsing refugia for seedlings of *Populus tremula* and *Salix caprea*. Forest Ecology and Management 250: 3-8.

Dumas, J.B.A. 1831. Procedes de l'analyse organique. Ann. Chim. Phys. 247-213.

Eissenstat, D.M., J.E. Mitchell, and W.W. Pope. 1982. Trampling damage by cattle on northern Idaho forest plantations. Journal of Range Management 35(6): 715-716.

Forester, J.D., A.R. Ives, M.G. Turner, D.P. Anderson, D. Fortin, H.L. Beyer, D.W. Smith, and M.S. Boyce. 2007a. State-space models link elk movement patterns to landscape characteristics in Yellowstone National Park. Ecological Monographs 77(2): 285-299.

Forester, J.D., D.P. Anderson, and M.G. Turner. 2007b. Do high-density patches of coarse wood and regenerating saplings create browsing refugia for aspen (*Populus tremuloides* Michx.) in Yellowstone National Park (USA)? Forest Ecology and Management 253:211-219.

Fredericksen, T.S., B. Ross, W. Hoffman, M. Lester, J. Beyea, M.L. Morrison, and B.N. Johnson. 1998. Adequacy of natural hardwood regeneration on forestlands in northeastern Pennsylvania. Northern Journal of Applied Forestry 15(3): 130-134.

Frey, B.R., V.J. Lieffers, S.M. Landhäusser, P.G. Comeau, and K.J. Greenway. 2003. An analysis of sucker regeneration of trembling aspen. Canadian Journal of Forest Resources 33: 1169-1179.

Ganskopp, D.C. 2001. Manipulated cattle distribution with salt and water in large arid-land pastures: a GPS/GIS assessment. Applied Animal Behaviour Science 73: 251-262.

Ganskopp, D.C. and D.W. Bohnert. 2009. Landscape nutritional patterns and cattle distribution in rangeland pastures. Applied Animal Behaviour Science 116: 110-119.

Ganskopp, D.C., R. Cruz, and D.E. Johnson. 2000. Least-effort pathways?: a GIS analysis of livestock trails in rugged terrain. Applied Animal Behaviour Science 68: 179-190.

Gillen, R.L., W.C. Krueger, and R.F. Miller. 1984. Cattle distribution on mountain rangeland in northeastern Oregon. Journal of Range Management 37(6): 549-553.

Grisez. T.J. 1960. Slash helps protect seedlings from deer browsing. Journal of Forestry 58: 385-387.

Hart, R.H., K.W. Hepworth, M.A. Smith, and J.W. Waggoner, Jr. 1991. Cattle grazing behavior on a foothill elk winter range in southeastern Wyoming. Journal of Range Mangement 44(3): 262-266.

Holechek, J.L., M. Vavra, J. Skovlin, and W.C. Krueger. 1982. Cattle diets in the blue mountains of Oregon II. Forests. Journal of Range Management 35(2): 239-242.

Jones, K.L. 1983. Current knowledge of the effects of cattle grazing on aspen in the Alberta parkland. Rangelands 5(2): 59-60.

Jung, S., D.A. Rickert, N.A. Deak, E.D. Aldin, J. Recknor, L.A. Johnson, and P.A. Murphy. 2003. Comparison of Kjeldahl and Dumas methods for determining protein contents of soybean products. Journal of American Oil Chemists 80(12):1169-1173.

Kie, J.G. and B.B. Boroski. 1996. Cattle distribution, habitats, and diets in the Sierra Nevada of California. Journal of Range Management 49(6): 482-488.

Kowalenko, C.G. 2001. Assessment of Leco CNS-2000 analyzer for simultaneously measuring total carbon, nitrogen, and sulphur in soil. Communications in Soil Science and Plant Analysis 32: 2065-2078.

Krzic, M., R.F. Newman, and K. Broersma. 2003. Plant species diversity and soil quality in harvested and grazed boreal aspen stands of northeastern British Columbia. Forest Ecology and Management 182: 315-325.

Krzic, M., H. Page, R.F. Newman, and K. Broersma. 2004. Aspen regeneration, forage production, and soil compaction on harvested and grazed boreal aspen stands. BC Journal of Ecosystems and Management 5(2): 30-38.

Kupferschmid, A.D. and H. Bugmann. 2005. Effect of microsites, logs and ungulate browsing on *Picea abies* regeneration in a mountain forest. Forest Ecology and Management 205: 251-265.

Launchbaugh, K.L and L.D. Howery. 2005. Understanding landscape use patterns of livestock as a consequence of foraging behaviour. Rangeland Ecology and Management 58(2): 99-108.

Lewis, C.E. 1980a. Simulated cattle injury to planted slash pine: defoliation. Journal of Range Management 33(5): 345-348.

Lewis, C.E. 1980b. Simulated cattle injury to planted slash pine: girdling. Journal of Range Management 33(5): 337-339.

Lewis, C.E. 1980c. Simulated cattle injury to planted slash pine: combinations of defoliation, browsing, and trampling. Journal of Range Management 33(5): 340-345.

Manly, B.F.J., L.L. McDonald, D.L. Thomas, T.L. McDonald, and W.P. Erickson. 2002. Resource selection by animals: statistical analysis and design for field studies. Second Edition. Kluwer, Boston, Massachusetts, USA.

McLean, A. and M.B. Clark. 1980. Grass, trees, and cattle on clearcut-logged areas. Journal of Range Management 33(3): 213-217.

Mitchell, J.E., D.M. Eissenstat, and A.J. Irby. 1982. Forest grazing – an opportunity for diplomacy. Rangelands 4(4): 172-174.

Morgan, R.K. 1991. The role of protective understorey in the regeneration system of a heavily browsed woodland. Vegetation 92: 119-132.

Mueggler, W.F. 1965. Cattle distribution on steep slopes. Journal of Range Mangement 18(5): 255-257.

Newman, R.F., B.M. Wikeem, M.D. Pitt, D. Quinton, P. Youwe, and G.W. Powell. 1994. Grass/tree/cattle research on forest range in British Columbia, Canada. Managing Canadian Rangelands for Sustainability & Profitability: Proceedings of the First Interprovincial Range Conference in Western Canada. Pgs. 175-181.

Owens, M.K., K.L. Launchbaugh, and J.W. Holloway. 1991. Pasture characteristics affecting spatial distribution of utilization by cattle in mixed brush communities. Journal of Range Management 44(2): 118-123.

Parker, K.L., C.T. Robbins, and T.A. Hanley. 1984. Energy expenditures for locomotion by mule deer and elk. Journal of Wildlife Management 48(2): 474-488.

Pinchak, W.E., M.A. Smith, R.H. Hart, and J.W. Waggoner Jr. 1991. Beef cattle distribution patterns on foothill range. Journal of Range Management 44(3): 267-275.

Pitt, M.D., R.F. Newman, P.L. Youwe, B.M. Wikeem, and D.A. Quinton. 1998. Using a grazing pressure index to predict cattle damage of regenerating seedlings. Journal of Range Management 51(2): 152-157.

Platts, P.J., C.J. McClean, J.C. Lovett, and R. Marchant. 2008. Predicting tree distributions in an east African biodiversity hotspot: model selection, data bias and envelope uncertainty. Ecological Modelling 218: 121-134.

Putfarken, D., J. Dengler, S. Lehmann, and W. Härdtle. 2008. Site use of grazing cattle and sheep in a large-scale pasture landscape: a GPS/GIS assessment. Applied Animal Behaviour Science 111: 54-67.

Ripple, W.J. and E.J. Larsen. 2001. The role of postfire coarse woody debris in aspen regeneration. Western Journal of Applied Forestry 16(2): 61-64.

Roath, L.R. and W.C. Krueger. 1982. Cattle grazing and behavior on a forested range. Journal of Range Management 35(3): 332-338.

Senft, R.L. 1989. Hierarchical foraging models: effects of stocking and landscape composition on simulated resource use by cattle. Ecological Modelling 46: 283-303.

Senft, R.L., M.B. Coughenour, D.W. Bailey, L.R. Rittenhouse, O.E. Sala, and D.M. Swift. 1987. Large herbivore foraging and ecological hierarchies. BioScience 37(11): 789-799.

Senft, R.L., L.R. Rittenhouse, and R.G. Woodmansee. 1983. The use of regression models to predict spatial patterns of cattle behavior. Journal of Range Management 36(5): 553-557.

Wallis de Vries, M.F. and P. Schippers. 1994. Foraging in a landscape mosaic: selection for energy and minerals in free-ranging cattle. Oecologia 100: 107-117.

White, H. 1980. A heteroskedasticity-consistent covariance matrix estimator and a direct test for heteroskedasticity. Econometrica 48: 817-838.

Willoughby, M.G., M.J. Alexander, and B.W. Adams. 2005. Range plant community types and carrying capacity for the montane subregion. Sixth approximation. Alberta Sustainable Resource Development, Public Lands and Forest Division. Pub. no.: T/071. ISBN: 0-7785-4062-4 (On-line edition).

Windmeijer, F.A. 1995. Goodness-of-fit measures in binary choice models. Econometric Reviews 14(1): 101-116.

Zimmerman, G.T. and L.F. Neuenschwander. 1984. Livestock grazing influences on community structure, fire intensity, and fire frequency within the Douglas-fir/ninebark habitat type. Journal of Range Management 37(2): 104-110.

7. Synthesis

7.1. Research Summary

The integration of livestock grazing and timber production on forested lands has become a significant resource management issue on Alberta public lands where there is demand to satisfy both land uses. This innovative research project was created to examine the interactions between cattle grazing and forestry operations within rangelands containing recently harvested deciduous and coniferous cut blocks of west-central and south-west Alberta, respectively. Specific research objectives were to determine cattle habitat preference, assess the extent of cut block use by cattle, uncover the mechanisms driving foraging behaviour, and to quantify damage to tree regeneration caused by cattle.

Two and 3 years following logging, cattle grazing deciduous forest in July clearly preferred to occupy mature aspen forest over clear cut and partially harvested areas, as well as skid roads characterized by dense slash accumulation (Chapter 3). Two stocking rates were tested to determine if habitat selection would change due to increased grazing intensity; the low stocking rate is that recommended by Alberta Sustainable Resource Development while the high stocking rate was double the former. Despite twice the suggested stocking rate, cattle habitat preference did not change and forage use levels remained conservative. Due to patchy grazing and low cattle impact, it was difficult to find strong relationships between forage use and influential environmental features at the patch and paddock scale. Within a patch, cattle concentrated grazing where biomass was abundant and of good nutritional quality. Grazing patches near water troughs and with limited obstruction relating to logging debris and low regeneration densities also received greater use by cattle.

In Chapter 4, cattle-related damage to regenerating saplings was minimal, with less than 10% of trees sustaining injury. The extent of sapling damage was reflective of stocking rate, as the proportion of injured stems doubled with an increase from low to high stocking. Stem densities within clear cut and partially harvested areas remained above minimum levels needed for cut block regeneration, while sucker growth on skid roads was less than optimal.

Given forage use levels corresponding to 50% or less, cattle grazing Montane rangelands during July, August and September consistently avoided recently harvested cut blocks and conifer forests, and instead preferred to occupy productive grassland habitats (particularly those in lowlands) and aspen stands (Chapter 5). On the whole, the mechanisms influencing forage consumption by cattle within these heterogeneous rangelands were more complex at the patch than landscape scale. Within a grazing patch, cattle forage use was largely driven by feed availability and production, with small positive influences associated with higher nutritional quality and remoteness from gravel roads. Conversely, patches located on steep, north-facing slopes at further distances from water received less use by cattle. At the landscape level, cattle focused grazing within easily accessible sites without challenging slopes, as well as those areas close to water and at further distances from roads.

When cattle did choose to use cut blocks, a combination of topographical, forage, and water proximity features regulated their specific site selection (Chapter 6). Preferred locations within cut blocks were low in elevation, near streams as a source of water, and provided high nutritional quality. The limited cattle presence within cut blocks resulted in just two instances of damage to conifer seedlings.

7.2. Management Implications

Research outcomes confirm that successful integration of timber and cattle production can be achieved on Alberta public lands without sacrificing independent resource goals, business objectives, and ecological integrity. The implementation of suitable stocking rates lead to conservative to moderate forage use (i.e. 50% or less), thereby allowing deciduous and coniferous cut blocks to vigorously regenerate with minimal interference from cattle. Although the removal of mature forest overstory allows for an increase in herbage release and subsequent forage production, maintaining stocking rates at pre-harvest levels will provide added insurance against overuse of cut blocks by cattle. However, if stocking rates are altered to match forage resources, range managers will need to be diligent in re-evaluating plant community dynamics on an annual basis, in addition to within years as climate and weather conditions change. In densely regenerating deciduous stands, the initial surge in forage production will be suppressed by competitive sapling growth and the reformation of canopy closure. Given that forage availability is a major factor driving cattle grazing behaviour, it is vital that adequate amounts of forage of sufficient quality should be available to prevent cattle from resorting to browsing and trampling young trees in their search for feed. This is particularly true given that high aspen sapling densities appear to deter cattle use of these areas, and may therefore reduce the area of secondary range (i.e. aspen forest) available to cattle, thereby concentrating more use on remaining primary range (grasslands).

