

CHANGES IN WINTER HABITAT USE BY MAMMALS FOLLOWING
COMMERCIAL THINNING OF LODGEPOLE PINE (*Pinus contorta*)
IN WEST CENTRAL ALBERTA

By

Kyle Emslie
0153935

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Lakehead University

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ABSTRACT

In 1996, Millar Western Forest Products initiated an adaptive management experiment to assess the potential benefits of commercial thinning and to monitor its effects on winter habitat use by multiple mammalian species, using indirect evidence (snow tracking). This program was known as the Commercial Thinning Winter Tracking Project (CTWTP). Track surveys are well suited to investigate habitat use, because transects can be restricted to specific habitat types and individual tracks can often indicate behaviour based on gait, movement pattern and other signs associated with the tracks. Differences in the frequency of track occurrence among habitat types can also indicate habitat preference. The CTWTP surveyed mammal track occurrence over 7 years on 30 transects within the 1695 ha Tom Hill study site southwest of Whitecourt, Alberta. Transects were located in one of four forest types: aspen dominated, black spruce dominated, reference lodgepole pine, and treatment (thinned) lodgepole pine. ANOVA and Tukey post-hoc tests were used to identify differences in mammal track occurrence among the three unthinned forest types and between the reference and treatment pine forest types. Moose and weasels were most common in black spruce. Snowshoe hare were most common in reference lodgepole pine. White-tailed deer and marten were more common in aspen. Fisher, rodents, lynx and coyote appear to have no preference for any of the three unthinned forest types. Comparisons between reference and thinned pine forest types identified three groups of species. Fisher and snowshoe hare appear to have decreased after thinning. Weasels, white-tailed deer and marten track occurrence increased after thinning. Species that do not appear to have been affected by the thinning were moose, rodents, squirrels, lynx and coyote. Principal Components Analysis (PCA) was used to identify correlations between track occurrence and habitat variables (i.e. snow depth, temperature). PCA identified positive and negative associations with a variety of habitat characteristics that may underlie the observed differences in track occurrence. Additional investigation focused on the ecology of more specific clades of wildlife and collection of track data at a variety of spatial scales may be a way of taking this broader summary of the CTWTP to a finer investigation of habitat use in the Tom Hill study site.

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INTRODUCTION

The Senate Subcommittee on the Boreal Forest (1999) recommended that provincial governments, industry, municipalities and other interests operating in the boreal forest of Canada create strategies to guarantee the health of the forest, while allowing traditional forest use and creating economic benefit. The Subcommittee further indicated the need for intensive forest management (IFM) if Canada's forest industry is to remain economically competitive. As IFM is practiced on the landscape, its effects on biodiversity must be monitored. Databases arising from monitoring programs in an adaptive management framework may be used in decision-making processes involving biodiversity protection.

Forest products companies can play a role in meeting the recommendations of the Senate Subcommittee. Millar Western Forest Products Ltd (MWFP) is one of western Canada's largest privately owned forest products companies and operates principally from a Forest Management Agreement (FMA) with the Government of Alberta in operations near Whitecourt, Alberta. The company produces dimensional lumber, value-added forest products and pulp fiber. Striving to achieve the clearest possible environmental policy, MWFP has initiated a variety of ecological research programs to improve understanding of the natural environment within its FMA area and elsewhere. In turn, this information can be used to develop operations geared toward sustainable use of forest resources.

MWFP is investigating IFM actions that could increase forest yield. In pine-dominated stands, thinning has been identified as a practice that might achieve this goal (Sullivan and Sullivan 1988, Martin and Lorimer 1997, Patriquin and Spencer 2004). In 1996, MWFP initiated an adaptive management experiment to assess the potential

benefits of commercial thinning and to monitor its effects on winter habitat use by multiple mammalian species, using indirect evidence (snow tracking). This program was known as the Commercial Thinning Winter Tracking Project (CTWTP). Winter track occurrence data provided a measure of relative abundance of mammals using a portion of the FMA area, the Tom Hill study site, from December through March, 1998–2006.

This Masters thesis includes the analysis and interpretation of CTWTP data for the 10 most abundant mammal species observed during the track surveys. The thesis begins with a literature review focused on the use of track surveys in wildlife assessment, as well as a discussion of the sampling protocols and statistical methods used in the CTWTP and the general habitat use patterns of each species monitored in the Tom Hill study site. Study objectives and expected outcomes follow an interim analysis of the CTWTP data (Patriquin and Spencer 2004).

LITERATURE REVIEW

Natural systems around the world are being altered as a result of anthropogenic disturbances, as well as a rapidly changing global environment and climate. As a consequence of these alterations, the scientific community, governments, policy makers, industry and local citizens are interested in identifying the nature and extent of change to natural systems through research initiatives. The ultimate goal of such research is to develop mechanisms to prevent or mitigate unwanted changes to ecosystems.

Wildlife populations are a specific target of monitoring programs for a variety of reasons, including but not limited to their aesthetic and spiritual value, their value as a natural resource and, most importantly, as functional components of an intact ecosystem. However, wildlife populations can be difficult to survey directly, because they are dynamic and individuals are free ranging and often rare across landscapes. Characteristics

of their habitat use can also be difficult to determine because several interacting variables in the physical and behavioural environment constitute habitat (Clark et al. 1993, Madhusudan and Johnsingh 1998).

One method that has shown promise for monitoring wildlife populations is the use of indirect signs, such as den sites, scat, evidence of foraging or predation and tracks (Stephens et al. 2006). The purpose of this review is to examine the use of track surveys in wildlife analysis. Track surveys have been employed to address a variety of research questions on wildlife, including their presence or absence in an area, relative abundance, habitat use, population change over time and population size. Since a variety of questions can be addressed by track surveys, there is a comparable variety of sample methodologies, statistical analyses and results associated with them.

Track surveys have not been limited to winter seasons. Road track surveys, where sand and gravel is the medium, may be more reliable because tracks are less likely to be obscured by changes to the tracking surface from freeze-thaw cycles and blowing snow (Van Dyle et al. 1986). Chalk-dusted track boards have also been used in surveys. In one study, boards were scent marked to attract otters, but this method provided a poor sample because individuals became habituated to the scent and were reluctant to step on track boards (Reid et al. 1987). Snow appears to be the most appropriate ground cover to apply track surveys because it a continuous medium that records activity across long distances and records evidence of all species moving above the subnivean layer. On the other hand, snow tracking is limited to high latitude and alpine habitats.

The presence or absence of a species within a study area is one of the most elementary questions of wildlife inventory. Tracks can easily provide this information because a species can be associated with unique track imprints, patterns and gaits

(Rezendes 1999). It is essential to first determine if a species of interest can be found in an area before embarking on a more intensive research program. Presence or absence surveys can also be useful in determining species range.

Often, confirmation of the presence of a species in an area is the only information that can come from tracking. For example, during the late 1980s and early 1990s, an American marten (*Martes americana*) reintroduction program was initiated in Vermont, USA and a variety of attempts were made to assess the success of the reintroduction, including snow track surveys (Moruzzi et al. 2003). Due to a low sampling effort following release, the study was unable to accurately document the occurrence of resident marten. A similar approach employing road track surveys was used to detect cougar (*Puma concolor*) presence in three study areas in the western USA, where cougar density was known from radio-collaring (Van Dyke et al. 1986). The authors uncovered only a weak relationship between track finding rates and other measures of cougar density. Such weak relationships suggest that it is unlikely for track surveys to provide reliable estimates of absolute density. However, track counts may provide measure of relative density between areas or habitats.

To obtain reliable estimates of abundance from tracking data, surveys must not interfere with the behaviour of individuals, must consist of independent observations, ideally identifying individuals, and must be conducted at a relatively high intensity. A common thread is that careful sample design and appropriate and widely applicable statistical analyses are required to produce results with adequate precision to be applied to the management process. For example, Reid et al. (1987) used track data to estimate population size in river otter (*Lontra canadensis*). The mean number of animals identified from their track survey was extrapolated across all transects in the study area. A key

assumption was that tracks in the survey were independent observations. To reduce the likelihood of repeated observations, only signs that appeared less than 24 hours old were tallied and individual tracks were carefully measured. Three hundred and sixty-four 500-m transects were sampled to estimate the population density within 20% of the actual population (95% confidence interval). This survey effort illustrates how an acceptable population estimate requires high sampling intensity.

The application of statistical analyses based on probability estimators to track survey data is problematic. The complex nature of the probability estimators means that two criteria must be met to produce reliable population estimates. First, it must be possible to follow animal tracks back to an individual's location at the end of a snowfall event from its location at the time of the survey (backtracking). Second, the total linear distance traveled by an individual perpendicular to the transect must be measured accurately. These conditions can be difficult to meet without the use of aircraft and intensive sampling effort over large survey areas. For example, to produce a population estimate of wolverine (*Gulo gulo*) in Alaska, a 1,871 km² study area was required (Becker 1991). This approach is not realistic for many studies, which are often supported by limited financial resources, occur in terrain unsuitable for aerial surveys, or are undertaken without expertise to test assumptions and to apply the appropriate statistical analyses.

A more straightforward approach to developing population estimates emerged from the long-standing use of snow track monitoring in the Russian federation (Stephens et al. 2006). The resulting Formozov-Malyshv-Pereleshin formula, which can be used to assess population size and estimate absolute density, works with non-stratified track transect data and can employ estimates of average travel distance for a given species

rather than requiring accurate measurement of daily movement. Comparison of simulated and real data demonstrated that the Formozov-Malyshev-Pereleshin formula is theoretically sound. When sampling effort is above a certain threshold, reliable estimates are possible.

Measures of relative abundance are useful tools for managers to monitor change in populations over time and do not require absolute population estimates. The Michigan Department of Natural Resources used a snow track survey as a means of monitoring furbearer populations (Earle and Tuovila 2003). This survey occurred only once during the winter and the resulting small sample size likely limited the power of analyses to detect change. Track surveys have been employed to monitor abundance of Amur tiger (*Panthera tigris altaica*) in the Russian Far East for >50 years. A critical assumption of this type of survey is that changes in track occurrence actually reflect changes in the tiger population (Hayward et al. 2002). A monitoring program of 10–20 transects, each 12–15 km long and sampled twice annually, had an 80% chance of detecting a 10% change in the tiger population between years.

Track surveys are well suited to investigate habitat use, because transects can be restricted to specific habitat types and individual tracks can often indicate behaviour based on gait, movement pattern and other signs associated with the tracks. Differences in the frequency of track occurrence among habitat types can also indicate habitat preference. For example, Thompson et al. (1989) investigated whether track transects could describe stand age preferences of boreal mammals in Northwestern Ontario, and if track counts could serve as an index of change in abundance among years. The track survey results were compared against live trapping data as a means to test their accuracy. Track data indicated most species had a preferred stand age class and logging activities

had a positive effect on some species, such as weasels (*Mustela erminea*, *M. frenata*, and *M. nivalis*), whereas the abundance of other species, like American marten, which prefer uncut forest, was depressed for a number of years after harvest. During the 1990s, a study in Newfoundland attempted to describe mammal habitat use in response to clearcutting. Differences in track occurrence were found between cut and uncut sites, but only for marten, snowshoe hare (*Lepus americanus*) and American red squirrel (*Tamiasciurus hudsonicus*) (Forsey and Baggs 2001). For these species, habitat use was concentrated in interior forest, with few or no tracks in clearcut areas, consistent with the understanding that these mid-sized mammals require mature forest stands to provide resting and nesting sites, a reliable food supply and refuge from predators. A study in the western USA examined the use of forest stands by American marten (Koehler et al. 1990). Sixty-five 100-m transects were established in stands categorized into six unique seral stages. Results indicated a preference for later seral stage stands for marten.

As with any research project, careful consideration must be given to statistical design to produce a tracking data set appropriate to the question. Although each study included in this review has a unique question and study site, there are some general design guidelines that have emerged from reviewing the literature. Transect length is an important consideration. It is common in track surveys to have short transects and high occurrences of zero counts. The proportion of zero counts can be reduced by increasing transect length (Hayward et al. 2002, Moruzzi et al. 2003). This recommendation may be important when the species of concern is wide-ranging or occurs at low density on the landscape, because short transects are less likely to intersect the path of such species. However, long transects may be impractical, particularly in rugged terrain or when differences between habitat types is the primary focus. When long transects cannot be

used, increasing the number of short transects restricted to specific habitat types is preferable (D'Eon 2001). Track data are also prone to a high degree of variability, which could be reduced by increasing the replication of counts over a short time frame (Thompson et al. 1989).

Another issue that must be addressed by the design of winter track surveys is the time between a snowfall and track observation. Researchers must allow a period of time following a snowfall for animals to move about the study area. Most researchers allow a minimum of 24 hours before beginning a survey, whereas others wait as long as 96 hours (Bayne et al. 2005). When tracking occurs during a multi-day time frame, transects sampled later in the period have had substantially more time for animals to move about, leading to higher rates of track occurrence (Reid et al. 1987). Standardizing track data to a measure of tracks per unit of linear distance sampled per unit of time is a means of addressing this form of sampling bias (Thompson et al. 1989, Hayward et al. 2002). However, as the time since snowfall increases, tracks degrade, primarily due to sun exposure (i.e. melting) and wind (i.e. blowing snow obscures tracks). The degradation of tracks has the potential to make fresh tracks appear old or unidentifiable to the species level (Beauvais and Buskirk 1999). Degradation may also result in tracks being omitted from a sample. An additional limitation to carrying out snow track surveys is that new snowfall can obscure tracks before they can be sampled.