As the amount of damage inflicted upon regenerating trees by cattle is a function of the number of animals retained on the land during a given grazing period; an increase in stocking rate is likely to result in more injured trees. A single annual grazing period during mid to late summer allows sufficient time for regenerating trees to establish carbohydrate reserves through photosynthesis in the spring, while adequate rest following grazing ensures that trees will achieve winter hardiness. Additionally, deferral of grazing until after July 15th permits time for greater forage accumulation and improved stem strength and resistance to damage (Lane 1998; Dockrill et al. 2004, 2006). Given the research findings here, cattle avoidance of clear cuts may provide a 'natural mechanism' for this deferral. However, clear cutting entire pastures may necessitate the deferral of grazing for 1 to 2 years following deciduous logging to allow regeneration to establish and thrive in the absence of alternative grazing resources.

The management of rangelands containing cut blocks, in addition to future cut block development, should take into account the primary factors driving cattle behaviour so as to limit or evade damage to regeneration and possible conflict. Besides feed quantity, water availability has a major influence on range use by cattle. Given that cattle concentrate their use near water, troughs are best located away from regenerating cut blocks. Similarly, in regions such as the Montane where streams commonly provide the only water source for cattle, future cut block developments located at high elevation sites further up slope from streams and primary grassland rangelands may be at lower risk of cattle use. Slope gradient, distance to water and remoteness from roads were the predominant Montane landscape characteristics that regulated forage use by cattle and provide further guidelines for sustainable cattle stocking rate determination in this environment. Additionally, cut block establishment on areas associated with steeper slopes and greater distances from water should receive less frequent, if any, use by cattle. Other attractants including salt and mineral could be placed away from regenerating cut blocks so as to discourage cattle occupancy. Livestock producers can also use herding techniques to move cattle to elevated uplands that appear to receive very little use, as well as areas further from clear cuts.

In the case of logging slash accumulation, slash can be considered helpful or a hindrance for land managers. Slash barriers can be used as a preventative tactic to effectively deter cattle accessibility into regenerating cut blocks. However, such obstructions would need to be carefully placed so as to avoid complete disruption of cattle distribution across the rangeland and subsequent uneven utilization. In instances where logging debris significantly interrupts grazing management or becomes a threat to livestock safety, slash could be removed through piling and burning. Further information would also be helpful examining the duration of slash effects on cattle use, as long-term impacts may be particularly problematic where grazing capacities include a significant contribution from forested communities (especially important in deciduous forest).

Winter harvesting of timber is best employed to minimize soil and vegetation disturbance, maintain organic matter, minimize weed establishment, and maximize regeneration potential (Navatril 1991; Bates et al. 2003; Krzic et al. 2003; Berger et al. 2004; MacIssac et al. 2006; Renkema et al. 2009). Livestock producers rely on healthy rangelands to feed their livestock throughout summer and fall months, and the removal of valuable organic matter through summer logging compromises site productivity and nutrient availability for plant growth (Krzic et al. 2004; Corns and Maynard 1998). Additionally, soil disturbance provides an opportunity for the establishment of invasive weeds that can quickly spread throughout pastures, thereby threatening the ecological integrity and grazing capacity of rangelands.

Ranchers, foresters, and rangeland managers can work together to create integrated resource management plans that allow cattle and forest industries to simultaneously prosper. Each partner contributes valuable knowledge and information towards the ideal locations of cut blocks within grazing lands; awareness of cattle habits and behaviour, environmental site characteristics, timber harvesting operations and standards, and provincial regulations can be melded together to create an optimal scenario. Tree regeneration is known to depend on several factors including soil type and nutrient status, pre-harvest stand conditions, genetics, season of harvest, logging techniques and equipment, climate, competition, and disease, all of which must be considered prior to implicating cattle for regeneration failure (Navatril et al. 1991; David et al. 2001; Frey 2003; MacIssac et al. 2006). Through a cooperative approach, suitable grazing systems can be implemented, cut blocks can be monitored for cattle activity and impacts, and acceptable levels of regeneration damage can be achieved (Mitchell et al. 1982; Allen and Bartolome 1989).

7.3. Ideas for Future Research

There are many opportunities to extend and further grazing timber integration research. Ranching and forest industries would benefit from a long term study over 5 to 20 years that tested varying stocking rates, seasons of grazing, and grazing deferral periods following logging on regeneration growth, vegetation and plant community dynamics, soil compaction, and water infiltration. Additional studies could focus on quantifying a threshold for acceptable regeneration damage relating to different cattle stocking rates. From a foraging behaviour perspective, research relating to how cattle use of logged areas and rangelands containing cut blocks changes over time as regenerating sites evolve. Lastly, it would be advantageous to create a range of study sites across Alberta in order to establish ‘grazing timber rules of thumb’ that are consistent despite differences in local weather and specific site characteristics.

7.4. Literature Cited

Allen, B.H. and J.W. Bartolome. 1989. Cattle grazing effects on understory cover and tree growth in mixed conifer clearcuts. Northwest Science 63(5): 214-220.

Bates, P.C., C.R. Blinn, and A.A. Alm. 1993. Harvesting impacts on quaking aspen regeneration in northern Minnesota. Canadian Journal of Forest Resources 23: 2403-2412.

Berger, A.L, K.J. Puettmann, and G.E. Host. 2004. Harvesting impacts on soil and understory vegetation: the influence of season of harvest and within-site disturbance patterns on clear-cut aspen stands in Minnesota. Canadian Journal of Forest Resources 34: 2159-2168.

Corns, I.G.W. and D.G. Maynard. 1998. Effects of soil compaction and chipped aspen residue on aspen regeneration and soil nutrients. Canadian Journal of Soil Science 78: 85-92.

David, A.J., J.C. Zasada, D.W. Gilmore, and S.M. Landhäusser. 2001. Current trends in the management of aspen and mixed aspen forests for sustainable production. The Forestry Chronicle 77(3): 525-532.

Dockrill, C.W.M., P.V. Blenis, A.W. Bailey, and J.R. King. 2004. Effect of summer cattle grazing on aspen stem injury, mortality and growth. The Forestry Chronicle 80(2): 257-261.

Dockrill, C.W.M., A.W. Bailey, P.V. Blenis, and J.R. King. 2006. Seasonal variation in resistance of aspen stems to shearing force. Rangeland Ecology and Management 59(2): 212-215.

Frey, B.R., V.J. Lieffers, S.M. Landhäusser, P.G. Comeau, and K.J. Greenway. 2003. An analysis of sucker regeneration of trembling aspen. Canadian Journal of Forest Resources 33: 1169-1179.

Krzic, M., R.F. Newman, and K. Broersma. 2003. Plant species diversity and soil quality in harvested and grazed boreal aspen stands of northeastern British Columbia. Forest Ecology and Management 182: 315-325.

Krzic, M., H. Page, R.F. Newman, and K. Broersma. 2004. Aspen regeneration, forage production, and soil compaction on harvested and grazed boreal aspen stands. BC Journal of Ecosystems and Management 5(2): 30-38.

Lane, C.T.P. 1998. Effects of full-tree skidding and livestock grazing on aspen regeneration. M.Sc. Thesis, University of Alberta, Edmonton, Alberta, Canada.

MacIsaac, D.A., P.G. Comeau, and S.E. Macdonald. 2006. Dynamics of regeneration gaps following harvest of aspen stands. Canadian Journal of Forest Resources 36: 1818-1833.

Mitchell, J.E., D.M. Eissenstat, and A.J. Irby. 1982. Forest grazing – an opportunity for diplomacy. Rangelands 4(4): 172-174.

Navatril, S. 1991. Regeneration challenges. In S. Navratil and P.B. Chapman, editors. Aspen management for the 21st century. Proceedings of a symposium held November 20-21, 1990, Edmonton, Alberta. For. Can., Northwest Reg., North. For. Cent. and Poplar Counc. Can., Edmonton, Alberta.

Renkema, K.N., V.J. Lieffers, and S.M. Landhäusser. 2009. Aspen regeneration on log decking areas as influenced by season and duration of log storage. New Forests 38(3): 323-335.

APPENDIX A: STUDY SITES

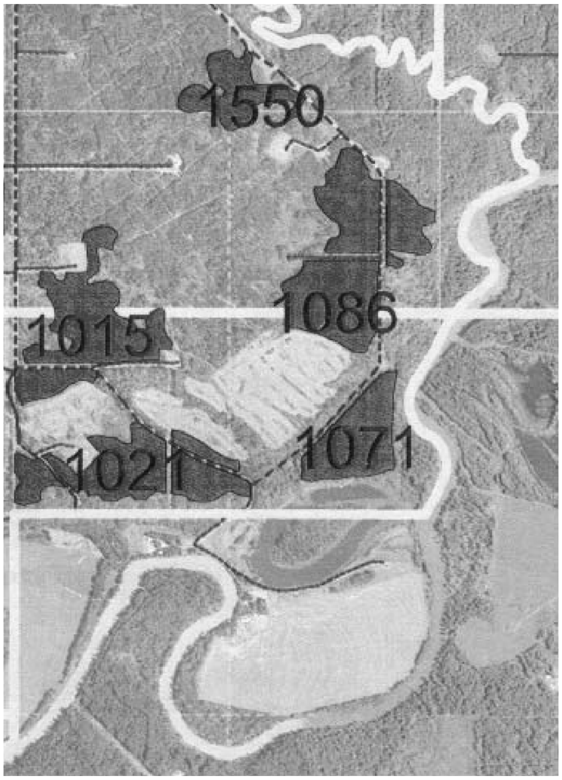

Figure A.1: Research at the deciduous study site was conducted in cut blocks 1021 and 1086 near the Pembina River.

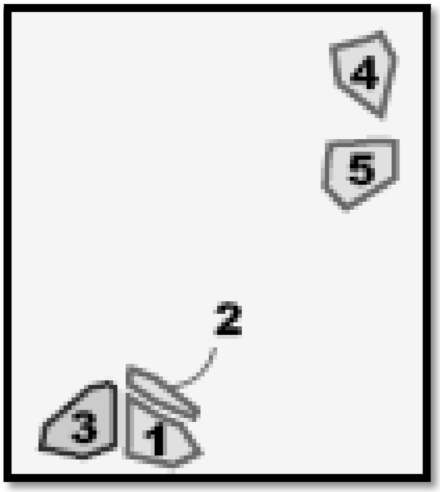

Figure A.2: Layout of grazing paddocks 1 and 3 within deciduous block 1021, and paddocks 4 and 5 within block 1086.

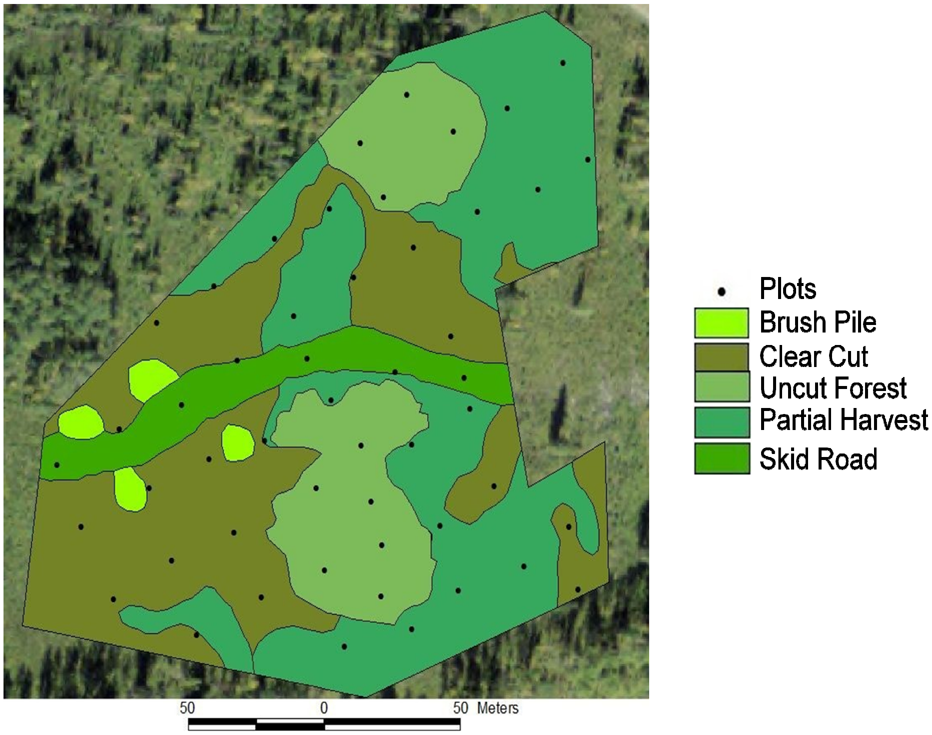

Figure A.3: Habitat type and plot distribution within paddock 3 at the deciduous study site.

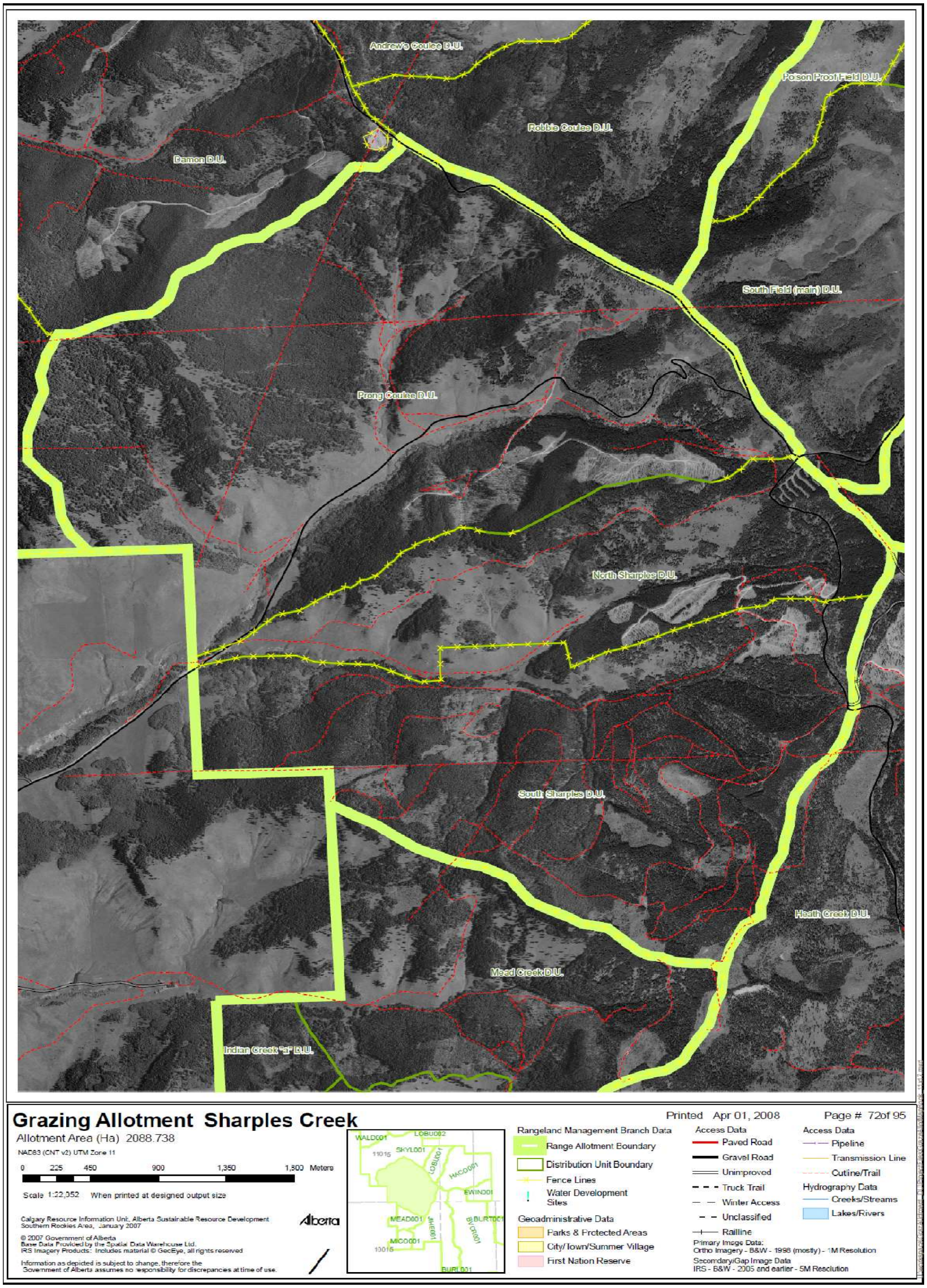

Figure A.4: Satellite image of Damon (Skyline allotment), Prong Coulee and North Sharples (Sharples Creek allotment) distribution units.

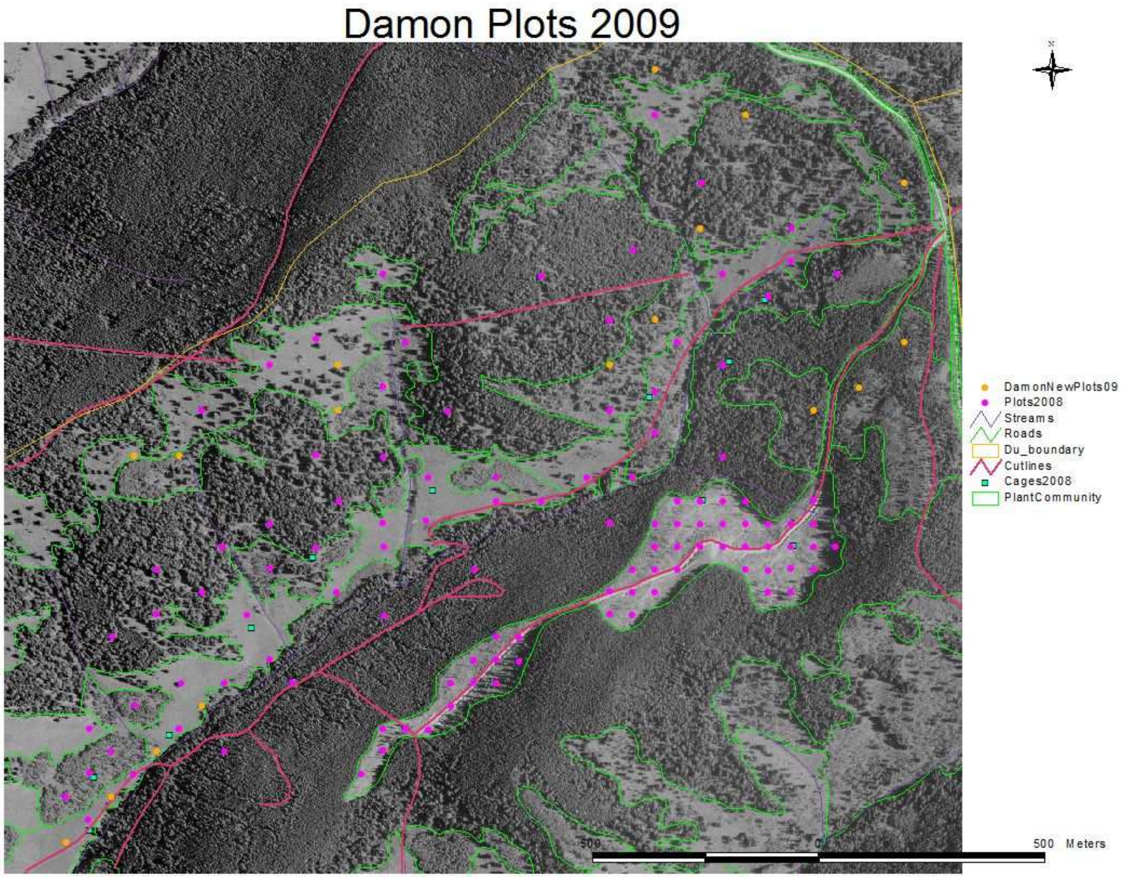

Figure A.5: Distribution of permanent sample plots throughout habitats within Damon distribution unit at the coniferous study site.

APPENDIX B: WEATHER DATA

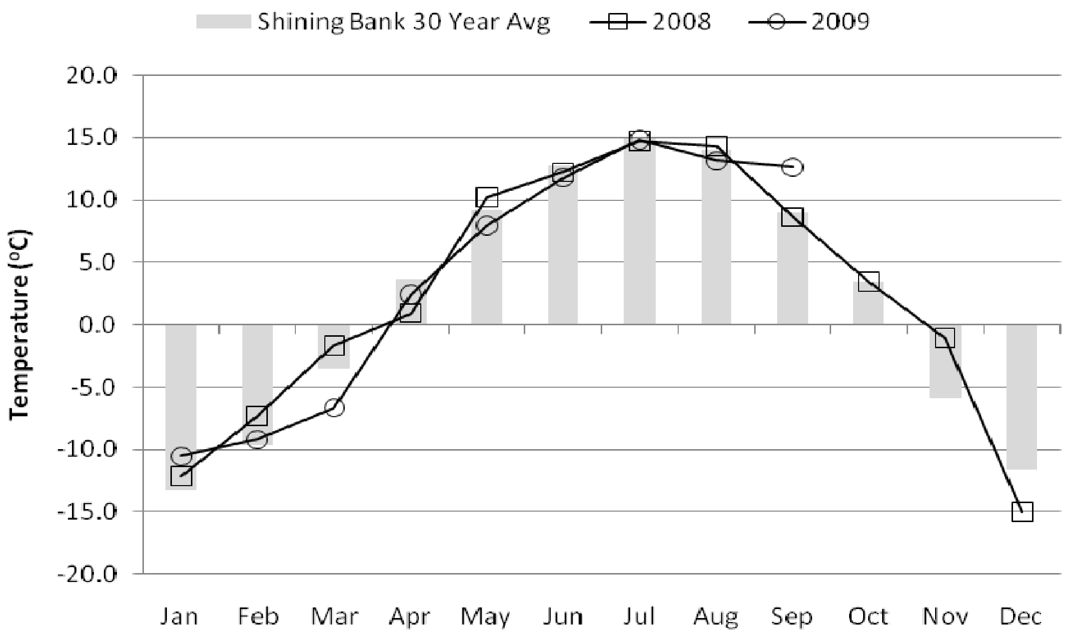

Figure B.1: Average monthly temperatures recorded by a temporary weather station at the study site in 2008 and 2009. Thirty year (1971-2000) average monthly temperatures are from Environment Canada's Shining Bank weather station (53°53'25.51"N 115°59'00.43" W).

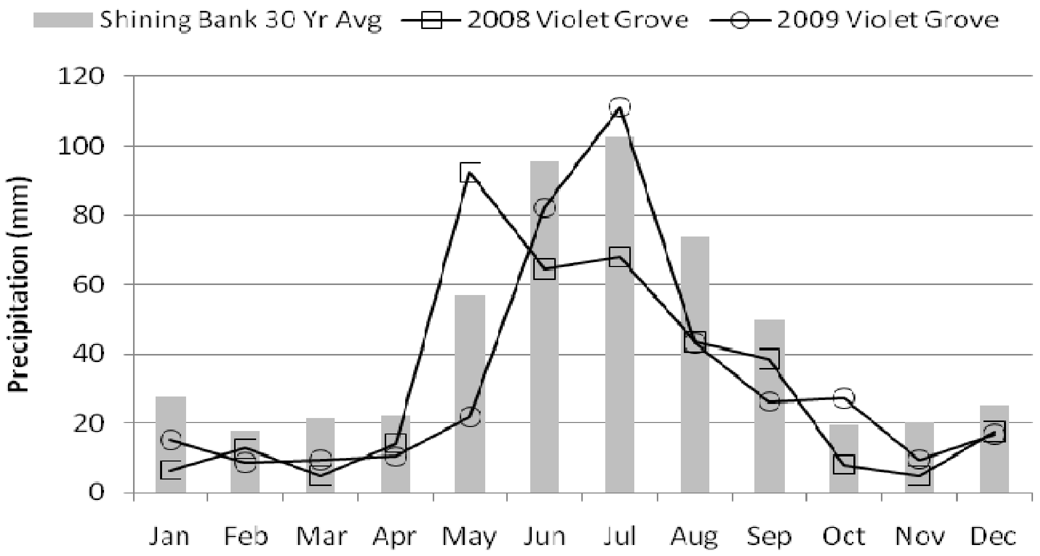

Figure B.2: Total monthly precipitation recorded by Environment Canada's Violet Grove weather station (53°09'51.97"N 115°02'13.40"W) in 2008 and 2009. Thirty year (1971-2000) average monthly precipitation values are from Environment Canada's Shining Bank weather station.

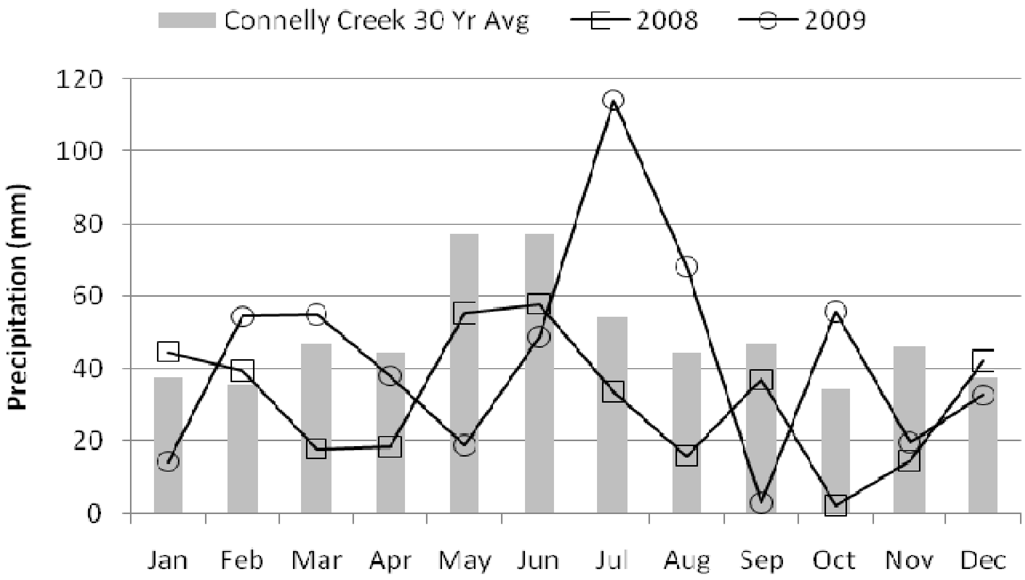

Figure B.3: Total monthly precipitation recorded by Environment Canada's Connelly Creek weather station in 2008 and 2009 (49°36'58.030"N 114°12'54.080"W) compared to the 30 year average (1971-2000).