Track surveys can be costly: they require large study areas and transects are often located in areas with minimal road access, in potentially harsh winter conditions. Therefore, the use of costly equipment like snowmobiles or all terrain vehicles may be required. Also, track surveys can be labour intensive, because each transect must be tracked by field staff within specific time frames. Long transects or surveys with

numerous transects require a large number of field staff to complete (Bayne et al. 2005). Furthermore, good tracking days are infrequent: field staff must be available to begin tracking when conditions are right. Down time can be costly in terms of wages to pay staff between suitable tracking periods.

Perhaps the most important consideration is that the quality of the data recorded from track surveys is directly related to the ability of staff to correctly identify and interpret observed tracks (Bayne et al. 2005). Field crews must be competent. Training and subsequent tracking is often inadvertently biased toward quantifying movement distances, while omitting estimates of the time spent in a specific habitat or identification of the behaviours of individuals within a habitat type (D'Eon 2001). Track counts can also be prone to sampling errors, such as counting the tracks of one individual as multiple individuals when its path intersects a transect multiple times (Reid et al. 1987, D'Eon 2001, Hayward et al. 2002). Track data can produce quality data with acceptable accuracy when applied to appropriate questions, and when care is taken in sample design and analysis.

A variety of analytical methods have been applied to track data. The most important consideration for more detailed research questions than determining a species' presence in an area is correcting for high frequency of zero counts in track data that result in a non-normal data distribution (Thompson et al. 1989, Earle and Tuovila 2003). To adjust for a skewed distribution, non-parametric tests can be used (e.g., Reid et al. 1987, Thompson et al. 1989, D'Eon 2001, Earle and Tuovila 2003). Non-parametric tests can be considered analogous to standard statistical tests, except specific assumptions about the distribution of the sample population are replaced by general assumptions (Dickinson-Gibbons and Chakraborti 1992). Typically, analysis occurs without prior knowledge of

the distribution function of the underlying population, and the only required assumption is that data are continuous. The most widely used method for investigating habitat use has been the Kruskal-Wallis test (also known as analysis of variance by ranks), the non-parametric analogue of a single-factor ANOVA, accompanied by post-hoc multiple comparisons to examine trends among years, habitats or environmental variables (e.g., Thompson et al. 1989, Forsey and Baggs 2001, Patriquin and Spencer 2004). Correlation and regression analyses have also been used to identify trends in habitat use (D'Eon 2001, Hayward et al. 2002). Probability estimators have shown promise as a method for developing population estimates, as well as the use of specifically designed formulae, such as the Formosov-Malyshev-Pereleshin formula (Becker 1991, Becker et al. 1998, Stephens et al. 2006). However, these methods are complex and a certain level of expertise is necessary for their correct application to track data. Also, estimates of daily travel distance for the species of interest are required for those methods (Becker 1991, Becker et al. 1998, Stephens et al. 2006).

Analysis of wildlife habitat use has often employed a univariate approach to explain habitat use by considering individual resources, like food supply or nesting sites, and the availability of these resources to animal selection or avoidance of a given habitat (Madhusudan and Johnsingh 1998). This approach has the advantage of being relatively simple to apply and interpret. However, univariate study of habitat use has important limitations. First is the assumption of *a priori* knowledge of those environmental variables that are most important for a given species. Second is that selection or avoidance of one habitat variable does not describe its importance relative to other habitat variables. Habitat use is more likely determined by several interacting variables in the physical and behavioural environment for a given species (Madhusudan and Johnsingh

1998). Univariate approaches may be unable to describe habitat use due the multidimensional nature of habitat (Clark et al. 1993).

In conclusion, the snow tracking method is labour intensive and dependent on well trained field staff. Sample design has a direct effect on the questions that can be addressed from the data. Using long transects or numerous short transects sampled often can reduce the number of zero counts, decreasing variability and increasing the precision of the survey. Before initiating a track survey, a specific research question should be decided upon, and the study designed to address that question directly.

STUDY OBJECTIVES AND EXPECTED OUTCOMES

At the outset of the CTWTP, MWFP established several objectives for the study. At the core of these was to assess the direct and indirect effects of commercial thinning on winter habitat quality and habitat use by regional vertebrate fauna. By assessing patterns and changes in track occurrence for 21 taxa (Table 1) over an 8-year period between reference (unthinned) and treatment (thinned) lodgepole pine stands, the CTWTP can address three research questions: 1) What is the variation in habitat use in mature forest across three types, dominated by lodgepole pine, trembling aspen (*Populus tremuloides* Michx.) and black spruce (*Picea mariana* (Mill.) BSP)? Here track occurrence will be compared among these three forest types, using data spanning the entire eight years of track surveys to describe habitat use in an undisturbed forest condition. 2) Are there differences in habitat use after commercial thinning? Comparison of baseline and post-treatment data in thinned lodgepole pine, as well as comparison of reference and treatment data, will serve to identify differences in track occurrences created by the commercial thinning treatment. 3) What habitat attributes influence any observed differences? A multivariate approach will be used to identify and describe associations between track occurrence and several environmental variables (including snowpack, weather and forest structure).

Expected outcomes in changes in habitat quality and habitat use for common species in the study area were developed from the work of Patriquin and Spencer (2004) unless otherwise referenced. Preliminary analysis of CTWTP data by Patriquin and Spencer (2004), used Kruskal-Wallis tests to compare track occurrences in early, mid and late winter, prior to and one year after thinning. Additional literature on the species tracked in the CTWTP is listed in Appendix A.

Table 1. Variables measured from 1998 to 2006 in the Tom Hill area as part of the track surveys

| Variable | Description |
|---------------------------------|---|
| Track (number/km/day) | Number of tracks observed Moose (<i>Alces alces</i>) White-tailed Deer (<i>Odocoileus virginianus</i>) Elk (<i>Cervus elaphus</i>) American Marten (<i>Martes americana</i>) Fisher (<i>Martes pennanti</i>) Weasels (<i>Mustela erminea</i> , <i>M. frenata</i> , <i>M. nivalis</i>) Wolverine (<i>Gulo gulo</i>) American North Porcupine (<i>Erethizon dorsatum</i>) Shrews (Soricidae) Mice and Voles (Muridae) American Red Squirrel (<i>Tamiasciurus hudsonicus</i>) Northern Flying Squirrel (<i>Glaucomys sabrinus</i>) Snowshoe Hare (<i>Lepus americanus</i>) Cougar (<i>Puma concolor</i>) Canada Lynx (<i>Lynx canadensis</i>) Wolf (<i>Canis lupus</i>) Coyote (<i>Canis latrans</i>) Red Fox (<i>Vulpes vulpes</i>) Bears (<i>Ursus americanus</i> , <i>U. arctos</i>) |
| Behaviour | Inferred based on gait, movement pattern and sign (ie. kill site). Coded into one of 6 categories: moving, resting, denning, feeding, hunting and other. |
| Snow depth (cm) | Total depth of snowpack |
| Snow density (%R _s) | Average resistance to penetrometer |
| Snowpack structure (cm) | Thickness and structure of each layer |
| Temperature (°C) | Measured at ground level, in snowpack, at snow surface and 3 m above ground. Also measured daily by automated weather station |
| Wind speed (km/h) | Measured by automated weather station |
| Relative humidity (%RH) | Measured by automated weather station |
| Forest structure | Perennial sample plots and initial transect characterization Vegetation plots |

Winter habitat use by moose is directly related to stand composition because moose require access to forage and prefer areas with less snowpack for ease of movement (Timmerman and McNichol 1988). During mid and late winter, moose track occurrence was lower in thinned stands in the study area, where the snowpack has the potential to be deeper and the air temperature lower, conditions unfavourable to moose whose movements can be restricted by 65 to 90 cm of snow. Moose track occurrence in this study was previously higher in undisturbed stands, especially in mid and late winter seasons. Similarly, white-tailed deer prefer areas where the snow is shallow (Kurta 1995). White-tailed deer in the study area preferred aspen and black spruce forest among the unthinned forests; seasonal comparisons indicate white-tailed deer used thinned stands less frequently in winter. It is expected that, as with moose, white-tailed deer will prefer undisturbed forest, particularly aspen-dominated forest, and will avoid areas of deep snow, as expected for the thinned lodgepole pine stands.

Marten prefer closed-canopy conifer stands (Kurta 1995). Thinned and reference stands differed in terms of marten use in winter, and use of thinned stands decreased as winter progressed. It is expected that marten track occurrence will continue to be higher in reference than in thinned stands of lodgepole pine. However, prey availability and increased abundance of coarse woody debris (CWD) may influence their use of thinned stands, since rodent occurrence increased after thinning. Fisher have a diverse diet and their habitat includes a variety of forest types (Arthur et al. 1989). Earlier analysis of track occurrence in the study area showed no difference in habitat use by fisher in any forest type. It is expected that fisher will show no preference for one forest type over another prior to thinning, but may avoid the open habitat in the thinned stands. Prey availability may be the most important factor in determining fisher habitat use. The three

smaller weasel species are considered habitat generalists and select habitat primarily on prey abundance (Klemola et al. 1999). A seasonal shift in track occurrence has been observed: weasels were using thinned stands more in mid than in late winter. It is expected that weasel habitat selection will be correlated with relative abundance of prey species.

Track occurrence in rodents was generally consistent in all forest types and seasonal variation was likely related to factors such as snow depth. It is expected that for mice and voles track occurrence will differ among seasons as a result of environmental characteristics such as snow depth or cover (i.e. CWD). Although squirrels can be observed in both coniferous and deciduous stands, they are more abundant in conifer stands (Kurta 1995). Use of all habitats by squirrels decreased during mid and late winter. It is expected that forage availability and climate will be the most important factors influencing squirrel track occurrence, but that there will be little or no differences in track occurrence among forest type.

In winter, snowshoe hare prefer stands with many shrubs, which provide both forage and cover for resting and predator escape if they occur above the snow (Thompson 1988). Snowshoe hare track occurrence declined sharply in pine stands immediately after thinning, but no other differences in snowshoe hare habitat use by forest type were detected. Occurrence of snowshoe hare tracks will likely remain low in treatment stands, a decline correlated with changes in availability of cover and forage.

The lynx is an obligate predator of snowshoe hare, which can comprise up to 85% of lynx diet (Thompson 1988, Kurta 1995). habitat use by lynx is often driven by prey availability. There was a difference in lynx track occurrence by forest type detected earlier: lynx tracks were least frequently observed in thinned pine stands. It is expected

that habitat use reflects the abundance of hare and that lynx tracks should continue to be fewer in thinned stands than in reference pine stands.

In boreal forests, coyote may be limited by both prey availability and snow depth (Murray et al. 1994, Zabel and Anthony 2003, Thibault and Ouellette 2005). No seasonal difference in track occurrence among forest types was detected in earlier analyses. It is expected that coyote habitat use is correlated with prey availability, but the nature of this relationship may be difficult to describe due to generalist feeding habits of this predator.

METHODS

Site Description

The study area, located south and west of Whitecourt, Alberta (Fig 1), is characteristic of the Lower Foothills Subregion (AGRA 1998), which forms part of the transition between the montane forests of the Rocky Mountains and the boreal forest (Achuff 1992). The subregion occurs on rolling topography, with elevations ranging from 500–1450 m. The Lower Foothills experience cool summers, with two-thirds of the annual precipitation falling during the growing season. Winters are warmer than adjacent boreal mixed-wood areas. Lodgepole pine forests are most common, particularly in areas that have been disturbed by wildfire. Common understory species include spruce (*Picea glauca* (Moench) Voss and *P. mariana* (Mill.) BSP) saplings, *Vaccinium* spp., prickly rose (*Rosa acicularis* Lindl.), Labrador tea (*Rhododendron groenlandicum* Oeder) and fireweed (*Epilobium angustifolium* L.). The associated wildlife community is influenced by the transitional nature of the region: both montane and boreal species are present, though boreal species tend to be more common.

Lodgepole pine stands in the Tom Hill area have been regenerating naturally since fires in 1941 and 1956 (AGRA 1998). The study site also contains patches of aspen-dominated deciduous stands, and black spruce/tamarack (*Larix laricina* (du Roi) K. Koch) stands in depression areas and along the floodplain of Oldman Creek, which forms the eastern boundary of the study area (Fig 1). The terrain is rolling, with slopes ranging from gentle (1–3%) to steep (9–17%). The elevation ranges from 1060–1153 m. Pine stands in Tom Hill selected for commercial thinning were fully stocked at high density, averaging 4500–5250 stems/ha. The goal for thinning was to release the remaining stems from competition and create a growth response to increase fiber production above that expected from natural regeneration and self-thinning. Details on thinning as a silvicultural tool and on its use in the Tom Hill study site are listed in Appendix B. Description of forest types is from AGRA Earth and Environmental (1998) and from Patriquin and Spencer (2004).

The aspen stands were 51 to 77 years old in 2007. At that time, average tree density was 2051 live stems/ha; snags (dead trees) comprised an additional 513 stems/ha. The average canopy tree height was 16.0 m and average diameter at breast height (DBH) was 16.7 cm. The understory was composed of white birch (*Betula papyrifera* Marsh.), lodgepole pine and white spruce saplings, a tall shrub layer (8% cover) dominated by green alder (*Alnus viridus* (Chaix.) D.C) and a low shrub layer (24% cover) dominated by alder, but also including honeysuckle (*Lonicera* spp.) and low-bush cranberry (*Viburnum edule* (Michx.) Raf.).



Fig 1. Geographic location of Tom Hill study site (outlined in red). Study site area is 1695 ha (Google Earth 2007)

The black spruce-dominated stands, 66 to 87 years old in 2007, occurred in low-lying areas with level topography. Larch, white spruce and lodgepole pine were also present at low density in black spruce stands. The average tree density was 6050 stems/ha, with an additional 641 snags/ha. The average height for black spruce was 5.0 m, with average DBH of 4.9 cm. The tall shrub layer was composed entirely of willow at 40% cover. The low shrub layer (60% cover) was dominated by Labrador tea, but bearberry (*Arctostaphylos uva-ursi* (L.) Spreng.), willow (*Salix* spp.), honeysuckle and prickly rose were also present at lower density.

The lodgepole pine stands selected for this project were 51 and 66 years old in 2007. Lodgepole pine density was 5256 stems/ha, with average tree height of 14 m and average DBH of 11 cm. White and black spruce were also present but were uncommon and much smaller than pine, with average height of 4 m and average DBH of 4 cm. Prior

to thinning, lodgepole pine stands had snags numbering 2051 stems/ha, more than in either of the other two forest types, and representing approximately 30% of total stems. Tall shrubs were dominated by willow and birch, but were rare (1.7% cover). Low shrubs (24% cover) were dominated by Labrador tea, but spruce and birch saplings were also common in the low shrub layer.

Prior to thinning, the treatment pine stands were similar to reference pine stands for the majority of measured stand characteristics, including stem density, age, height, DBH and species composition. Treatment stands had a slightly lower density of both live trees and snags and lower shrub cover (12%) than the reference stands (26%). This difference was primarily due a lower density of Labrador tea in the treatment stands. However, the shrub layer was more diverse in treatment than in reference stands, including low-bush cranberry, honeysuckle, prickly rose, balsam fir (*Abies balsamea* (L.) Mill.) and green alder, which were not present in the reference stands. The mean pre-treatment CWD density was 6.9 pieces/90 m transect before treatment and increased to 26.0 pieces /90 m transect after treatment, while live tree density declined from a mean of 2456 stems/ha to a mean of 1359 stems/ha. Decay class, length and diameter of CWD also decreased after thinning.

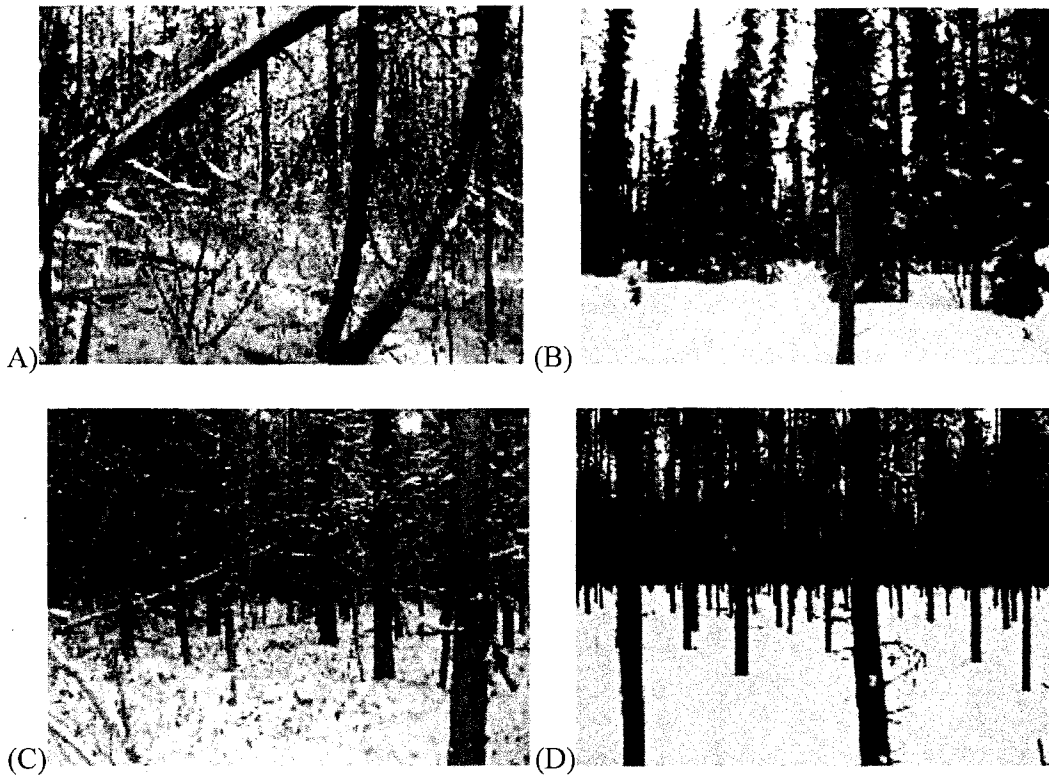


Fig 2. Images of four stand types; aspen (A), black spruce (B), reference lodgepole pine (C), and thinned lodgepole pine (D).

Study Description

Transects were located in stands with a minimum area of 10 ha (Patriquin and Spencer 2004). Thirty transects were established in four forest types (Fig 2): three in aspen-dominated forest, three in black spruce-dominated forest, six in unthinned lodgepole pine forest (reference) and eighteen in thinned lodgepole pine forest (treatment) (Appendix C). Transect lengths ranged from 750–800 m and were broken into three segments arranged in a crossing pattern to fit within the stand boundaries. Transect lines were flagged at 5 m intervals, with distance marked on the flagging tape.

The goal was to track each transect three times within each seasonal block, for a total of nine tracking events on each transect each year of survey. Track surveys were

conducted every winter from 1998-1999 until spring 2007, excluding 2000-2001 when harvesting operations occurred, and the winter of 2005-2006 when, weather and snow conditions were unsuitable for tracking (Table 2). Field crews were provided with reference materials from Rezendes (1999) and trained in the field by an experienced member of the crew before surveying transects alone. The field season was divided into three time periods corresponding to early (first snowfall to 01 January), mid (02 January through 15 February) and late (16 February to spring thaw) winter. Tracking began 24 hours after snowfall, and all transects were surveyed within 96 hours of a snowfall. For each transect walked, the date, days since snowfall and observer name were recorded. Species, number of individuals and an estimate of each individual's behaviour were recorded for each track seen within 5 m of transect centerline, as was the location of the track along the transect (to the nearest 5-m increment). When necessary the trail was also backtracked to interpret behaviour. Behaviour was coded into six categories: moving, resting, denning, feeding, hunting and other (with description). For large mammals, an azimuth on the direction of travel was recorded to reduce the likelihood of pseudoreplication by recording the track twice on a separate portion of the same transect. Snowshoe hare tracks were difficult to count accurately due to the number of tracks in a small area and the repeated use of trails. Thus, multiple use trails associated with snowshoe hare were assigned into one of three intensity classes: individual, low (two uses) and high (four or more uses). The length of the track pocket and intensity of use were the typical codes for snowshoe hare track observations. Other miscellaneous considerations while collecting data included incidental observation of wildlife or other associated sign such as scat.

Table 2. Summary of track surveys completed in each year

| Year | Early winter | Mid-winter | Late winter | Total |
|---------------|--------------|------------|-------------|-------|
| Pre-thinning | | | | |
| 1998-1999 | 2 | 3 | 1 | 6 |
| 1999-2000 | 1 | 3 | 3 | 7 |
| Post-thinning | | | | |
| 2001-2002 | 3 | 2 | 3 | 8 |
| 2002-2003 | 0 | 3 | 2 | 5 |
| 2003-2004 | 3 | 2 | 1 | 6 |
| 2004-2005 | 3 | 3 | 1 | 7 |
| 2006-2007 | 3 | 3 | 3 | 9 |

Permanent sample plots were used to measure forest structure (Table 1). Two meteorological stations in one treatment and one control pine stand collected daily temperature, wind speed and relative humidity data. At the 150-m increment of each transect, microclimate and snowpack data were recorded during each tracking event, including air temperature at 3 m above snow surface, snow temperature (at ground level, in the snowpack and at snow surface), snow depth and snow density. Time and sky conditions were also noted. Snowpack depth and structure were measured by digging new snow pits on each transect. Snowpack structure was coded into six classifications: powder, packed powder, powder melt, ice lens, pukak-ice and pukak. The thickness of each layer was measured and to measure snowpack resistance a 150-g cylinder was dropped from 50 cm above the snowpack. Its penetration depth was measured five times.

Statistical Analysis

Records of track occurrence for the two winters prior to treatment served as a baseline data set and allowed inference of differences in habitat use among forest types. Records collected after thinning were compared to records for the same locations before treatment and to records from the reference stands in the lodgepole pine forest to make inferences on the effect of thinning on habitat use. All data collected during the CTWTP

track surveys were entered into a Microsoft Access (2007) database. Track occurrence was standardized because transects were not of equal length and the surveys occurred at different periods of time after a snowfall event. Track occurrence data were converted to the variable Tracks/km/day (Equation 1.)

$$\text{Tracks/km/day} = (\text{Tracks} \times D) \div t \quad \text{Equation 1}$$

where:

Tracks = total number of track observations for a given transect during a survey
 D = transect length (km)
 t = Number of days since snowfall

Descriptive statistics were used to illustrate the distribution of this track occurrence variable. Comparisons of means, medians, variance and kurtosis values among forest types and for baseline and treatment data in the pine stands were used to determine if the sample was normally distributed. Frequency distributions were prepared to illustrate all data distributions (Appendix D). Because of zero counts, track encounters were distributed with a positive or right skew for all species. To confirm that the sample was not normally distributed, a Wilks-Shapiro test for normality was used. A natural logarithmic (\ln) transformation was applied to the track occurrence variable for all species. A time series of the mean track occurrence for each forest type was prepared for every species, where 1998 and 1999 represent the baseline data, and 2001–2006 (except 2005) represent the post-thinning data for the treatment plots (Table 2).

Two other variables used in the CTWTP analysis were derived from the raw data. First was the temperature gradient (ΔT), which represents the difference between temperature at ground level (T_G) and air temperature (T_A) at approximately 3 m above snow surface (Equation 2, Patriquin and Spencer 2004).

$$\Delta T = T_G - T_A \quad \text{Equation 2}$$

Second was the penetration resistance of the snowpack. This variable describes the hardness of the snowpack. It is calculated as the average penetration depth of the penetrometer relative to the total snowpack depth (Equation 3, Patriquin and Spencer 2004). Resistance is expressed as a percentage, with 100% equal to no penetration of snowpack and 0% being penetration to ground level.

$$\%R_s = [(SD - PD) \div SD] \times 100 \quad \text{Equation 3}$$

where:

$\%R_s$ = penetration resistance
 SD = average snowpack depth
 PD = average penetration depth

To address the first research objective, to quantify the variation in habitat use among the three baseline forest types, a one-way ANOVA was used to describe the variation in track occurrence among the three forest types. The ANOVA was used to test the null hypothesis that there is no difference in track occurrence among the three unthinned forest types. The null and alternative hypotheses could be stated generally as:

$$H_0 = \mu_{PI} = \mu_{Aw} = \mu_{Sb}$$

$$H_A = \mu_{PI} \neq \mu_{Aw} \neq \mu_{Sb}$$

where:

μ_{PI} = mean track occurrence in unthinned lodgepole pine stands

μ_{AW} = mean track occurrence in aspen-dominated stands

μ_{SB} = mean track occurrence in black spruce-dominated stands

For this test, a single-factor ANOVA was used (Equation 4, $df = 2$).

The predictor or grouping variable was stand type, either lodgepole pine, aspen-dominated or black spruce-dominated. The dependent or response variable was the log-transformed track occurrence ($\ln\text{Tracks}$).

$$Y_{ij} = \mu + \alpha_i + E_{ij} \quad \text{Equation 4}$$

where:

Y_{ij} = the j th replicate observation from the response variable from the i th group.

μ = the population mean from the response variable.

α_i = the effect of the i th group.

E_{ij} = the error associated with the j th replicate from the i th group.

If the ANOVA results indicated a failure to accept the null hypothesis, then multiple comparisons were used to identify which forest types were different from one another. Tukey's HSD test was used to compare each group mean with the other two group means and determine where significant differences existed at the stand level (Quinn and Keough 2002).

To address the second objective, a one-way ANOVA was used to identify any differences in track occurrence after the commercial thinning in the lodgepole pine stands. Once again the response variable was $\ln\text{Tracks}$. However, in this case the grouping variable was forest type, but consisted of only the reference and thinned lodgepole pine stands for the post-treatment years ($df = 1$). Because only two forest types were included, multiple comparisons were not needed for interpretation of the treatment ANOVA results. The general null hypothesis for this test was no difference in track occurrence between the thinned and reference lodgepole pine stands. The alternative was a difference in track occurrence between the thinned and control lodgepole pine stands

for at least one species. This can also be expressed as:

$$H_0 = \mu_T = \mu_B$$
$$H_A = \mu_T \neq \mu_B$$

where

μ_T = mean track occurrence in thinned lodgepole pine stands.

μ_B = mean track occurrence in reference lodgepole pine stands.

To address the third research objective, a multivariate approach using ordination was taken to examine the relationships between track occurrence and the habitat variables that may be influencing any differences detected in the ANOVA testing. Principal components analysis (PCA) was used to reveal relationships in the CTWTP data that may have been difficult to identify by comparing variables individually. Only principle components reporting eigenvalues ≥ 1 were considered significant and included in the PCA interpretation. The results of the PCA were presented as scree plots, where the X and Y axes represent the newly derived principal components. Three separate plots were prepared for each species, with the cases labeled by forest type, season and year. Ten variables were included in the ordinations:

- Ground temperature
- Air temperature (3 m above snow surface)
- Average snow depth
- Average penetration
- Temperature gradient
- Snow resistance
- Percent cover low shrub layer
- Percent cover tall shrub layer
- Stems/ha
- Snags/ha

There are a few important points to consider when interpreting the results presented in this document. Although most species were analyzed individually, three groups represent small clades of species. First, the rodent group included all mouse, vole and shrew track occurrences. These species were grouped together because their tracks are difficult to identify to the species level. In addition, the primarily subnivean habits of this group during the winter season can make detection difficult. Pooling observations for these species to create a larger dataset made relationships at the stand level more evident. Second, the weasel group included track observations for ermine and least and long-tailed weasels. These observations were pooled because size overlap of tracks prevents identification to the species level. Third, both the red squirrel and the northern flying squirrel were present in the CTWTP study area, but their tracks were not distinguished in the field, so tracks for both species were identified only as squirrel in the data.