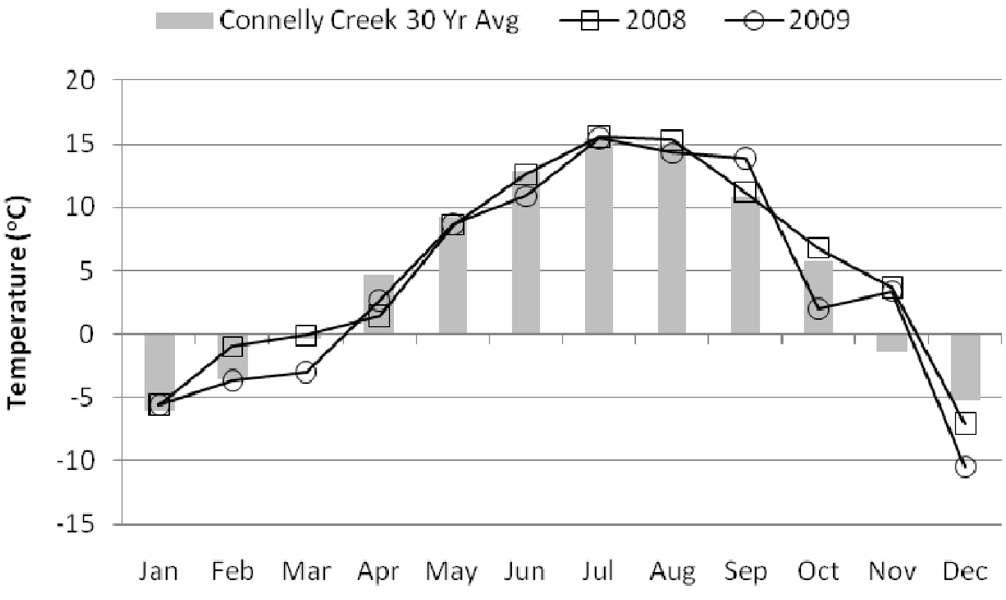

Figure B.4: Average monthly temperatures recorded by Environment Canada's Connelly Creek weather station in 2008 and 2009 (49°36'58.030"N 114°12'54.080"W) compared to the 30 year average (1971-2000).

APPENDIX C: FORAGE BIOMASS AND UTILIZATION ESTIMATE VALIDATION

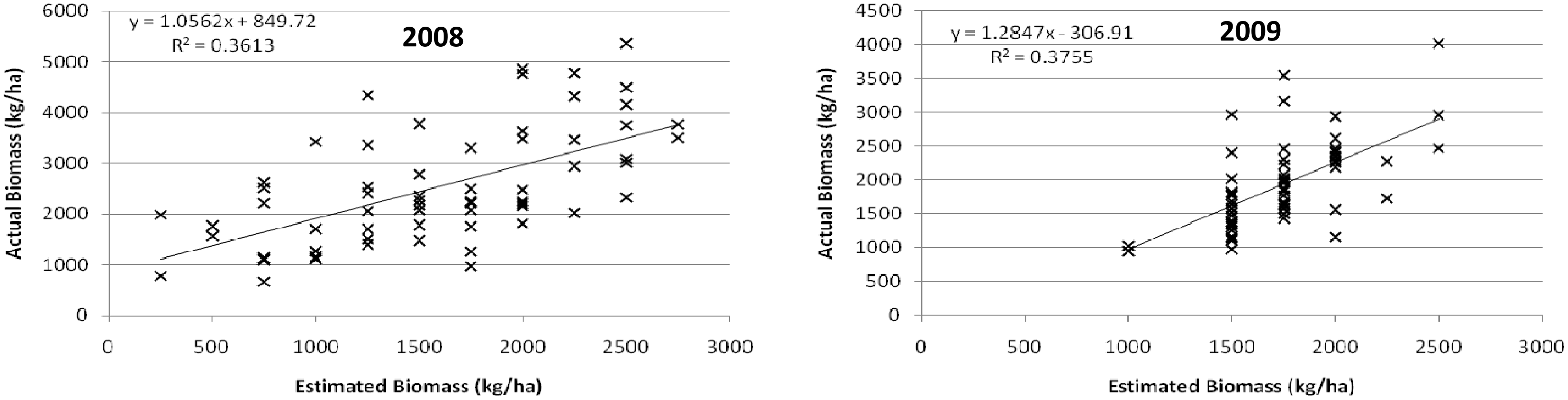

Figure C.1: Linear relationship between actual and estimated forage biomass (kg/ha) values at the deciduous site in 2008 and 2009.

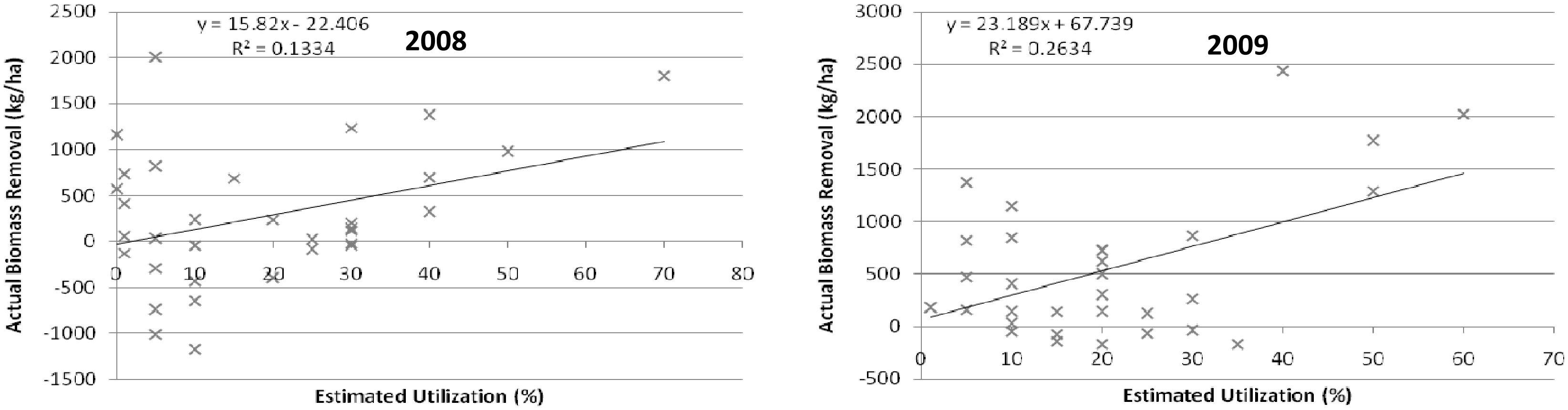

Figure C.2: Linear relationship between actual biomass removal (kg/ha) and estimated forage utilization (%) values at the deciduous site in 2008 and 2009.

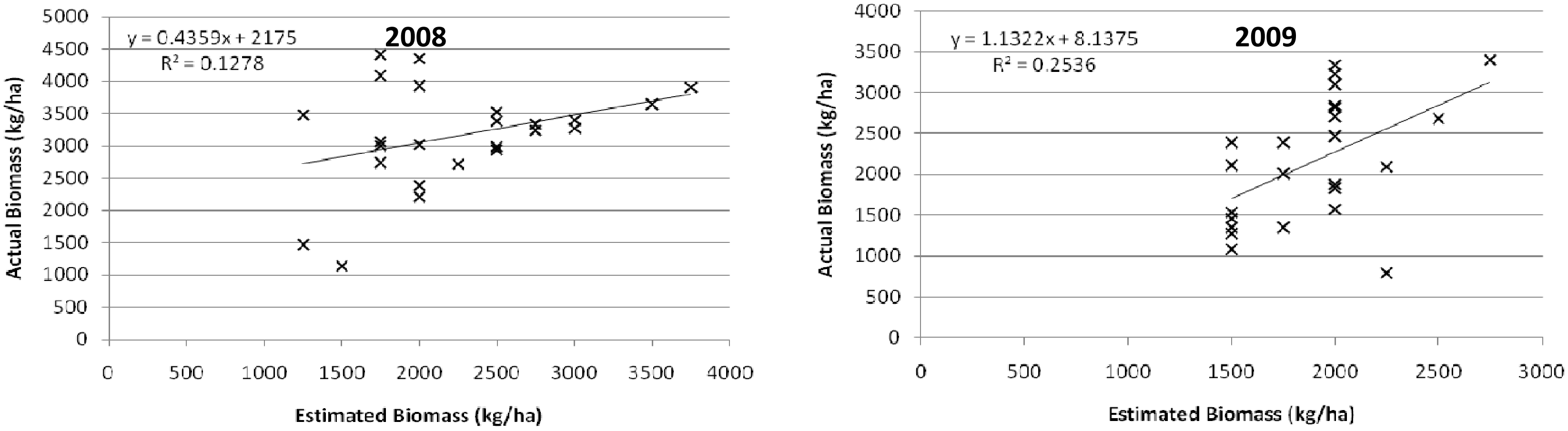

Figure C.3: Linear relationship between actual and estimated forage biomass (kg/ha) values within grassland habitats at the coniferous site in 2008 and 2009.

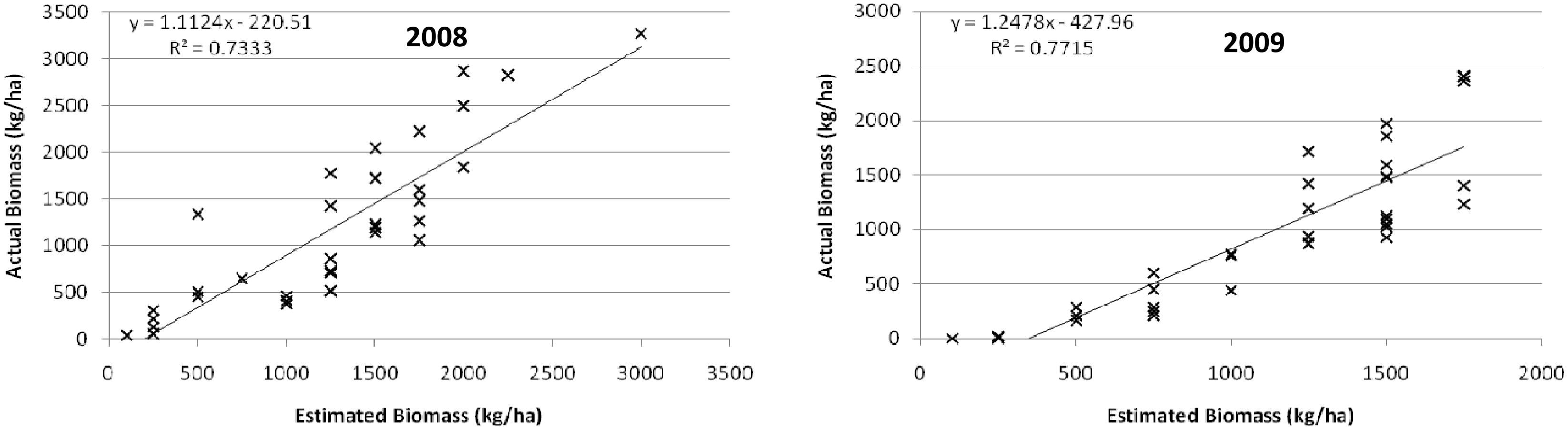

Figure C.4: Linear relationship between actual and estimated forage biomass (kg/ha) values within forested habitats at the coniferous site in 2008 and 2009.

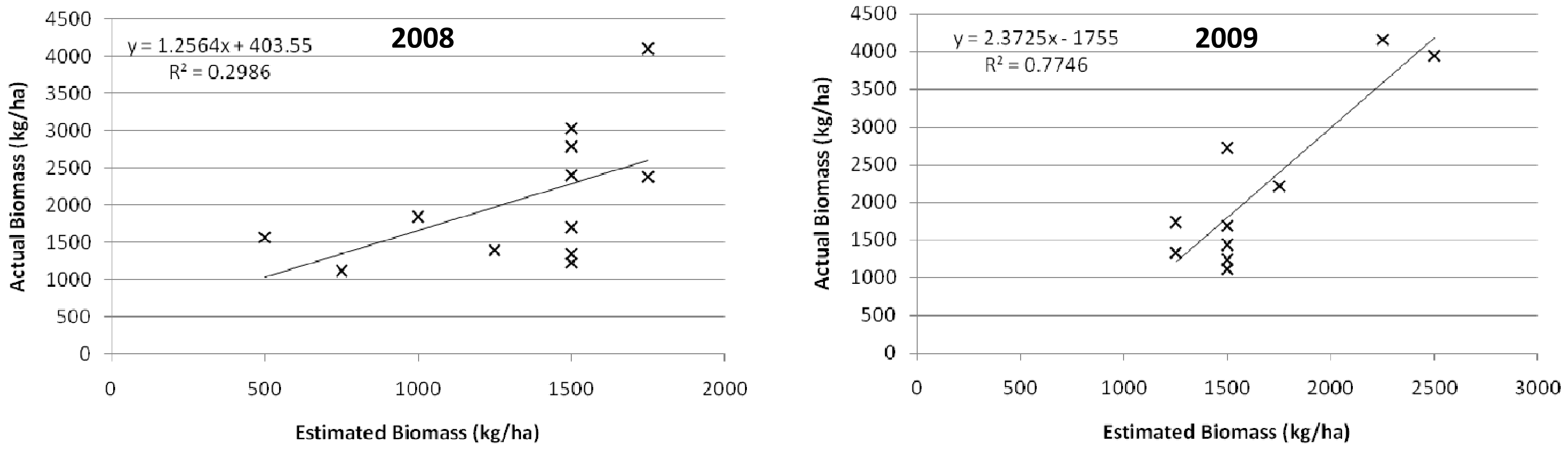

Figure C.5: Linear relationship between actual and estimated forage biomass (kg/ha) values within cut blocks at the coniferous site in 2008 and 2009.

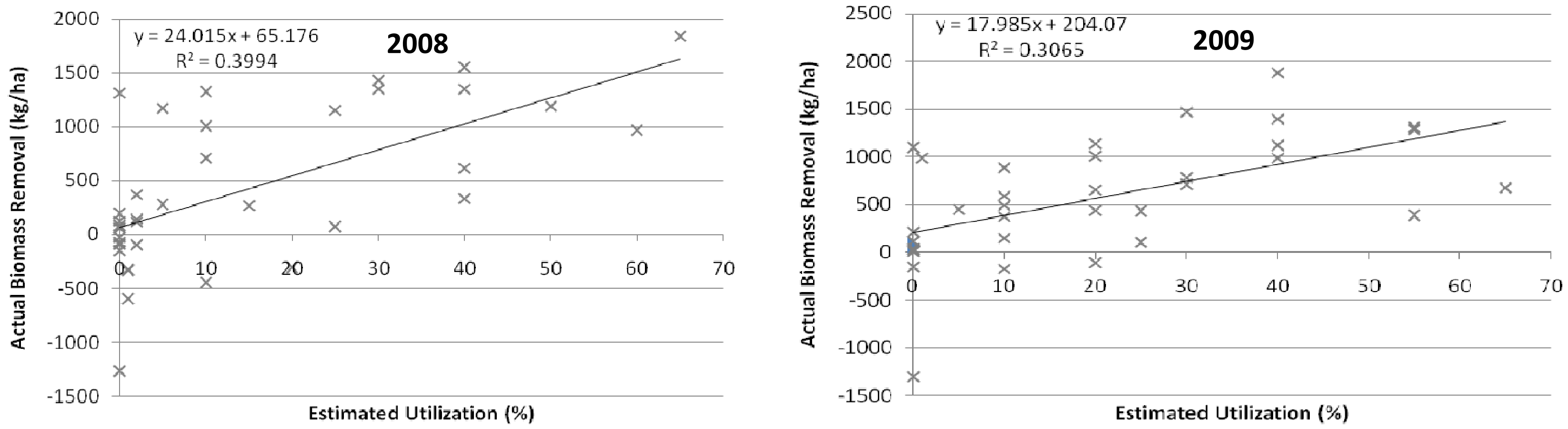

Figure C.6: Linear relationship between actual biomass removal (kg/ha) and estimated forage utilization (%) values at the coniferous site in 2008 and 2009.

APPENDIX D: CATTLE SPATIAL ASSESSMENT

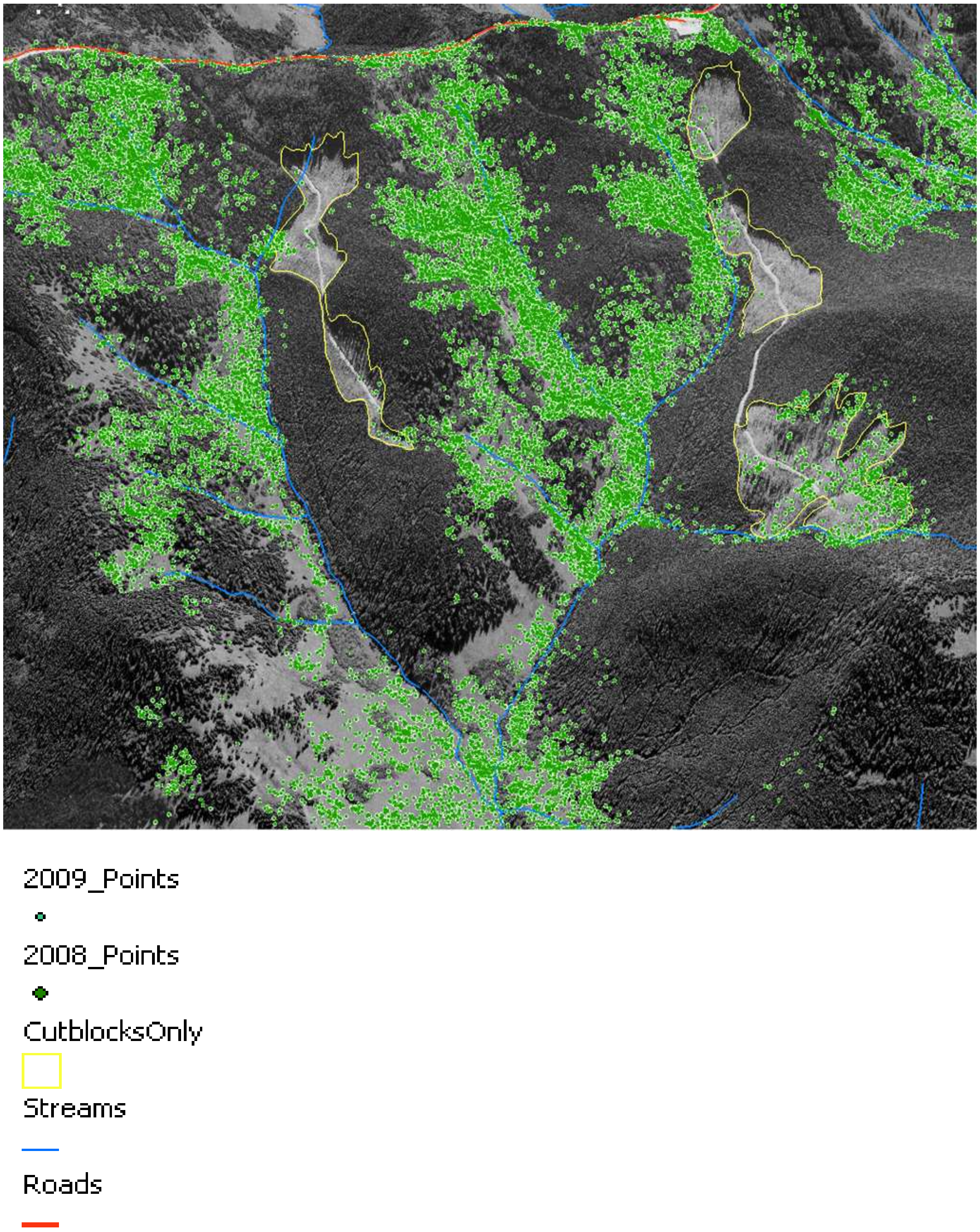

Figure D.1: GPS points resulting from cattle grazing in Damon distribution unit during July 2008.

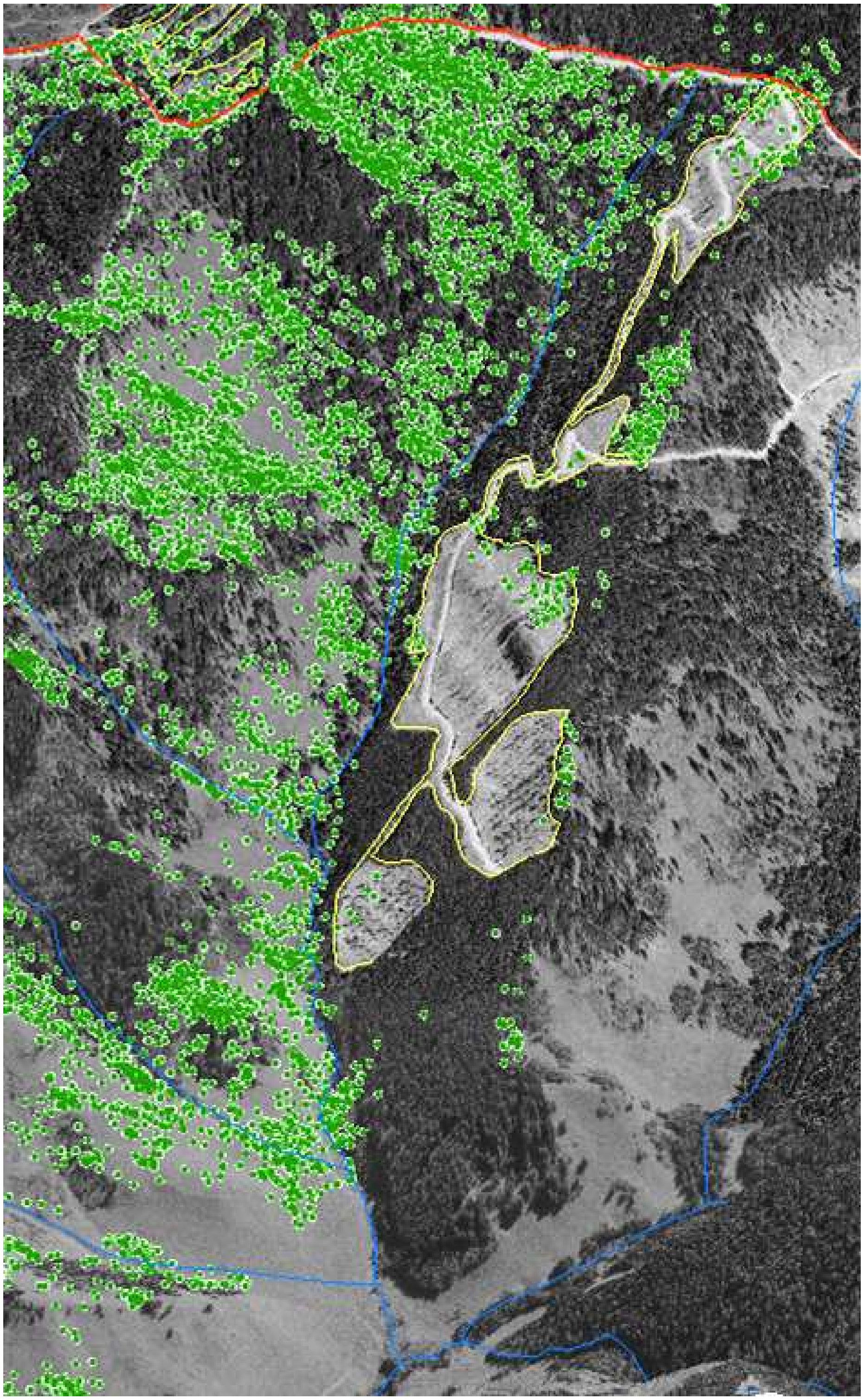

Figure D.2: GPS points resulting from cattle grazing in North Sharples distribution unit during August 2008.

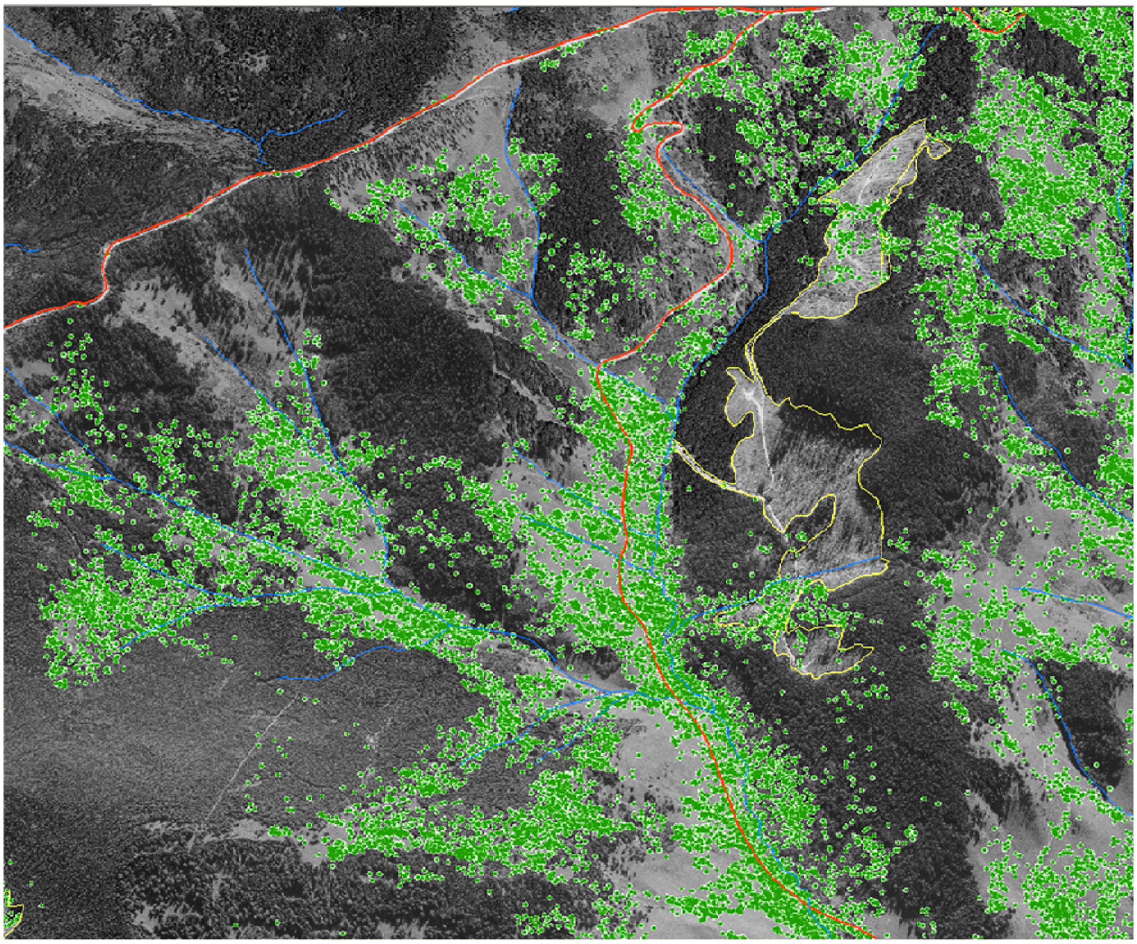

Figure D.3: GPS points resulting from cattle grazing in Prong Coulee distribution unit during September 2008.