All CTWTP analysis was completed using SPSS version 16 (SPSS 2007). The results depicted in this report are presented using the untransformed variable tracks/km/day. However, the transformed variable \ln Tracks was employed for all analyses. Alpha was set at 0.05. The term track occurrence represents the tracks/km/day variable throughout this document. Because zeros can not be \ln transformed they were substituted by the value 0.001. Combining the rodent, weasel, and squirrel track occurrences into groups may have limited the ability of subsequent analysis to characterize habitat use at the species level. Species like moose, white-tailed deer, lynx and coyote may be selecting habitat at a scale beyond that of the Tom Hill site as a result of the large home ranges these species have. Track cluster data for snowshoe hare was not included in the numerical analysis because the focus was on comparing relative abundance rather than quantifying the intensity of habitat use. The behaviour

observations were not used in the analysis because limited back tracking effort and potential errors in track interpretation the data was not considered reliable enough to be included.

RESULTS

Differences in track occurrence among forest types are illustrated by Fig 3. Moose ($F= 4.819$, $df= 2$, $P = 0.009$) and weasel ($F= 28.598$, $df= 2$, $P = <0.001$) track occurrences were higher in black spruce-dominated forest than in lodgepole pine forest (Tukey's test $P = 0.008$ and $P = < 0.001$, respectively). Track occurrence for moose did not differ between aspen and lodgepole pine forest (Tukey's test $P = 0.199$) or between aspen and black spruce forest (Tukey's test $P = 0.755$). On the other hand, weasel track occurrence was also higher in black spruce than aspen Tukey's test ($P < 0.001$) and higher in aspen than lodgepole pine (Tukey's test $P = 0.043$). Snowshoe hare ($F=81.2$, $df= 2$, $P = <0.001$) track occurrence was highest in lodgepole pine forest (Tukey's test $P < 0.001$). White-tailed deer ($F= 11.215$, $df= 2$, $P = <0.001$) track occurrence was higher in aspen-dominated forest than in black spruce forest (Tukey's test $P < 0.001$), but not different from black spruce forest lodgepole pine forest (Tukey's test $P = 0.089$), while marten ($F= 5.932$, $df= 2$, $P = 0.003$) track occurrences differed between the aspen and pine forests (Tukey's test $P = 0.003$), but similar to white-tailed deer, marten track occurrence did not differ for black spruce forest and either aspen (Tukey's test $P = 0.497$) or lodgepole pine forest (Tukey's test $P = 0.317$). Track occurrences did not differ among any of the forest types for fisher ($F= 0.252$, $df= 2$, $P = 0.778$), rodents ($F= 0.790$, $df= 2$, $P = 0.455$), squirrels ($F= 2.021$, $df= 2$, $P = 0.134$), lynx ($F= 2.019$, $df= 2$, $P = 0.136$) and coyote ($F= 0.454$, $df= 2$, $P = 0.636$).

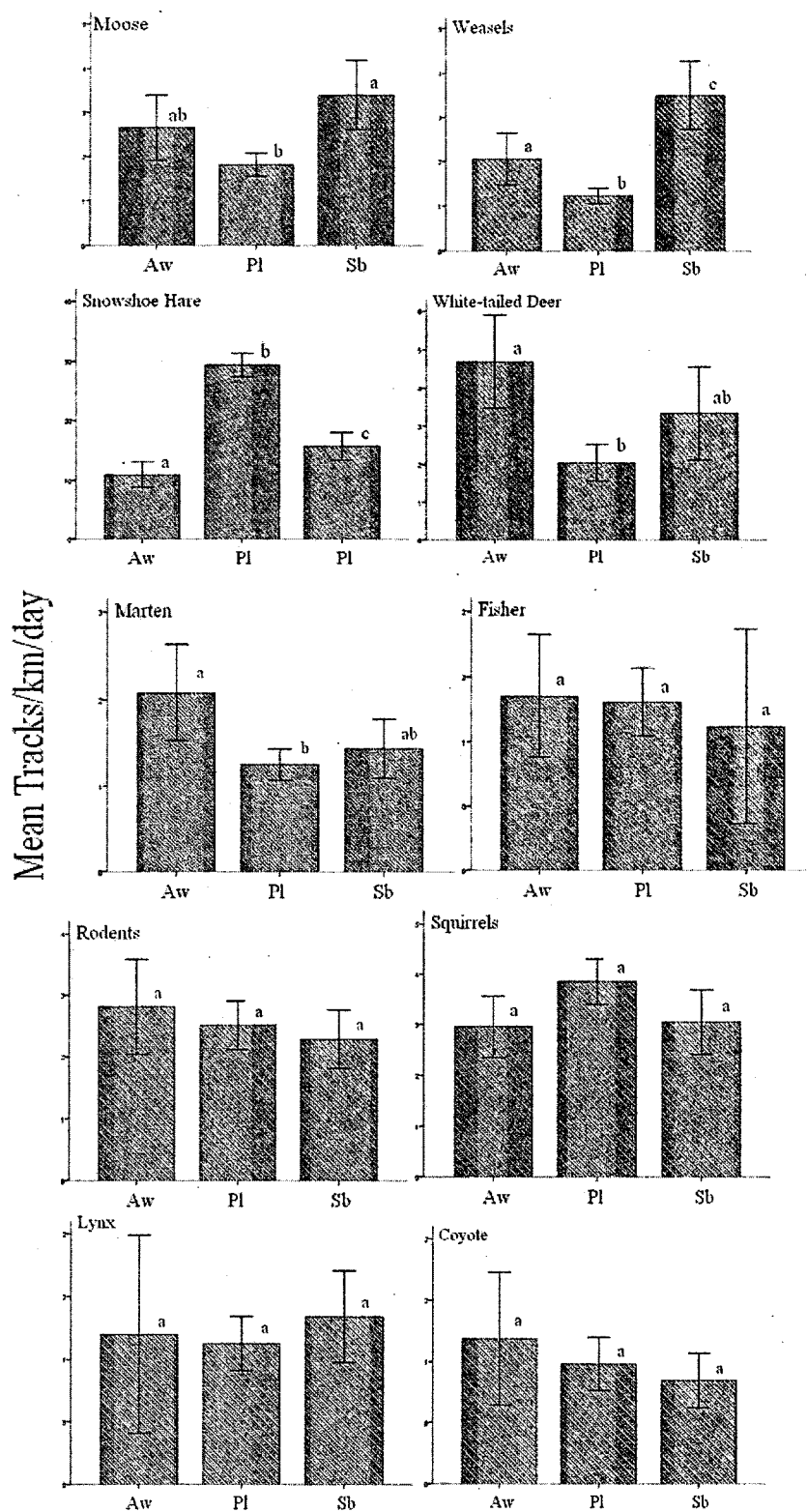


Fig 3. ANOVA histograms for track occurrence among all three forest types. Error bars indicate ± 2 standard errors. Track occurrences not significantly different for two forest types are indicated by the same letter above each column.

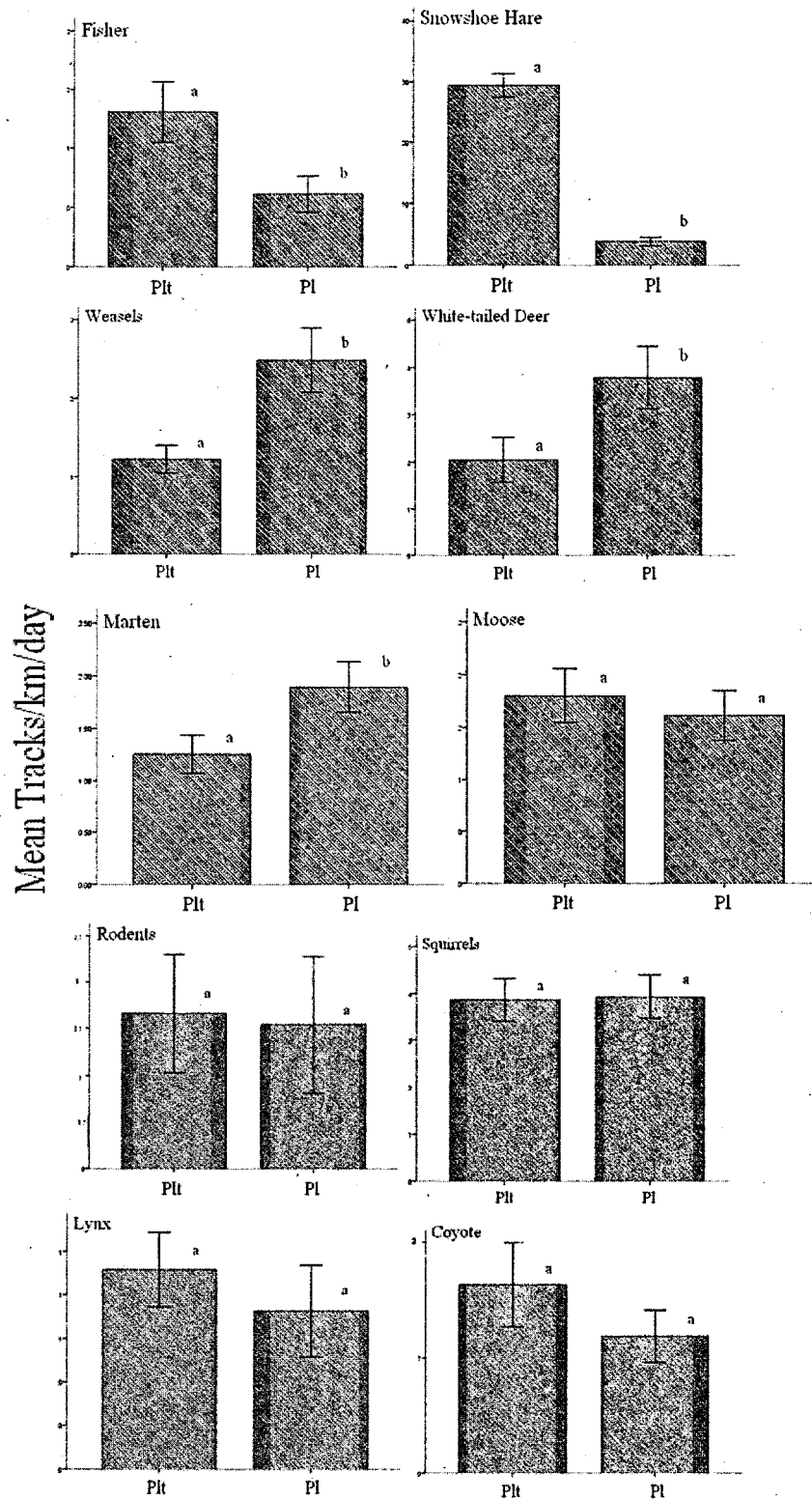


Fig 4. ANOVA histograms for track occurrence between reference pine and treatment pine forest types. Error bars indicate ± 2 standard errors. Track occurrences not significantly different for the reference and treatment stands are indicated by the same letter above each column.

Differences associated with the thinning treatment in lodgepole pine forest are illustrated in Fig 4. Fisher track occurrence was higher in the reference pine than in thinned forest ($F= 6.063$, $df= 1$, $P = 0.016$), as was snowshoe hare track occurrence ($F= 3.419$, $df= 1$, $P < 0.001$). In contrast, weasel, deer and marten track occurrences were higher in thinned than in reference lodgepole ($F= 46.485$, $df= 1$, $P < 0.001$; $F= 15.180$, $df= 1$, $P < 0.001$; $F= 21.457$, $df= 1$, $P < 0.001$ respectively). Mean weasel track occurrence in thinned forest was twice that recorded in the reference forest. Track occurrence did not differ between reference pine and thinned pine forest for moose ($F= 1.699$, $df= 1$, $P = 0.193$), rodents ($F= 0.063$, $df= 1$, $P = 0.802$), squirrels ($F= 1.211$, $df= 1$, $P = 0.272$), lynx ($F= 3.419$, $df= 1$, $P = 0.066$) or coyote ($F= 2.341$, $df= 1$, $P = 0.129$).

Principal components analysis identified at least three principal components with eigenvalues ≥ 1 . Only principal components 1 and 2, which explain most of the variation for all species, are included in Table 3. For all species, correlations between habitat variables and track occurrences were not the result of seasonal or annual variation (Appendix E). In all cases group separation within the PCA space was most clearly defined when cases were labeled by forest type. The strongest correlations among habitat variables and the principal components are listed as a table of factor loadings (Table 4). Species responded individually to variation in habitat.

Table 3. Principal components analysis summary table for all common species in the Tom Hill study area

| Species | Principal Component | Eigenvalue | % of Variance | Cumulative % |
|-------------------|---------------------|------------|---------------|--------------|
| Moose | 1 | 3.12 | 31.12 | 31.12 |
| | 2 | 2.38 | 23.84 | 54.95 |
| | 3 | 1.70 | 17.01 | 72.97 |
| White-tailed Deer | 1 | 3.47 | 34.76 | 34.76 |
| | 2 | 2.17 | 21.73 | 56.50 |
| | 3 | 1.83 | 18.35 | 74.85 |
| Marten | 1 | 2.83 | 28.29 | 28.29 |
| | 2 | 2.47 | 24.74 | 53.04 |
| | 3 | 2.01 | 20.12 | 73.16 |
| Fisher | 1 | 3.54 | 35.40 | 35.40 |
| | 2 | 2.42 | 24.21 | 59.61 |
| Weasels | 1 | 3.07 | 30.77 | 30.77 |
| | 2 | 2.47 | 24.72 | 55.49 |
| | 3 | 1.93 | 19.38 | 74.87 |
| Rodents | 1 | 3.11 | 31.14 | 31.14 |
| | 2 | 2.31 | 23.10 | 54.24 |
| | 3 | 1.94 | 19.44 | 73.69 |
| Squirrels | 1 | 2.93 | 29.30 | 29.30 |
| | 2 | 2.43 | 24.33 | 53.64 |
| | 3 | 2.03 | 20.37 | 74.01 |
| Snowshoe Hare | 1 | 3.19 | 31.93 | 31.93 |
| | 2 | 2.45 | 24.53 | 56.46 |
| | 3 | 1.84 | 18.47 | 74.93 |
| Lynx | 1 | 3.31 | 33.15 | 33.15 |
| | 2 | 2.21 | 22.13 | 55.28 |
| | 3 | 2.16 | 21.60 | 76.89 |
| Coyote | 1 | 3.33 | 33.38 | 33.38 |
| | 2 | 2.19 | 21.97 | 55.36 |
| | 3 | 1.95 | 19.51 | 74.87 |

Table 4. Strongest variable correlations with principal components and their factor loadings (in parentheses) from principal components analysis of track occurrence by species

| Species | Principal Component | Positive Factor Loading | Negative Factor Loading |
|-------------------|---------------------|--|---|
| Moose | 1 | Stems/ha (0.785), Tall Shrub Cover (0.721) | Low Shrub Cover (-0.645), Air temp (-0.609) |
| | 2 | Temperature Gradient (0.660), Snags/ha (0.537) | Air Temperature (-0.658), Tall Shrub Cover (-0.530) |
| White-tailed Deer | 1 | Low Shrub Cover (0.869), Tall Shrub Cover (0.809) | Air Temperature (-0.632), Snags/ha (-0.589) |
| | 2 | Air Temperature (0.751), Ground Temperature (0.543) | Temperature Gradient (-0.710), Snags/ha (-0.439) |
| Marten | 1 | Temperature Gradient (0.761), Average Snow Depth (0.63) | Air Temperature (-0.765) |
| | 2 | Low Shrub Cover (0.802), Stems/ha (0.852) | Average Snow Depth (-0.474), Snow Resistance (-0.486) |
| Fisher | 1 | Temperature Gradient (0.754), Snow Hardness (0.642) | Air Temperature (-0.794), Ground Temperature (-0.646) |
| | 2 | Low Shrub Cover (0.885), Tall Shrub Cover (0.864) | Average Snow Depth (-0.495), Snowpack Resistance (-0.503) |
| Weasels | 1 | Temperature Gradient (0.698), Tall Shrub Cover (0.669) | Air Temperature (-0.734), Snags/ha (-0.479) |
| | 2 | Stems/ha (0.822), Low Shrub Cover (0.679) | Average Snow Depth (-0.651), Snow Resistance (-0.575) |
| Rodents | 1 | Average Snow Depth (0.682), Temperature Gradient (0.627) | Air Temperature (-0.663), Snags/ha (-0.572) |
| | 2 | Low Shrub Cover (0.828), Tall Shrub Cover (0.752) | Temperature Gradient (-0.367) |
| Squirrels | 1 | Average Snow Depth (0.709), Snow Resistance (0.671) | Air Temperature (-0.661), Snags/ha (-0.613) |
| | 2 | Low Shrub Cover (0.935), Tall Shrub Cover (0.891) | Temperature Gradient (-0.232) |
| Snowshoe Hare | 1 | Temperature Gradient (0.703), Average Snow Depth (0.669) | Air Temperature (-0.736), Ground Temperature (-0.536) |
| | 2 | Low Shrub Cover (0.838), Tall Shrub Cover (0.794) | Temperature Gradient (-0.531), Snags/ha (-0.433) |
| Lynx | 1 | Temperature Gradient (0.753), Average Snow Depth (0.583) | Air Temperature (-0.759), Ground Temperature (-0.556) |
| | 2 | Stems/ha (0.845), Low Shrub Cover (0.646) | Snow resistance (-0.583) |
| Coyote | 1 | Average Snow Depth (0.774), Snow Resistance (0.742) | Snags/ha (-0.706), Air Temperature (-0.83) |
| | 2 | Stems/ha (0.901), Low Shrub Cover (0.753) | Average Snow Depth (-0.403), Snow Resistance (-0.374) |

DISCUSSION

The overarching goal of the CTWTP was to assess the effects of commercial thinning on mammal habitat use. Of the 10 species included in this report three distinct groups emerged. Species that appeared to have declined in response to the treatment include the snowshoe hare and the fisher. In a study of lodgepole pine forest, snowshoe hare populations declined similarly after thinning (Sullivan and Sullivan 1988). Snowshoe hare prefer forested habitats with dense understory to provide forage, escape or thermal cover. The commercial thinning harvest created a much more open forest, mean trees/ha was 2456 before thinning, and 1359 after. The reduced cover potentially determined decline in snowshoe hare track occurrence. Fisher are thought to be more of a generalist in their habitat selection, but because fisher are predatory and snowshoe hare a common prey item, the decline in hare occurrence may explain the decline in fisher tracks.

The second group of species includes weasels, marten, and white-tailed deer, having increased after the thinning. Both weasels and marten feed extensively on small mammals. During the winter season small mammals are most common in the subnivean layer and their predators require avenues to access the subnivean space they occupy. Weasels and marten also use subnivean space for resting and denning sites. Payer and Harrison (2003) observed that marten sought out structural features of the forest such as CWD, snags, stumps, and leaning trees, all of which can provide access to the subnivean space. Although CWD was not measured directly as a component of the CTWTP, observations from the field work indicated a significant increase in the volume of CWD in the thinned pine stands. Limbs, small diameter (< 10 cm) stems, other non-merchantable trees and brush are left on the forest floor by the processor during thinning.

The result is a mat of CWD that may provide easier access below the snow pack for hunting or resting by weasels and marten.

Temperature appears to be an important habitat attribute for white-tailed deer. It may be that the thinned forest has a difference in temperature that benefits deer compared to the reference pine forests. This correlation with temperature attributes is unexpected, as snow depth has been identified by both D'Eon (2001) and Morrison et al. (2003) as a critical factor influencing deer winter habitat use. It may be that the snowpack in most years of the CTWTP was below the critical depths for deer (25 to 35 cm) possibly explaining why there was no correlation with snowpack depth or hardness. In years when depth exceeds 25 cm snow, depth and snow resistance are likely to have a stronger influence on deer habitat use.

In the third group, squirrels, moose, other rodents, lynx, and coyote had no increase or decrease in response to the commercial thinning. Squirrels have a diverse diet. While thinning changes the forest structure (i.e. spacing and understory cover), it does not alter the species composition of canopy trees and consequently the cone and fruit crops associated with the lodgepole pine stands. Ransome et al. (2004) observed a similar pattern of no change in red squirrel populations after thinning. Small mammal populations have strong and unpredictable cycles in the North American boreal forest (Morris 2005), potentially explaining the lack of difference in rodent track occurrence. Other species that did not appear to have differed in their use of thinned forest may have habitat use focused on a forest type other than forest dominated by lodgepole pine. Moose, for example, were most common in the aspen forest type throughout the study period. Some mammals not affected by the thinning treatment, like the larger predators, may have larger home ranges than what would be expected for populations affected by

the scale of the thinning.

Forest structure (percent shrub cover, the density of stems and snags), followed by temperature (air or ground temperature or the temperature gradient between them) and snowpack (depth and hardness), were the most important variables influencing the occurrence of mammal tracks in the Tom Hill study area. Moose and white-tailed deer track occurrence appeared to be most correlated with forest structure variables, whereas the tracks of weasels and rodents were more strongly associated with temperature. Coyote, marten and fisher tracks all appeared to have some association with differences in the snowpack. It is possible that these three categories represent the most critical winter habitat attributes for mammal species found in the lower foothills region of Alberta.

Mammal diversity changed very little as a result of the commercial thinning harvests. Some species became more common in treatment stands, while others were less frequently observed. The most notable change was in snowshoe hare track occurrence, which declined sharply in treatment stands after the thinning harvest was completed. This may not be important as it first appears, because there are readily available refugia in the nearby unthinned forest types. In Newfoundland, Forsey and Baggs (2001) observed a shift in habitat use by snowshoe hares to un-cut areas after clear-cut harvesting. In another study of pre-commercial thinning in northwestern Montana, an association was observed between snowshoe hare and unthinned retention patches at the stand level (Ausband and Baty 2007). When an environmental disturbance creates unsuitable habitat for a given species, local populations often retreat to nearby habitats that can provide for their needs. Other species that did not differ in their use of pine forest before and after thinning may have less preference for forest dominated by lodgepole pine. For example,

moose were more common in the aspen and black spruce forest types than the pine forest type throughout the monitoring period.

The commercial thinning harvest in the Tom Hill site influenced mammal habitat use in a variety of ways. Ultimately the majority of mammals in this study either exhibited an increase in track occurrence following thinning or were not affected. The relationships between temperature, and snowpack appear to be interesting avenues for further research. More detailed comparison of track occurrence and measurement of forest structure data at the transect scale are two other ways to follow up the CTWTP. Fire, clear cutting, or other forest disturbances in lodgepole pine can lead to the development of high-density stands with low tree species diversity and a sparse understory. These stands are good candidates for commercial thinning when trees are of sufficient size to produce merchantable fibre.

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LITERATURE REVIEW – THINNING AS A SILVICULTURAL TOOL

High density forest stands offer limited growing space for individual trees, intense competition, and slower growth (AGRA 1998). Thinning is an Intensive Forest Management (IFM) practice that removes trees before a stand reaches maturity to achieve a desired spacing. There are two types of thinning. Pre-commercial thinning removes trees before they reach merchantable size (Alexander 1960). Commercial thinning removes trees that are of merchantable size (Williamson 1982). In general, both practices are thought to improve the growth of the remaining trees in a stand. Alexander (1960) surveyed pre-commercially thinned stands at varying spacing and found that diameter growth increased with thinning intensity. Fiddler et al. (1995) observed a similar growth response in commercially thinned Ponderosa pine (*Pinus ponderosa*) stands. Thinning is also considered an effective means of reducing mortality (Alexander 1960, Williamson 1982, Fiddler et al. 1995), possibly due in part to removal of the poor quality stems and intermediate or overtopped trees, while leaving the best quality trees. Thinning may also allow quicker development of structural features associated with late seral stages (Sullivan et al. 2006).

Lodgepole pine (*Pinus contorta* var. *latifolia*) has been identified as a species that responds well to thinning (Alexander 1960, Sullivan et al. 2006). Disturbance by wildfire or clearcutting can be followed by the development of high-density stands, which are characterized by low diversity in tree species and a sparse understory (Sullivan et al. 2006). When these initial conditions exist, thinning lodgepole pine can increase the growth rate of remaining trees. Sullivan et al. (2006) monitored pre-commercially thinned stands of lodgepole pine between 17 and 27 years of age. Fifteen years after thinning, trees in thinned stands had higher diameter and volume growth, but their height

did not differ relative to reference stands. In another study, 20 years after thinning, lodgepole pine (35–78 years old) experienced an increase in diameter growth at all thinning treatments regardless of intensity (Alexander 1960). A positive linear relationship existed between diameter growth and tree growing space. Ultimately Alexander (1960) concluded that thinning in high-density lodgepole pine stands is able to protect the best available trees for later harvest, shorten rotation time and increase total yield.

The thinning treatment at the Tom Hill study site was intended to increase spacing and reduce the stem density in selected stands. Spacing factor is an index of stand density that represents the amount of growing space available to a tree relative to its height (T. McCready, MWFP, personal communication). The target spacing factor was a 4% increase from 11.7 to 15.7%. This target was achieved by removing an average of 1097 trees/ha, resulting in a mean density 1360 trees/ha. CWD was also surveyed before and after treatment in the thinned pine stands. The mean pre-treatment density of 6.9 pieces/90 m transect increased to 26.0 pieces /90 m transect after treatment (Patriquin and Spencer 2004). Decay class, length, and diameter of CWD also decreased as a result of thinning.

Thinning in high-density stands results in substantive changes their structural characteristics, likely to produce a change in use of the forest by wildlife. The direction of changes is difficult to predict. Small mammal populations and ungulates increased with thinning in red pine (*Pinus resinosa*) stands, which in early development stages often provide poor quality wildlife habitat (Bender et al. 1997). In a lodgepole pine forest, snowshoe hare populations ultimately declined after thinning, when the habitat became less desirable (Sullivan and Sullivan 1988). If thinning improves habitat quality

through development of structure associated with late seral conditions, it must also be assumed that habitat preference is a response to structure more so than age. Variation in the response of wildlife populations to thinning suggests that the response is unique to the habitat requirements of each forest type and wildlife species.