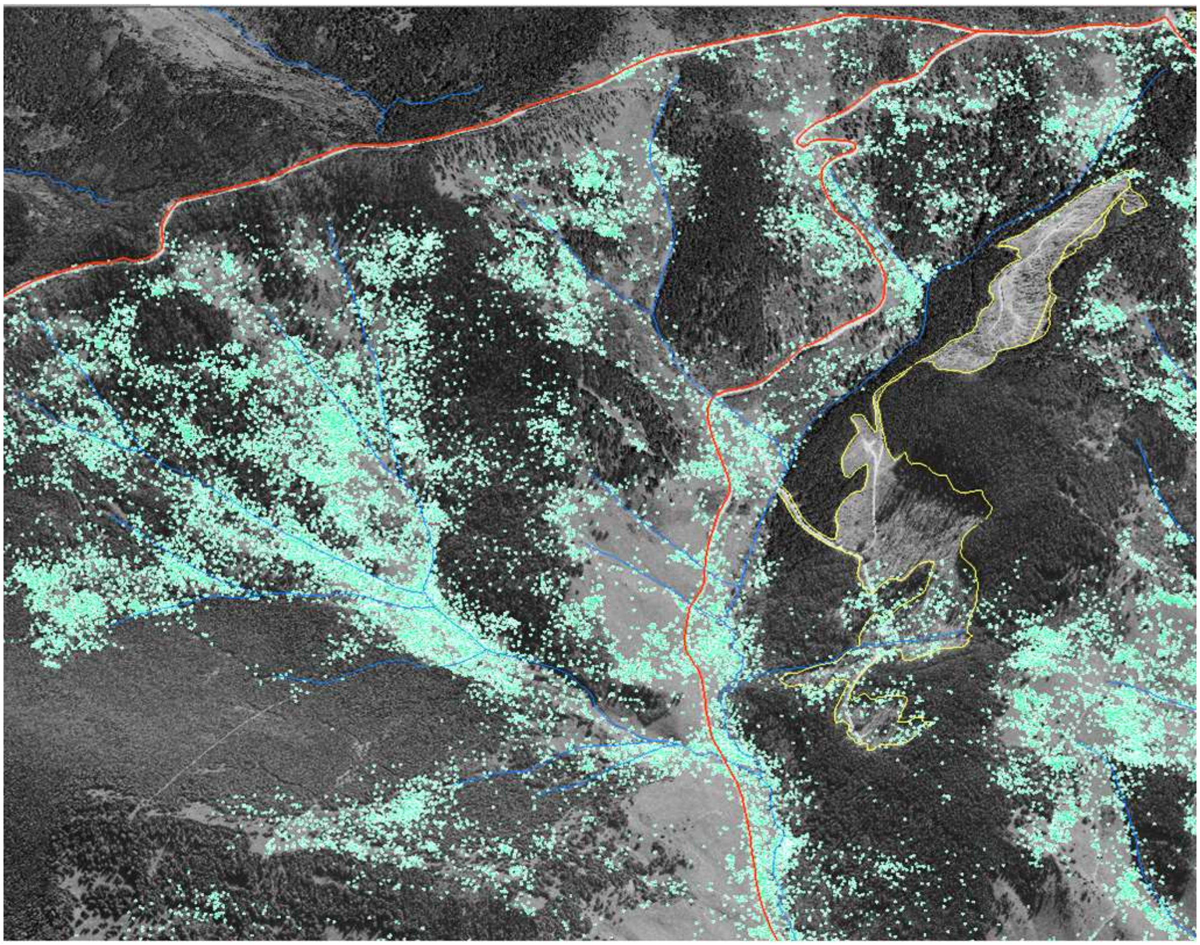

Figure D.4: GPS points resulting from cattle grazing in Prong Coulee distribution unit during July 2009.

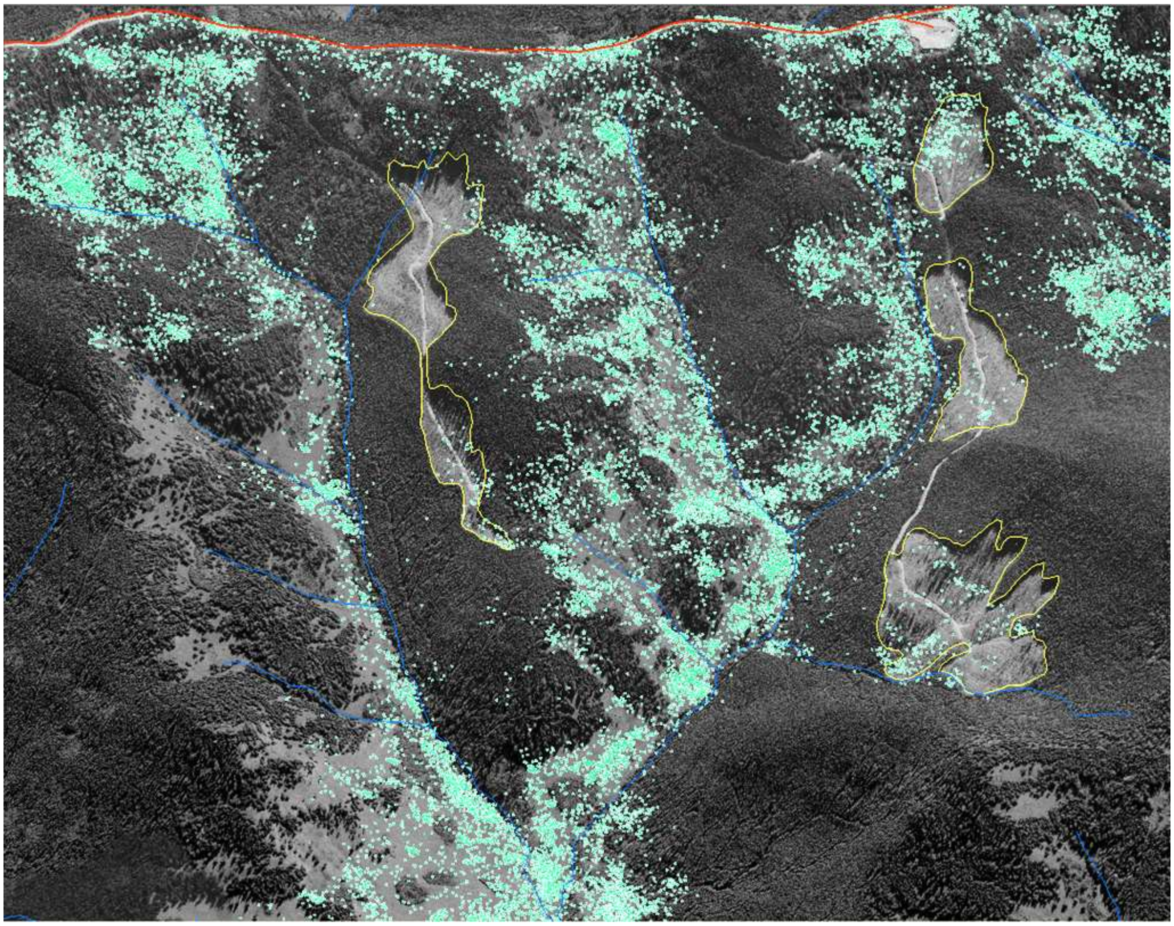

Figure D.5: GPS points resulting from cattle grazing in Damon distribution unit during August 2009.

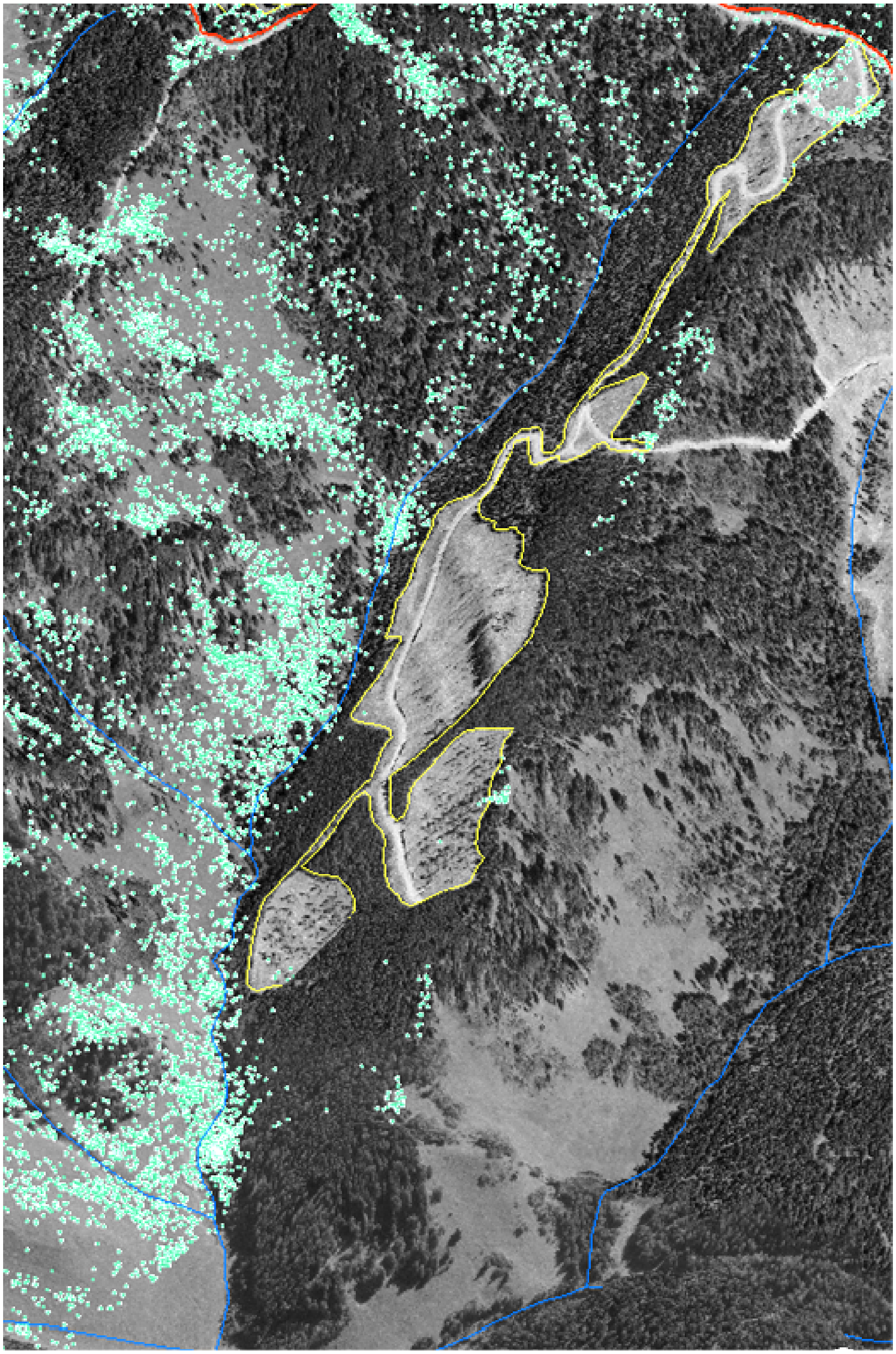

Figure D.6: GPS points resulting from cattle grazing in North Sharples distribution unit during September 2009.

APPENDIX E: SPECIES COMPOSITION DATA

Table E.1: Foliar cover (%) and frequency of occurrence (%) of all dominant grass and grass-like species among the various habitats at the deciduous site in 2008.

	Habitat							
2008	Clear Cut n=96		Uncut Forest n=46		Partial Harvest n=60		Skid Road n=28	
Grasses and Grass-Likes	Cover (%)	Frequency (%)	Cover (%)	Frequency (%)	Cover (%)	Frequency (%)	Cover (%)	Frequency (%)
Agropyron repens	5	1	10	2	-	-	-	-
Agropyron trachycaulum	-	-	30	2	10	3	-	-
Bromis ciliatus	5	2	14	9	10	2	5	4
Bromus inermis	6	9	4	4	2	7	-	-
Calamagrostis canadensis	22	74	18	43	21	60	25	64
Elymus innovatus	1	1	-	-	-	-	-	-
Phleum pratense	-	-	-	-	-	-	4	4
Poa spp.	8	4	30	11	16	7	1	4
Carex spp.	-	-	2	2	-	-	-	-

Table E.2: Foliar cover (%) and frequency of occurrence (%) of all dominant shrub species among the various habitats at the deciduous site in 2008.