APPENDIX B- HABITAT USE BY WILDLIFE COMMON IN THE STUDY AREA

Although moose (*Alces alces*), the largest North American cervid, can occupy a home range up to 20 km², the winter range may be only 20% of the summer range (Kurta 1995). During winter, moose are most often found in areas of high forage production (Timmermann and McNichol 1988), where they feed on the twigs and buds of both deciduous and coniferous species (Kurta 1995). Common winter food items include the current year's growth of many deciduous shrubs and trees, as well as balsam fir. Moose prefer areas with dense cover and nearby food patches, because these areas reduce their energy requirements and may increase winter survival. Snow depth may also be an important factor in determining winter habitat use by moose, because snow can reduce access to forage material (conceals it) and restrict movement (Telfer 1970, Timmermann and McNichol 1988), making it more difficult to travel to feeding sites. Moose movement may be restricted at snow depths as low as 65 cm and snow depths greater than 90 cm may severely limit moose activity. Dense conifer cover has also been described as important winter habitat for moose (Tomm et al. 1981). These areas often have a vegetation species composition that provides acceptable forage material. Also, the dense canopy can result in a shallower snowpack and provide thermal cover by sheltering moose from wind, thereby reducing heat loss (Telfer 1970, Timmermann and McNichol 1988). Dense cover can also provide protection from predators (Tomm et al. 1981, Timmermann and McNichol 1988).

White-tailed deer (*Odocoileus virginianus*) have similar habitat preferences as moose, preferring low-lying areas with dense cover in winter (Smith 1991, Kurta 1995). Many individuals will occupy the same area, often referred to as 'yards'. White-tailed deer also reduce foraging behaviour in the winter to conserve energy, preferring a sit and

wait approach, slowly consuming a localized food supply (Kurta 1995). Preferred forage is deciduous twigs and buds; conifers are also consumed but to a lesser extent (Kurta 1995). There are two key factors that influence winter habitat use by white-tailed deer. First is snow depth: depths of only 25 to 35 cm have been shown to greatly reduce movement (Telfer 1970). During periods with a shallow snowpack, deer will be more wide spread, and can be observed in many different habitats, including sheltered and open habitats (D'Eon 2001). However, during periods of deep snow, deer tend to aggregate in areas where the snow is shallowest. The second is the availability of cover. Numerous studies have demonstrated that deer select areas with dense conifer cover under a variety of snow conditions (Telfer 1970, Tomm et al. 1981, D'Eon 2001, Morrison et al. 2003). Selection of shelter areas by deer varies in relation to snow depth. When the snow depth is low, deer prefer areas with dense cover and nearby open areas that often provide a source of browse. The proximity of forage may be more important under shallow snow conditions (Morrison et al. 2003). But as snow depth increases and movement becomes difficult, deer appear to select these sheltered areas for the comparatively shallow snowpack, regardless of the browse availability near the site.

American marten, a medium sized member of the family Mustelidae comparable in size to a small domestic cat, often prey on rodents in the open subnivean layer supported by CWD under the snowpack (Kurta 1995). Their primary prey species include small mammals like mice, voles and squirrels. In general, marten can be considered a forest-dependent species that prefers mature forests (Thompson 1988, Kurta 1995, Kurki et al. 1998, Payer and Harrison 2003). Numerous studies have identified an association between marten abundance and late successional forests, particularly stands dominated by conifers (Thompson 1988, Koehler et al. 1990, Payer and Harrison 2003). The

preference for mature conifer stands may be related to a number of habitat characteristics. These stands tend to have a large amount of vertical structure and basal area (Payer and Harrison 2003). Structural elements like snags, stumps, CWD, downed logs and low hanging branches have been identified as attributes of good marten habitat (Thompson 1988, Wilbert et al. 2000, Payer and Harrison 2003). These structures provide resting and denning sites, as well access to prey (Koehler 1990, Wilbert et al. 2000). Marten are primarily carnivorous, but some fruits are eaten when seasonally available (Kurta 1995). As a result of their predatory nature, prey availability may also be an important influence on marten habitat use (Raine 1983, Thompson 1988). Marten tend to use open or disturbed areas less than mature forest stands (Thompson 1988, Thompson et al. 1989) and in disturbed forests, their home range is 3–4 times that of mature forests. This selection against open areas appears strongest during the winter. Marten are not as impeded by snow depth as some other mammals, but snow and temperature may also influence their habitat use. Deep snow can provide insulation but also impede movement, and cold temperatures can increase the energetic costs of thermoregulation (Wilbert et al. 2000).

The fisher (*Martes pennanti*), a mustelid that is nearly twice the size of a marten, has a home range from 15–35 km² in area. Males tend to occupy a larger area that overlaps the home ranges of several females (Kurta 1995). The fisher has a diverse diet: common prey species include snowshoe hare, small rodents, squirrels, porcupines, carrion and seasonally available fruits and berries (Arthur et al. 1989, Kurta 1995). Due to the varied diet of the fisher, favourable habitat is thought to include a variety of forest types (Arthur et al. 1989). It has been suggested that any forested area with a sufficient prey base could be occupied by fisher. Arthur et al. (1989) were not able to identify

preferences between habitat types. However in winter, fisher tend to rest in ground burrows in mixed-wood and conifer stands, hunt in dense conifer stands and avoid deciduous stands (Arthur et al. 1989, Kurta 1995). These mature stands likely provide important cover during the winter (Thomasma et al. 1991), thus fisher often avoid open habitats, disturbed areas and clear cuts (Zabel and Anthony 2003). Another factor that may influence habitat use in winter is snow depth. Fisher may be more limited than smaller mustelids by deep snow, because of higher foot loadings and deeper sinking depths after a snowfall (Zabel and Anthony 2003, Raine 1983).

Three weasel species, ermine (*Mustela erminea*), long-tailed weasel (*M. frenata*) and least weasel (*M. nivalis*) appear to be habitat generalists found anywhere from farm fields and meadows to dense conifer stands (Kurta 1995, Klemola et al. 1999). All three species are primarily carnivorous, feeding on small mammals, birds and to a lesser extent, insects and berries (Kurta 1995). Each of these species makes use of subnivean spaces for finding and catching prey in the winter (Klemola et al. 1999). The ermine or stoat is widely distributed and is most common in the boreal and northern regions, as is the least weasel (Kurta 1995). However, the long tailed weasel is most in common the temperate southern regions of North America. The ermine and least weasel are found in a wide variety of habitats, although they may be less common in mature forests (Kurta 1995, Forsey and Baggs 2001). The long tailed weasel inhabits forest and field edges, as well as forest stands with abundant shrub cover. The wide variety of habitats occupied by these weasel species, as well as a similar diet, suggests that weasels may select habitats based on prey availability (Klemola et al. 1999, Aunapuu and Oksanen 2003). Inter-specific competition can also play a role in determining habitat use for small mustelids. The least weasel can specialize on small mammals, while the larger ermine can diversify its diet to

include other species like grouse and hare when preferred prey are scarce, allowing these species to coexist. The least weasel and the ermine move efficiently above and below the snow, while the larger long tailed weasel is more restricted by deep snow (Kurta 1995, Aunapuu and Oksanen 2003). This may reduce competition between the long tailed weasel and its smaller relatives (Aunapuu and Oksanen 2003).

The small mammal community in the boreal forest is a diverse group that includes members of both Soricidae (shrews) and Muridae (mice and voles) families (Kurta 1995). Members of this community are primarily ground dwelling and occupy a wide variety of habitats in the boreal forest. For example, deer mice (*Peromyscus spp.*), one of the most common small mammals, are most abundant in wooded areas but are also found in shrubby sites and recent clear cuts or burns. Meanwhile, the meadow vole (*Microtus pennsylvanicus*), another common boreal small mammal, prefers moist grassy areas and also frequents wetland areas. Due to the wide variety of habitats occupied by small mammals, as well as the coexistence of multiple species in similar habitats, competition and niche differentiation probably play an important role in determining habitat use (Zabel and Anthony 2003). Small mammals react in different ways to forest disturbances: some species exhibit a positive response in terms of abundance to forest harvest (Sullivan et al. 2005), while others respond negatively (Thompson et al. 1989). Small mammals are both common and widespread in temperate forests and as such, these animals represent an important food source for many of the predators and may be an important factor in determining habitat selection for predators.

Both red squirrels (*T. hudsonicus*) and northern flying squirrels (*Glaucomys sabrinus*) are present in the boreal forests of West Central Alberta. Habitat use by these species is similar: both prefer older undisturbed forests with a dense canopy (Holloway

and Malcolm 2006). Conifer stands are preferred over deciduous stands, though squirrels can be found in both forest types (Kurta 1995, Holloway and Malcolm 2006). Primary foods include seeds, nuts, conifer buds and fungi. There are also some important differences between these species. The red squirrel has a diverse diet, but is associated with habitats where conifer seed production is high, while the northern flying squirrel is associated with old-growth stands (Holloway and Malcolm 2006). The red squirrel is also diurnal, whereas the flying squirrel is primarily nocturnal (Kurta 1995). Red squirrels are highly territorial, which could mean that territory availability may be more important than forage availability to this species' habitat selection (Gurnell 1984). The flying squirrel is much more social, especially in winter, when multiple individuals can share a single nest (Kurta 1995). Each species reacts differently to some habitat characteristics. During winter, the red squirrel tends to reduce activity during cold periods (Kurta 1995), whereas the flying squirrel remains active, even during periods when temperatures are as low as -20°C. The two species may also respond differently to silvicultural treatments. In a survey of pre-commercially thinned lodgepole pine stands, the northern flying squirrel responded positively in high density treatments and negatively in low density treatments (Ransome et al. 2004). However, red squirrel populations did not show any response to the same thinning treatments.

The home range for a snowshoe hare (*L. americanus*) is approximately 8 ha. Hare are herbivorous: their winter forage includes the bark, twigs and buds of woody plants, as well as conifer needles (Litvaitis et al. 1985, Kurta 1995). Hare prefer heavily forested habitats with dense understory cover that provides forage, escape cover and thermal cover (Thompson 1988). Thus, differences in habitat use by hare may be explained by understory composition (Litvaitis et al. 1985). They thrive in dense conifer and mixed-

wood stands (Kurta 1995) and are often found in low-lying areas like bogs and spruce swamps. During the summer hare may increase their use of open habitats because of the availability of herbaceous forage. Snowshoe hare are not likely limited by snow conditions (Kurta 1995): their large feet act as 'snowshoes' and provide flotation. Snowshoe hare are one of the most common and important prey species in the boreal forest (Kurta 1995, Ausband and Baty 2005) for fishers, coyotes and especially lynx. Hare abundance may influence the habitat preferences of these predators.

Lynx (*L. canadensis*) are short tailed cats that commonly occur in boreal, sub-boreal and montane mixed-wood forests of North America, Lynx are often found in dense conifer and deciduous stands (Poole et al. 1996, Poole 2003), occupying a territory ranging from 10–50 km² (Kurta 1995). Numerous studies have identified a preference for early successional forests (Thompson 1988, Thompson et al. 1989, Poole et al. 1996, Mowat and Slough 2003, Poole 2003). Lynx are also found in mature forest and riparian areas, while they tend to avoid young stands and open areas (Mowat and Slough 2003, Poole 2003). It has been proposed that lynx habitat selection is more strongly associated with understory density than with any overstory characteristics (Mowat and Slough 2003). The abundance of hare, their most common prey item, seems to be the most important factor in determining lynx habitat selection (Thompson 1988, Thompson et al. 1989, Koehler 1990, Poole et al. 1996, Mowat and Slough 2003, Poole 2003), although their diet also includes squirrels, small mammals, grouse and occasionally deer fawns. The relationship between hare and lynx has been well described: lynx are obligate predators of snowshoe hare, which may make up as much as 85% of their diet. Lynx are so strongly associated with hare abundance that their populations vary in relation to the cyclical variation in hare abundance (Saunders 1963, Kurta 1995, Poole 2003). Because

these species are so closely linked, lynx habitat use reflects their dependence on hare populations, lynx are most common in areas where hare are abundant (Thompson 1988, Poole et al. 1996, Mowat and Slough 2003).

The coyote (*Canis latrans*) is a medium sized canid averaging 1.1–1.3 m in body length and weighing from 12 to 21 kg. The coyote is an opportunistic mesocarnivore (diet consists of 50–70% meat), and feeds on a wide variety of prey including mammals, birds, invertebrates and fruit (Bekoff, 1977, Zabel and Anthony 2003). The coyote occasionally tackles large prey items, but most prey are of equal or lesser body size. The coyote originated in the prairies and plains of western North America (Thibault and Ouellet 2005), but is one of the America's most adaptable predators and now has a nearly cosmopolitan range in North America (Kurta 1995). Though most often found in prairie, brush or wooded edge habitats, this species can exist in a mosaic of clearcuts and linear corridors. Forested habitats have been considered marginal for the coyote (Thibault and Ouellet 2005); however, range expansion into boreal forests indicates wooded areas can support coyote populations and coyotes have been observed to select forest habitat more often than expected (Murray et al. 1994, Thibault and Ouellet 2005). It appears that coyote, like lynx, select habitats where hare and other important prey species are most abundant and where dense vegetation allows the coyote to get closer to prey prior to detection, thereby improving hunting success (Thibault and Ouellet 2005). The abundance of coyotes in the boreal region appears to be limited by hunting success and in winter, by snow depth (Murray et al. 1994, Zabel and Anthony 2003, Thibault and Ouellet 2005). Snow depth and hunting success are also likely interconnected. Coyotes have been observed using dense conifer stands more frequently when snow was deep and using open habitats more often when snow was shallow or hard-packed (Thibault and

Ouellet 2005). Snowpack depth is an important habitat characteristic for the coyote, which have a relatively high footload, and likely suffer from reduced mobility and increased energetic costs when snow is deep (Zabel and Anthony 2003). Coyotes are more selective of snow depth and hardness than other boreal predators like lynx (Murray et al. 1994).

There is a group of species that has been observed in the study area but are rare. Rare species or those that occur infrequently can be very difficult to sample (Hirst and Jackson 2007). In the study area, these species include bears (*Ursus americanus*), that are not active in winter. Cougars (*P. concolor*) are wide ranging predators, traveling up to 80 km from their core home range (Soper 1964). Elk (*Cervus elaphus*) are rare and the study area falls outside the species range identified by Soper (1964). Shrews are common in the study area, but the subnivean habits of this group make their detection difficult in winter (Kurta 1995). Wolverines (*G. gulo*) can be locally rare at any given time and occupy large home ranges, up to 2000 km² (Kurta 1995).

SITE AND STUDY DESCRIPTION SUMMARY TABLES

1. Transect descriptions.

| Treatment | Species ^a | Transect | Transect Length (m) | Year Thinned |
|-----------|----------------------|----------|---------------------|--------------|
| Thinned | Pl | A197 | 800 | 2000/2001 |
| Thinned | Pl | A438 | 700 | 2000/2001 |
| Thinned | Pl | B438 | 800 | 2000/2001 |
| Thinned | Pl | C197 | 800 | 2000/2001 |
| Thinned | Pl | C438 | 650 | 2000/2001 |
| Thinned | Pl | D438 | 700 | 2000/2001 |
| Thinned | Pl | E438 | 700 | 2000/2001 |
| Thinned | Pl | F438 | 700 | 2000/2001 |
| Thinned | Pl | D197 | 700 | 2000/2001 |
| Thinned | Pl | G438 | 775 | 2000/2001 |
| Thinned | Pl | B176 | 800 | 2001/2002 |
| Thinned | Pl | B217 | 750 | 2001/2002 |
| Thinned | Pl | C217 | 750 | 2001/2002 |
| Thinned | Pl | D217 | 800 | 2001/2002 |
| Thinned | Pl | E217 | 700 | 2001/2002 |
| Thinned | Pl | 29 | 800 | 2001/2002 |
| Thinned | Pl | A217 | 800 | 2001/2002 |
| Thinned | Pl | A176 | 800 | 2001/2002 |
| Control | Aw | 27 | 700 | N/A |
| Control | Aw | 346 | 600 | N/A |
| Control | Aw | 455 | 700 | N/A |
| Control | Pl | 174 | 700 | N/A |
| Control | Pl | A423 | 650 | N/A |
| Control | Pl | B423 | 700 | N/A |
| Control | Pl | 154 | 700 | N/A |
| Control | Pl | 205 | 750 | N/A |
| Control | Pl | F217 | 750 | N/A |
| Control | Sb | 191 | 650 | N/A |
| Control | Sb | A218 | 700 | N/A |
| Control | Sb | B218 | 700 | N/A |

^a Pl=Lodgepole Pine, Aw= Aspen, Sb= Black Spruce

2. Changes in tree spacing, stem density, and volume from commercial thinning.

| BLOCK | Area (ha) | Spacing factor (%) | Trees/ha | Basal Area (m²/ha) | Volume (m³/ha) |
|----------------|----------------------|-------------------------------|-----------------|--|--------------------------------------|
| Pre-thinning | | | | | |
| TH 714 | 62.1 | NA | NA | NA | NA |
| TH 716 | 48.5 | 11.8 | 2248 | 36.0 | 268.6 |
| TH 717 | 20.7 | 11.6 | 2326 | 40.0 | 300.8 |
| MEAN | | 11.6 | 2456 | 36.5 | 260.9 |
| Post-thinning | | | | | |
| TH 714 | 62.1 | NA | NA | NA | NA |
| TH 715 | 59.5 | 15.5 | 1540 | 21.6 | 148.4 |
| TH 716 | 48.5 | 15.8 | 1256 | 23.6 | 184.4 |
| TH 717 | 20.7 | 15.6 | 1283 | 26.1 | 205.9 |
| MEAN | | 15.6 | 1359 | 23.8 | 179.5 |
| Amount Removed | | | | | |
| TH 714 | 62.1 | NA | NA | NA | NA |
| TH 715 | 59.5 | 4.0 | 1256 | 11.9 | 64.9 |
| TH 716 | 48.5 | 4.0 | 992 | 12.5 | 84.3 |
| TH 717 | 20.7 | 4.0 | 1043 | 13.9 | 95.0 |
| MEAN | | 4.0 | 1097 | 12.8 | 81.4 |

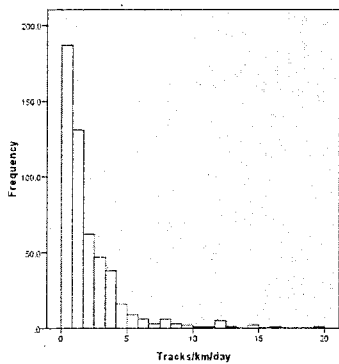
TESTS FOR NORMALITY AND HISTOGRAMS

A.1. Moose

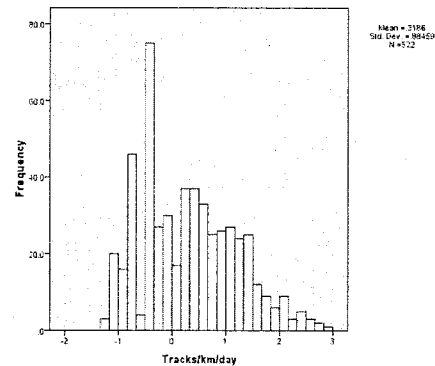
Wilks-Shapiro test for normality

| Species | Tracks _{km/Day} | lnTracks |
|---------|--------------------------|----------|
| | Sig. | Sig. |
| Aw | .000 | .058 |
| Sb | .000 | .079 |
| Pl | .000 | .001 |
| Plt | .000 | .000 |

Frequency distributions of track occurrence for moose (A= Tracks_{km/Day} and B= lnTracks)



A)



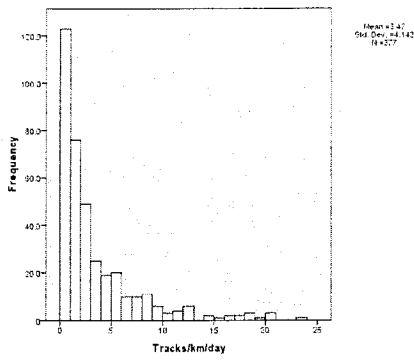
B)

A.2. White-tailed Deer

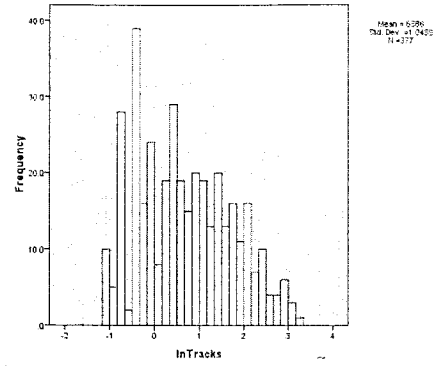
Wilks-Shapiro test for normality

| Species | Tracks _{km/Day} | lnTracks |
|---------|--------------------------|----------|
| | Sig. | Sig. |
| Aw | .000 | .103 |
| Sb | .000 | .002 |
| Pl | .000 | .002 |
| Plt | .000 | .073 |

Frequency distributions of track occurrence for deer (A= Tracks_{km/Day} and B= lnTracks)



A)



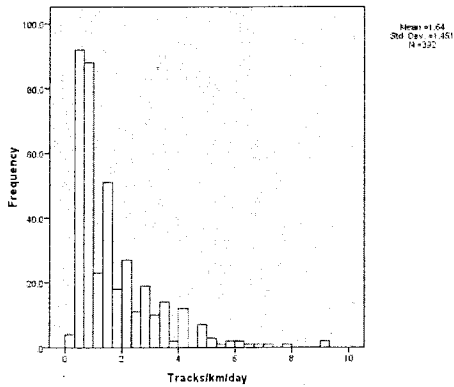
B)

Marten

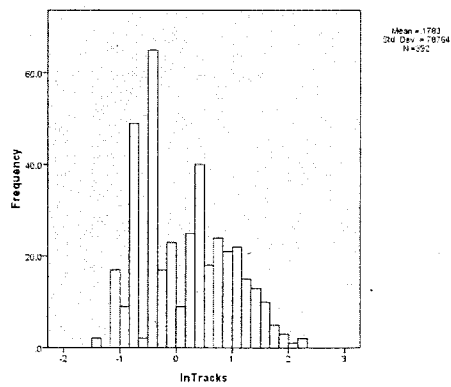
Wilks-Shapiro test for normality

| Species | Tracks _{km/Day} | |
|---------|--------------------------|------|
| | Sig. | Sig. |
| Aw | .000 | .083 |
| Sb | .000 | .000 |
| Pl | .000 | .001 |
| Plt | .001 | .019 |

Frequency distributions of track occurrence for marten (A= Tracks_{km/Day} and B= lnTracks)



A)



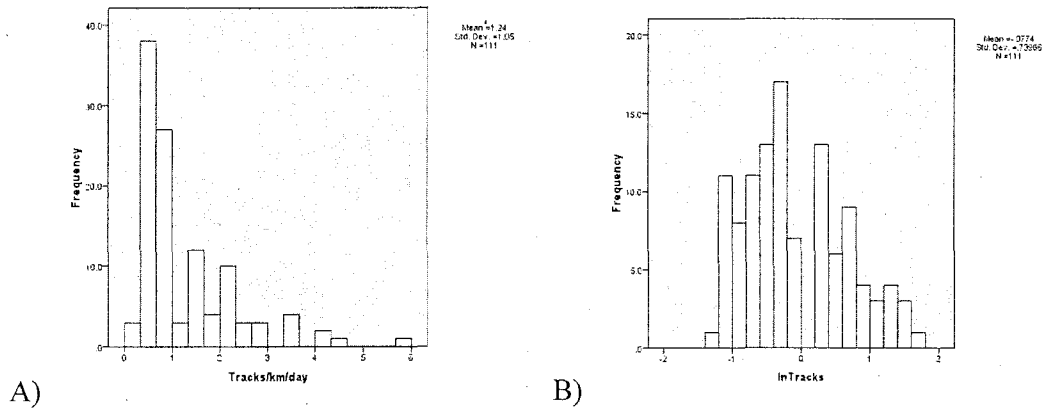
B)

Fisher

Wilks-Shapiro test for normality

| Species | Tracks _{km/Day} | InTracks |
|---------|--------------------------|----------|
| | Sig. | Sig. |
| Aw | .001 | .027 |
| Sb | .000 | .134 |
| Pl | .022 | .401 |
| Plt | .004 | .198 |

Frequency distributions of track occurrence for fisher (A= Tracks_{km/Day} and B= InTracks)

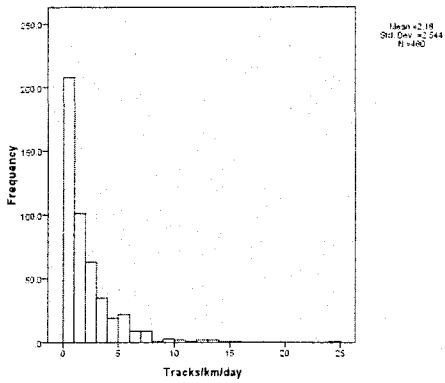


Weasels

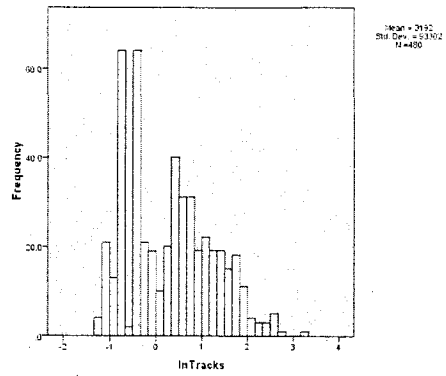
Wilks-Shapiro test for normality

| Species | Tracks _{km/Day} | InTracks |
|---------|--------------------------|----------|
| | Sig. | Sig. |
| Aw | .000 | .014 |
| Sb | .000 | .000 |
| Pl | .000 | .002 |
| Plt | .000 | .009 |

Frequency distributions of track occurrence for weasels (A= Tracks_{km/Day} and B= lnTracks)



A)



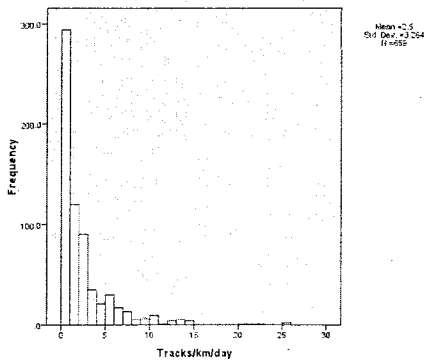
B)

Mice, Voles and Shrews

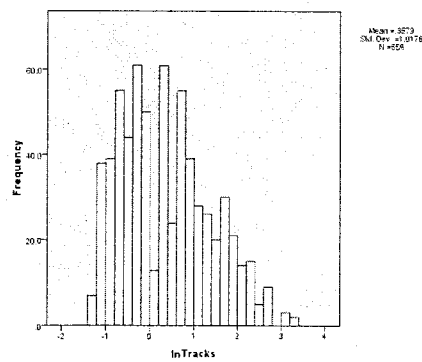
Wilks-Shapiro test for normality

| Species | Tracks _{km/Day} | lnTracks |
|---------|--------------------------|----------|
| | Sig. | Sig. |
| Aw | .000 | .012 |
| Sb | .000 | .000 |
| Pl | .000 | .000 |
| Plt | .000 | .008 |

Frequency distributions of track occurrence for small mice, voles and shrews (A= Tracks_{km/Day} and B= lnTracks)



A)