	Habitat							
2008	Clear Cut n=96		Uncut Forest n=46		Partial Harvest n=60		Skid Road n=28	
Shrubs	Cover (%)	Frequency (%)	Cover (%)	Frequency (%)	Cover (%)	Frequency (%)	Cover (%)	Frequency (%)
Amelanchier alnifolia	4	60	4	63	3	67	2	39
Cornus stolonifera	2	2	-	-	-	-	-	-
Corylus cornuta	33	9	24	9	23	15	25	4
Lonicera dioica	2	13	3	17	2	5	-	-
Lonicera involucrata	8	9	-	-	10	2	4	7
Prunus pensylvanica	-	-	5	2	-	-	-	-
Ribes oxyacanthoides	4	3	-	-	5	2	1	7
Rosa acicularis	5	77	5	50	4	83	6	82
Rubus idaeus	13	30	16	48	6	28	13	36
Salix bebbiana	5	18	2	2	6	12	4	4
Salix discolor	-	-	-	-	-	-	1	4
Salix scouleriana	-	-	30	2	-	-	-	-
Shepherdia canadensis	2	2	13	9	3	10	-	-
Spiraea betulifolia	-	-	-	-	-	-	15	4
Symphoricarpos albus	3	35	9	61	2	33	2	36
Vaccinium myrtilloides	-	-	-	-	2	2	-	-
Viburnum edule	4	21	4	15	2	18	3	11

Table E.3: Foliar cover (%) and frequency of occurrence (%) of all dominant forb species among the various habitats at the deciduous site in 2008.

	Habitat							
2008	Clear Cut n=96		Uncut Forest n=46		Partial Harvest n=60		Skid Road n=28	
Forbs	Cover (%)	Frequency (%)	Cover (%)	Frequency (%)	Cover (%)	Frequency (%)	Cover (%)	Frequency (%)
Actaea rubra	4	3	-	-	1	3	-	-
Aralia nudicaulis	3	2	6	13	3	2	5	4
Aster ciliolatus	3	13	19	9	2	8	1	4
Astragalus canadensis	3	1	-	-	-	-	-	-
Cirsium arvense	-	-	-	-	-	-	25	4
Cornus canadensis	4	4	9	24	3	22	3	7
Delphinium glaucum	4	1	10	2	-	-	-	-
Epilobium angustifolium	11	10	2	2	1	2	6	14
Equisetum arvense	19	6	15	30	11	8	18	18
Fragaria virginiana	3	17	5	28	3	35	2	14
Galeopsis tetrahit	-	-	-	-	-	-	3	7
Galium boreale	3	10	-	-	2	13	4	18
Geranium richarsonii	1	3	-	-	-	-	-	-
Heracleum lanatum	1	1	9	9	10	2	2	4
Lathyrus ochroleucus	3	43	5	37	2	42	2	14
Maianthemum canadense	-	-	1	2	-	-	-	-
Mertensia paniculata	3	35	5	11	2	35	3	43
Oryzopsis asperifolia	-	-	-	-	5	2	-	-
Petasites palmatus	2	8	1	2	2	18	2	18
Rubus pubescens	2	8	3	9	-	-	3	4
Sanicula marilandica	-	-	-	-	1	2	-	-
Taraxacum officinale	-	-	16	9	10	2	-	-
Thalictrum venulosum	3	17	6	15	3	18	2	7
Trifolium hybridum	-	-	-	-	-	-	2	4
Trifolium pratense	6	4	10	2	-	-	14	7
Trifolium repens	10	1	5	7	-	-	12	14
Vicia americana	2	20	3	15	2	8	1	14
Viola canadensis	2	1	-	-	-	-	2	4

Table E.4: Foliar cover (%) and frequency of occurrence (%) of all dominant grass and grass-like species among the various habitats at the deciduous site in 2009.

	Habitat							
2009	Clear Cut n=96		Uncut Forest n=46		Partial Harvest n=60		Skid Road n=28	
Grasses and Grass-Likes	Cover (%)	Frequency (%)	Cover (%)	Frequency (%)	Cover (%)	Frequency (%)	Cover (%)	Frequency (%)
Agropyron repens	30	1	-	-	-	-	-	-
Bromis ciliatus	8	2	4	2	-	-	5	4
Bromus inermis	14	2	15	2	10	10	-	-
Calamagrostis canadensis	17	85	12	61	14	77	13	79
Elymus innovatus	8	5	-	-	-	-	-	-
Phleum pratense	-	-	8	4	-	-	10	4
Poa spp.	7	6	7	11	8	12	9	14
Schizache purpurascens	-	-	-	-	2	2	-	-

Table E.5: Foliar cover (%) and frequency of occurrence (%) of all dominant shrub species among the various habitats at the deciduous site in 2009.

	Habitat							
2009	Clear Cut n=96		Uncut Forest n=46		Partial Harvest n=60		Skid Road n=28	
Shrubs	Cover (%)	Frequency (%)	Cover (%)	Frequency (%)	Cover (%)	Frequency (%)	Cover (%)	Frequency (%)
Amelanchier alnifolia	3	61	4	57	3	58	2	43
Cornus stolonifera	3	1	-	-	-	-	-	-
Corylus cornuta	26	10	11	9	16	15	20	4
Lonicera dioica	3	5	2	7	3	5	1	4
Lonicera involucrata	7	8	2	4	6	8	4	7
Ribes oxyacanthoides	5	5	1	2	4	5	10	4
Rosa acicularis	4	84	5	65	5	85	8	86
Rubus idaeus	12	28	8	50	5	33	13	43
Salix bebbiana	4	17	-	-	6	10	10	7
Shepherdia canadensis	4	5	13	11	8	8	-	-
Spiraea betulifolia	2	1	4	2	1	2	15	4
Symphoricarpos albus	2	48	3	72	3	50	2	39
Vaccinium myrtilloides	1	1	3	4	2	3	-	-
Viburnum edule	4	15	3	4	2	10	1	7

Table E.6: Foliar cover (%) and frequency of occurrence (%) of all dominant forb species among the various habitats at the deciduous site in 2009.

	Habitat							
	Clear Cut n=96		Uncut Forest n=46		Partial Harvest n=60		Skid Road n=28	
2009								
Forbs	Cover (%)	Frequency (%)	Cover (%)	Frequency (%)	Cover (%)	Frequency (%)	Cover (%)	Frequency (%)
Agrimonia striata	5	1	-	-	-	-	-	-
Aralia nudicaulis	2	10	7	15	4	10	6	7
Aster ciliolatus	5	13	5	13	3	18	2	7
Aster conspicuus	2	7	3	2	-	-	-	-
Cirsium arvense	-	-	-	-	-	-	5	4
Cornus canadensis	4	6	10	33	7	23	-	-
Delphinium glaucum	5	1	3	9	-	-	-	-
Epilobium angustifolium	5	10	-	-	2	2	5	4
Equisetum arvense	4	5	7	15	3	7	4	7
Fragaria virginiana	4	28	5	28	4	30	3	4
Galium boreale	2	10	3	4	3	8	2	21
Geranium richarsonii	2	6	-	-	3	2	2	4
Heracleum lanatum	-	-	3	2	-	-	-	-
Lathyrus ochroleucus	2	2	1	7	-	-	2	4
Lathyrus venosus	-	-	3	2	-	-	-	-
Mertensia paniculata	4	41	6	7	5	32	5	57
Oryzopsis asperifolia	7	3	3	11	3	7	-	-
Petasites palmatus	2	7	3	4	4	15	2	7
Rubus pubescens	4	21	9	13	4	15	4	32
Sanicula marilandica	2	1	-	-	-	-	-	-
Solidago canadensis	2	1	-	-	-	-	-	-
Taraxacum officinale	-	-	6	7	-	-	-	-
Thalictrum venulosum	3	9	2	4	3	12	2	11
Trifolium hybridum	5	1	9	9	-	-	18	7
Trifolium pratense	7	3	5	20	11	7	6	14
Trifolium repens	5	2	7	7	10	2	-	-
Viola canadensis	2	5	4	9	3	10	1	4

Table E.7: Foliar cover (%) and frequency of occurrence (%) of all dominant grass and grass-like species among the various habitats at the coniferous site in 2008.

	Habitat											
2008	Lowland Grass n=36		Upland Grass n=35		Aspen n=29		Mixed Wood n=33		Conifer n=42		Cut Block n=154	
Grasses and Grass-Likes	Cover (%)	Frequency (%)	Cover (%)	Frequency (%)	Cover (%)	Frequency (%)	Cover (%)	Frequency (%)	Cover (%)	Frequency (%)	Cover (%)	Frequency (%)
Agropyron dasystachyum	15	3	-	-	-	-	-	-	-	-	-	-
Agropyron trachycaulum	-	-	-	-	15	3	8	15	1	2	-	-
Agrostis scabra	-	-	-	-	-	-	-	-	-	-	5	2
Bromus inermis	31	56	13	6	19	10	20	3	10	2	-	-
Bromus pumpellianus	-	-	-	-	15	3	-	-	-	-	-	-
Calamagrostis canadensis	-	-	-	-	23	7	-	-	-	-	16	45
Calamagrostis rubescens	-	-	-	-	25	7	25	3	8	29	20	25
Carex spp.	15	3	-	-	35	3	-	-	15	2	6	3
Elymus innovatus	-	-	-	-	25	3	28	21	9	29	13	24
Festuca campestris	25	14	47	66	16	7	11	6	5	2	-	-
Festuca idahoensis	25	3	3	3	-	-	-	-	-	-	-	-
Hordeum jubatum	-	-	-	-	-	-	-	-	-	-	10	1
Phleum pratense	31	44	33	34	24	41	19	27	30	5	5	1
Poa spp.	28	36	24	17	26	28	28	30	10	10	5	11
Stipa curtiseta	-	-	18	6	-	-	-	-	-	-	-	-
Stipa viridula	45	3	-	-	10	3	12	9	6	7	-	-

Table E.8: Foliar cover (%) and frequency of occurrence (%) of all dominant forb species among the various habitats at the coniferous site in 2008.

	Habitat											
2008	Lowland Grass n=36		Upland Grass n=35		Aspen n=29		Mixed Wood n=33		Conifer n=42		Cut Block n=154	
Forbs	Cover (%)	Frequency (%)	Cover (%)	Frequency (%)	Cover (%)	Frequency (%)	Cover (%)	Frequency (%)	Cover (%)	Frequency (%)	Cover (%)	Frequency (%)
Achillea millefolium	4	8	4	6	5	3	-	-	3	2	-	-
Actaea rubra	-	-	-	-	-	-	-	-	-	-	10	1
Agoseris glauca	-	-	-	-	-	-	-	-	-	-	5	1
Anaphalis margaritacea	-	-	-	-	-	-	-	-	-	-	1	1
Androsace chamaejasme	-	-	-	-	-	-	-	-	1	2	-	-
Anemone multifida	4	6	-	-	-	-	-	-	-	-	-	-
Antennaria parvifolia	-	-	20	3	-	-	-	-	-	-	-	-
Arnica cordifolia	-	-	-	-	-	-	-	-	3	10	8	12
Artemisia absinthium	3	3	-	-	-	-	-	-	-	-	-	-
Artemisia frigida	-	-	-	-	-	-	-	-	2	5	-	-
Artemisia ludoviciana	10	6	-	-	8	7	-	-	-	-	-	-
Aster ciliolatus	5	3	-	-	5	21	8	58	6	24	4	3
Aster conspicuus	-	-	-	-	-	-	10	3	2	7	11	42
Aster ericoides	-	-	3	6	-	-	-	-	-	-	-	-
Aster laevis	-	-	6	11	-	-	-	-	-	-	-	-
Balsamorhiza sagittata	-	-	15	3	-	-	10	6	3	2	-	-
Chenopodium album	-	-	-	-	-	-	-	-	-	-	2	1
Cirsium arvense	7	19	4	3	-	-	-	-	-	-	8	10
Cornus canadensis	-	-	-	-	-	-	-	-	12	26	10	26
Cynoglossum officinale	-	-	-	-	4	7	-	-	3	2	-	-
Epilobium angustifolium	4	8	5	3	7	28	-	-	-	-	7	29
Epilobium ciliatum	-	-	-	-	-	-	-	-	-	-	2	7
Erigeron glabellus	-	-	-	-	10	3	2	3	8	7	-	-
Fragaria virginiana	6	8	8	9	11	17	5	21	3	19	-	-
Galium boreale	4	3	4	17	10	3	8	6	4	17	2	1
Galium triflorum	-	-	-	-	-	-	-	-	1	2	-	-

	Habitat											
2008	Lowland Grass n=36		Upland Grass n=35		Aspen n=29		Mixed Wood n=33		Conifer n=42		Cut Block n=154	
Forbs	Cover (%)	Frequency (%)	Cover (%)	Frequency (%)	Cover (%)	Frequency (%)	Cover (%)	Frequency (%)	Cover (%)	Frequency (%)	Cover (%)	Frequency (%)
Geranium viscosissimum	5	22	8	23	5	14	4	18	5	2	-	-
Geum triflorum	5	11	13	14	-	-	-	-	-	-	-	-
Heracleum lanatum	-	-	-	-	-	-	-	-	3	2	-	-
Lathyrus ochroleucus	-	-	-	-	2	17	3	18	3	5	5	22
Linnea borealis	-	-	-	-	-	-	15	3	15	21	10	8
Lithospermum ruderale	5	3	8	6	8	7	7	6	2	2	-	-
Lupinus sericeus	3	11	7	9	-	-	3	3	10	2	-	-
Medicago lupulina	3	3	-	-	-	-	-	-	-	-	-	-
Monarda fistulosa	5	6	12	37	7	31	3	12	10	2	-	-
Orthilia secunda	-	-	-	-	-	-	-	-	3	5	-	-
Orthocarpus luteus	-	-	2	3	-	-	-	-	-	-	-	-
Osmorhiza berteroi	-	-	-	-	-	-	4	3	2	2	5	1
Oxytropis sericea	3	3	-	-	-	-	-	-	-	-	-	-
Plantago major	-	-	-	-	-	-	-	-	-	-	5	1
Potentilla arguta	-	-	4	3	-	-	-	-	-	-	-	-
Potentilla diversifolia	3	3	-	-	-	-	-	-	-	-	-	-
Potentilla gracilis	8	6	10	6	-	-	-	-	-	-	-	-
Pyrola asarifolia	-	-	-	-	10	3	2	3	2	2	-	-
Silene menziesii	-	-	-	-	-	-	5	3	-	-	-	-
Smilacina stellata	-	-	2	3	-	-	2	3	2	2	-	-
Solidago canadensis	-	-	-	-	14	7	-	-	-	-	-	-
Solidago missouriensis	5	8	5	3	-	-	-	-	3	2	-	-
Streptopus amplexifolius	-	-	-	-	-	-	-	-	-	-	4	2
Taraxacum officinale	-	-	10	3	2	3	-	-	3	2	1	4
Thalictrum venulosum	-	-	-	-	-	-	5	3	4	19	8	3
Tragopogon dubius	-	-	-	-	-	-	-	-	-	-	1	1
Utrica dioica	-	-	-	-	-	-	-	-	10	2	-	-
Vicia americana	-	-	-	-	-	-	4	6	2	5	3	3

Table E.9: Foliar cover (%) and frequency of occurrence (%) of all dominant shrub species among the various habitats at the coniferous site in 2008.

	Habitat											
2008	Lowland Grass n=36		Upland Grass n=35		Aspen n=29		Mixed Wood n=33		Conifer n=42		Cut Block n=154	
Shrubs	Cover (%)	Frequency (%)	Cover (%)	Frequency (%)	Cover (%)	Frequency (%)	Cover (%)	Frequency (%)	Cover (%)	Frequency (%)	Cover (%)	Frequency (%)
Alnus crispa	-	-	-	-	-	-	-	-	-	-	35	1
Amelanchier alnifolia	3	6	7	9	11	24	4	36	2	10	5	1
Arctostaphylos uva-ursi	-	-	-	-	-	-	25	6	8	7	4	4
Clematis occidentalis	-	-	-	-	-	-	-	-	2	2	3	1
Juniperus communis	5	3	6	17	-	-	23	12	7	7	-	-
Lonicera involucrata	-	-	-	-	-	-	-	-	2	2	-	-
Potentilla fruticosa	5	11	-	-	-	-	1	6	-	-	-	-
Prunus virginiana	-	-	-	-	8	10	-	-	7	7	-	-
Ribes oxyacanthoides	-	-	-	-	2	3	13	6	2	14	3	10
Rosa arkansana	-	-	4	57	-	-	-	-	-	-	-	-
Rosa woodsii	3	64	-	-	7	83	4	91	3	57	3	45
Rubus idaeus	-	-	-	-	11	28	5	3	14	10	10	50
Rubus parviflorum	-	-	-	-	-	-	-	-	20	2	7	18
Salix spp.	-	-	-	-	-	-	-	-	-	-	5	1
Shepherdia canadensis	-	-	-	-	-	-	20	3	-	-	2	1
Spiraea betulifolia	-	-	-	-	-	-	-	-	10	2	7	44
Symphoricarpos occidentalis	6	8	10	11	6	34	7	33	13	21	-	-
Vaccinium caespitosum	-	-	-	-	-	-	-	-	7	5	-	-
Vaccinium myrtilloides	-	-	-	-	-	-	-	-	10	2	-	-

Table E.10: Foliar cover (%) and frequency of occurrence (%) of all dominant grass and grass-like species among the various habitats at the coniferous site in 2009.

2009	**Habitat**											
	Lowland Grass n=40		Upland Grass n=39		Aspen n=34		Mixed Wood n=47		Conifer n=47		Cut Block n=154	
Grasses and Grass-Likes	Cover (%)	Frequency (%)	Cover (%)	Frequency (%)	Cover (%)	Frequency (%)	Cover (%)	Frequency (%)	Cover (%)	Frequency (%)	Cover (%)	Frequency (%)
Agropyron intermedia	-	-	-	-	-	-	-	-	-	-	10	1
Agropyron trachycaulum	-	-	3	3	-	-	-	-	-	-	-	-
Agrostis scabra	-	-	-	-	-	-	-	-	-	-	5	3
Bromus inermis	22	43	23	8	17	9	7	6	20	2	-	-
Bromus pumpellianus	-	-	-	-	10	3	-	-	-	-	-	-
Calamagrostis canadensis	-	-	-	-	-	-	-	-	-	-	14	12
Calamagrostis rubescens	-	-	-	-	-	-	18	17	7	21	18	51
Carex spp.	-	-	10	3	-	-	-	-	2	4	6	5
Danthonia parryi	3	5	4	13	-	-	-	-	-	-	-	-
Deschampsia cespitosa	-	-	-	-	-	-	-	-	-	-	9	1
Elymus glauca	-	-	-	-	18	6	8	4	2	2	4	2
Elymus innovatus	-	-	-	-	40	3	25	34	8	32	16	44
Festuca campestris	32	20	42	79	13	18	9	13	8	9	-	-
Festuca idahoensis	15	3	8	5	-	-	-	-	-	-	-	-
Hordeum jubatum	-	-	-	-	-	-	-	-	-	-	2	1
Phleum pratense	21	38	25	33	20	32	18	13	8	9	5	4
Poa spp.	22	45	27	8	24	41	12	26	8	6	5	7
Stipa curtiseta	5	3	-	-	-	-	-	-	-	-	-	-
Stipa richardsonii	4	5	7	13	-	-	-	-	-	-	-	-
Stipa viridula	-	-	-	-	-	-	5	2	15	2	-	-

Table E.11: Foliar cover (%) and frequency of occurrence (%) of all dominant forb species among the various habitats at the coniferous site in 2009.

	Habitat											
2009	Lowland Grass n=40		Upland Grass n=39		Aspen n=34		Mixed Wood n=47		Conifer n=47		Cut Block n=154	
Forbs	Cover (%)	Frequency (%)	Cover (%)	Frequency (%)	Cover (%)	Frequency (%)	Cover (%)	Frequency (%)	Cover (%)	Frequency (%)	Cover (%)	Frequency (%)
Achillea millefolium	3	15	4	3	1	6	3	9	-	-	3	1
Agoseris glauca	-	-	-	-	-	-	10	2	-	-	-	-
Anaphalis margaritacea	-	-	-	-	-	-	-	-	-	-	1	1
Anemone multifida	3	8	-	-	-	-	-	-	-	-	-	-
Antennaria parvifolia	-	-	2	3	-	-	-	-	-	-	-	-
Arnica cordifolia	-	-	-	-	-	-	-	-	3	4	8	3
Artemisia frigida	-	-	-	-	-	-	-	-	2	6	-	-
Artemisia ludoviciana	10	3	-	-	10	3	-	-	-	-	-	-
Aster ciliolatus	-	-	-	-	-	-	3	6	-	-	-	-
Aster conspicuus	5	3	2	3	3	15	7	36	3	32	7	40
Aster laevis	-	-	-	-	-	-	10	4	-	-	-	-
Balsamorhiza sagittata	-	-	5	3	4	3	-	-	-	-	-	-
Cirsium arvense	2	5	-	-	8	6	-	-	-	-	8	16
Cornus canadensis	-	-	-	-	-	-	-	-	8	21	7	14
Cynoglossum officinale	-	-	-	-	-	-	11	4	3	6	-	-
Disporum trachycarpum	-	-	-	-	-	-	-	-	1	2	-	-
Epilobium angustifolium	4	13	4	3	6	35	5	6	-	-	6	34
Epilobium ciliatum	-	-	-	-	-	-	-	-	-	-	3	10
Erigeron glabellus	-	-	-	-	-	-	-	-	5	9	-	-
Erysimum cheiranthoides	-	-	-	-	-	-	-	-	-	-	6	1
Fragaria virginiana	5	13	4	23	6	32	4	36	3	13	4	2
Galium boreale	-	-	2	3	-	-	3	9	1	13	1	1
Geranium viscosissimum	3	18	4	10	3	21	3	6	3	4	-	-
Geum aleppicum	-	-	-	-	-	-	-	-	-	-	3	1

	Habitat											
2009	Lowland Grass n=40		Upland Grass n=39		Aspen n=34		Mixed Wood n=47		Conifer n=47		Cut Block n=154	
Forbs	Cover (%)	Frequency (%)	Cover (%)	Frequency (%)	Cover (%)	Frequency (%)	Cover (%)	Frequency (%)	Cover (%)	Frequency (%)	Cover (%)	Frequency (%)
Geum triflorum	7	18	4	18	15	3	2	2	-	-	-	-
Heracleum lanatum	-	-	-	-	1	3	-	-	-	-	-	-
Lathyrus ochroleucus	-	-	-	-	4	12	3	17	2	2	5	20
Linnea borealis	-	-	-	-	-	-	-	-	10	21	9	7
Lithospermum ruderale	4	13	4	21	-	-	2	4	4	4	-	-
Lupinus sericeus	-	-	-	-	-	-	3	6	-	-	5	3
Mertensia paniculata	-	-	-	-	-	-	1	2	-	-	-	-
Monarda fistulosa	3	5	3	33	4	18	7	6	-	-	-	-
Orthilia secunda	-	-	-	-	-	-	-	-	3	2	-	-
Osmorhiza berteroi	-	-	-	-	-	-	10	4	2	6	4	2
Pipera unalascensis	-	-	-	-	-	-	-	-	1	2	3	1
Polygonum aviculare	-	-	-	-	-	-	-	-	-	-	5	1
Potentilla arguta	3	3	-	-	-	-	-	-	-	-	-	-
Potentilla diversifolia	4	13	-	-	-	-	-	-	-	-	-	-
Potentilla gracilis	3	5	3	8	-	-	-	-	-	-	-	-
Potentilla norvegica	-	-	-	-	-	-	-	-	-	-	4	1
Pyrola asarifolia	-	-	-	-	-	-	-	-	4	4	3	1
Smilacina stellata	-	-	4	3	-	-	2	4	2	2	-	-
Solidago canadensis	-	-	-	-	5	9	-	-	-	-	-	-
Solidago missouriensis	-	-	2	3	-	-	2	2	3	2	-	-
Streptopus amplexifolius	-	-	-	-	-	-	-	-	1	2	-	-
Taraxacum officinale	2	3	3	3	2	3	7	6	-	-	2	2
Thalictrum venulosum	-	-	-	-	2	9	5	11	2	15	5	4
Tragopogon dubius	-	-	-	-	-	-	-	-	-	-	2	1
Trifolium repens	-	-	-	-	-	-	-	-	4	8	5	1
Vicia americana	-	-	-	-	-	-	-	-	-	-	5	1
Viola canadensis	-	-	-	-	-	-	-	-	1	2	-	-

Table E.12: Foliar cover (%) and frequency of occurrence (%) of all dominant shrub species among the various habitats at the coniferous site in 2009.

	Habitat											
2009	Lowland Grass n=40		Upland Grass n=39		Aspen n=34		Mixed Wood n=47		Conifer n=47		Cut Block n=154	
Shrubs	Cover (%)	Frequency (%)	Cover (%)	Frequency (%)	Cover (%)	Frequency (%)	Cover (%)	Frequency (%)	Cover (%)	Frequency (%)	Cover (%)	Frequency (%)
Alnus crispa	-	-	-	-	-	-	-	-	-	-	12	2
Amelanchier alnifolia	2	5	3	10	7	44	3	28	2	15	3	1
Arctostaphylos uva-ursi	-	-	-	-	-	-	3	11	9	6	4	1
Juniperus communis	5	3	-	-	-	-	39	11	5	4	3	1
Lonicera involucrata	-	-	-	-	-	-	-	-	5	2	-	-
Potentilla fruticosa	4	5	3	18	1	3	4	13	-	-	-	-
Prunus virginiana	-	-	-	-	6	6	-	-	1	2	-	-
Ribes lacustre	-	-	-	-	-	-	-	-	-	-	1	1
Ribes oxyacanthoides	-	-	-	-	4	3	8	9	5	9	3	11
Rosa acicularis	-	-	-	-	10	3	-	-	-	-	3	1
Rosa arkansana	-	-	3	67	-	-	-	-	-	-	-	-
Rosa woodsii	4	60	-	-	7	91	5	77	3	43	3	55
Rubus idaeus	3	3	-	-	7	18	3	6	7	6	9	62
Rubus parviflorum	-	-	-	-	-	-	-	-	-	-	4	12
Salix spp.	-	-	-	-	-	-	-	-	-	-	2	3
Shepherdia canadensis	-	-	-	-	-	-	20	2	-	-	1	1
Spiraea betulifolia	-	-	-	-	-	-	7	11	5	3	4	44
Symphoricarpos occidentalis	5	8	10	8	4	47	5	30	8	21	2	1
Vaccinium scoparium	-	-	-	-	-	-	-	-	3	6	-	-