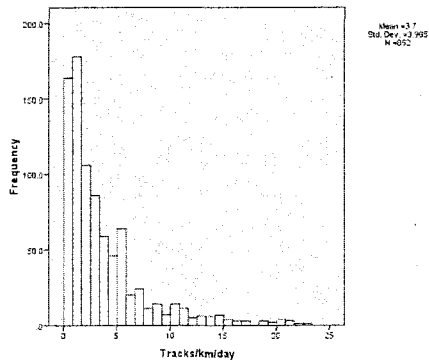
B)

Squirrels

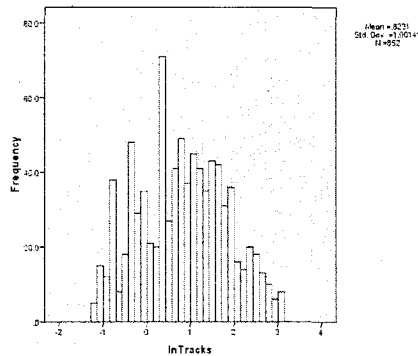
Wilks-Shapiro test for normality

| Species | Tracks _{km/Day} | InTracks |
|---------|--------------------------|----------|
| | Sig. | Sig. |
| Aw | .000 | .045 |
| Sb | .000 | .000 |
| Pl | .000 | .005 |
| Plt | .000 | .011 |

Frequency distributions of track occurrence for squirrels (A= Tracks_{km/Day} and B= InTracks)



A)



B)

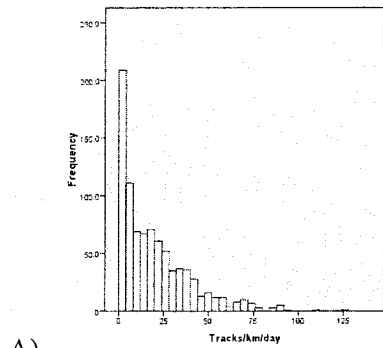
Snowshoe Hare

Wilks-Shapiro test for normality

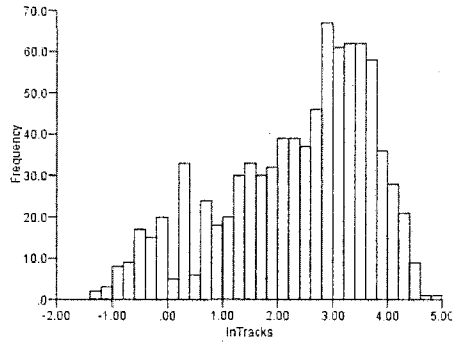
| Species | Tracks _{km/Day} | InTracks |
|---------|--------------------------|----------|
| | Sig. | Sig. |
| Aw | .000 | .045 |
| Sb | .000 | .000 |
| Pl | .000 | .005 |
| Plt | .000 | .011 |

Frequency distributions of track occurrence for snowshoe hare (A= Tracks_{km/Day} and B=

InTracks)



A)



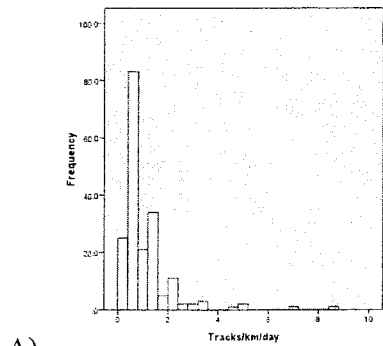
B)

Lynx

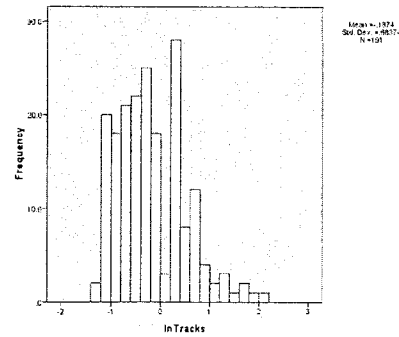
Wilks-Shapiro test for normality

| Species | Tracks _{km/Day} | InTracks |
|---------|--------------------------|----------|
| | Sig. | Sig. |
| Aw | .000 | .022 |
| Sb | .000 | .720 |
| Pl | .000 | .000 |
| Plt | .000 | .083 |

Frequency distributions of track occurrence for lynx (A= Tracks_{km/Day} and B= lnTracks)



A)



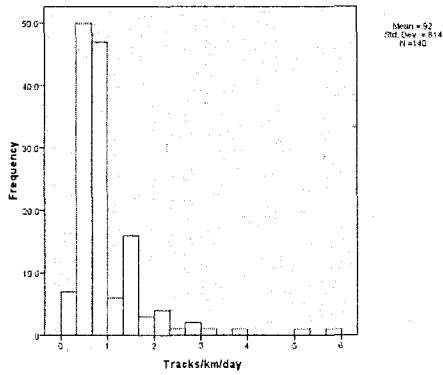
B)

Coyote

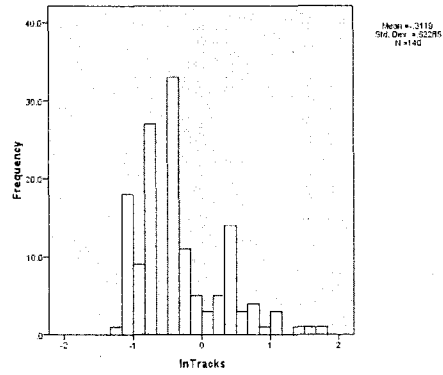
Wilks-Shapiro test for normality

| Species | Tracks _{km/Day} | InTracks |
|---------|--------------------------|----------|
| | Sig. | Sig. |
| Aw | .000 | .124 |
| Sb | .000 | .001 |
| Pl | .000 | .009 |
| Plt | .011 | .306 |

Frequency distributions of track occurrence for coyote (A= Tracks_{km/Day} and B= InTracks)

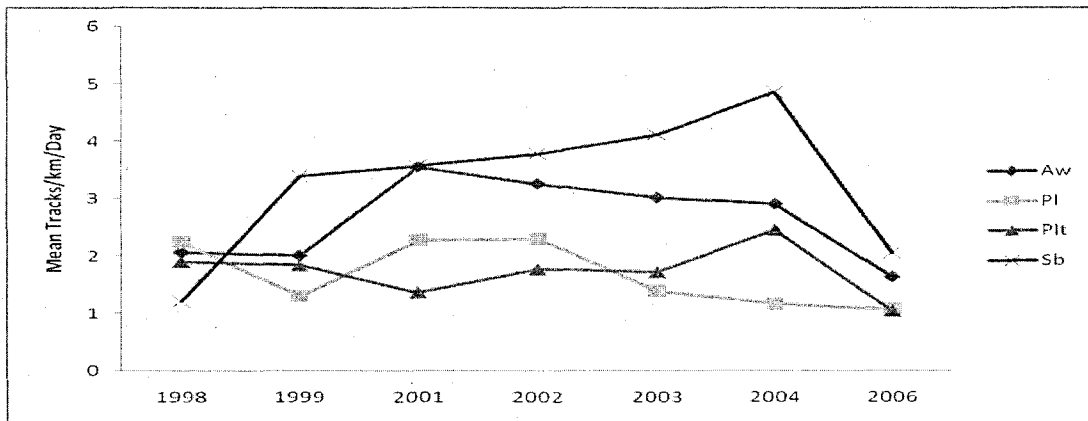


A)

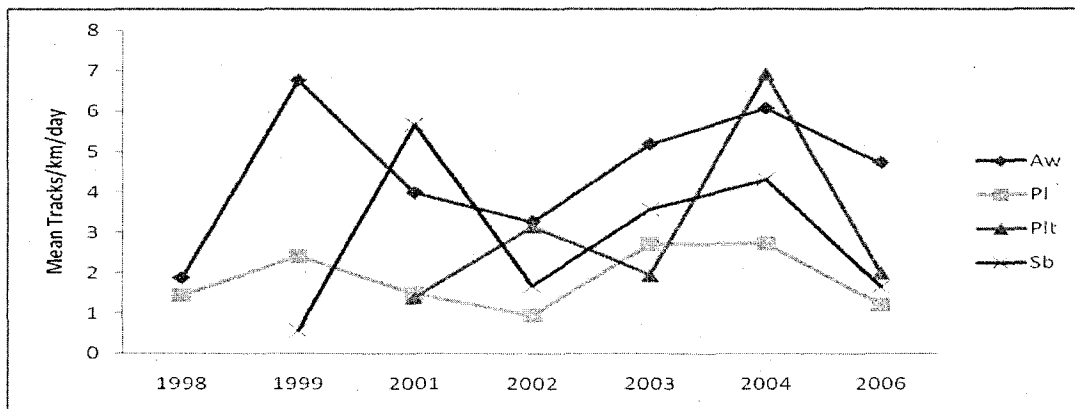


B)

Moose track occurrence varied among years for each stand type, with no changes associated with thinning in the treatment stands (1). Track occurrence was lower in all forest types during the final survey year. Among stands, track occurrence appeared highest in black spruce and lowest in both pine-dominated forest types. White-tailed deer track occurrence varied considerably among years within each stand, though in the final year, deer appeared to be more common in aspen than other forest types (2)

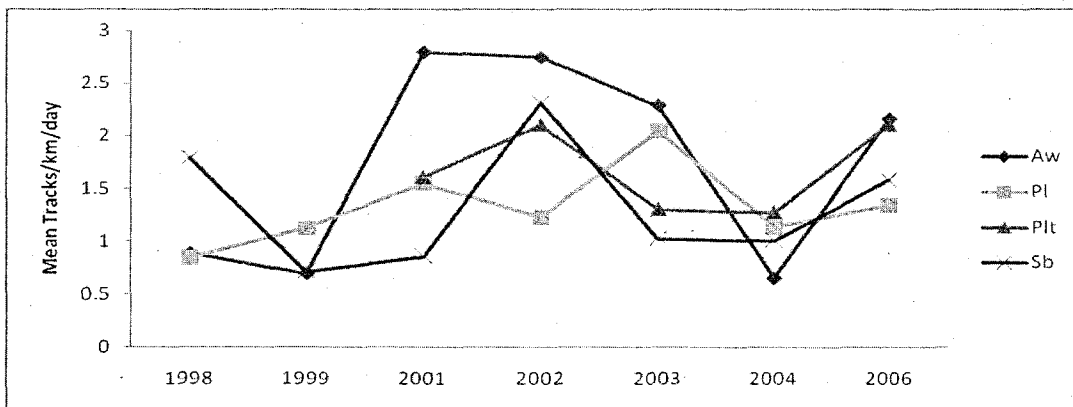


1. Moose track occurrence time series. 1998–99 represent the pre-thinned surveys and 2001–06 represent the post-thinned surveys for the thinned lodgepole pine stands. Forest types are represented as follows: Aw = Aspen, PI = Unthinned pine, Plt = Thinned pine and Sb = Black Spruce.

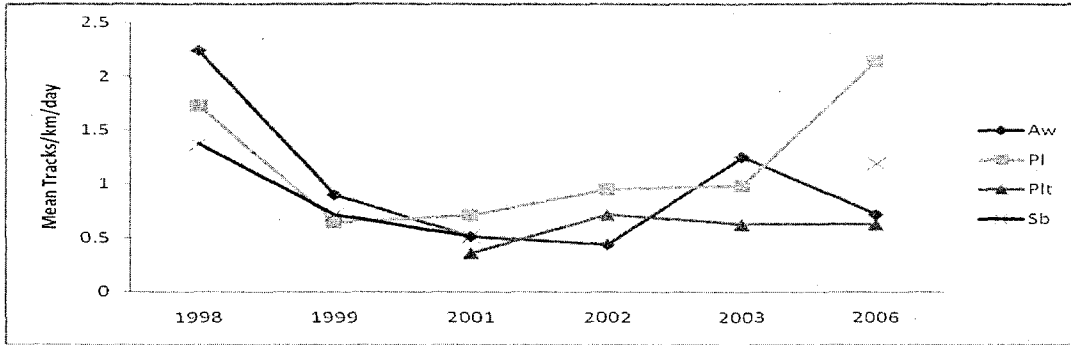


2. White-tailed deer track occurrence time series; 1998–99 represent the pre-thinned surveys and 2001–06 represent the post-thinned surveys. Stand types are represented as follows: Aw = Aspen, PI = Unthinned pine, Plt = Thinned pine and Sb = Black Spruce.

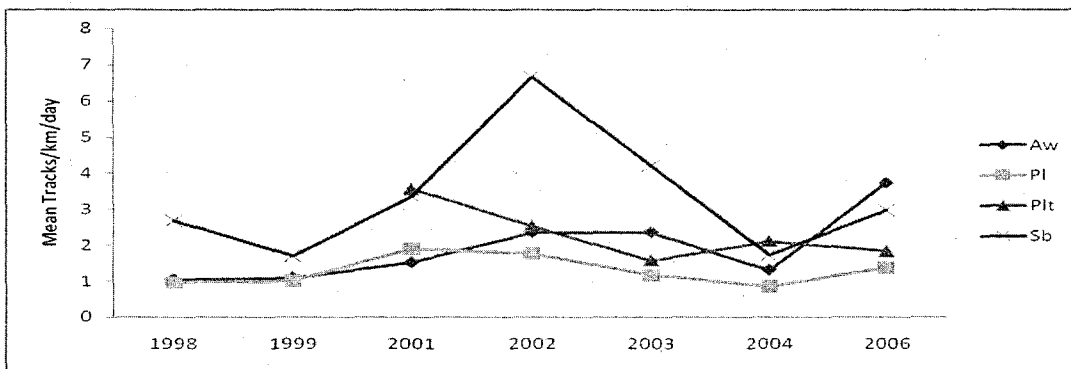
Marten track occurrences were variable between the stand types, as well as from year to year (3). In aspen stands, the mean track occurrence appeared to increase after thinning and was higher than the other forest types in all but one of the post-thinned survey years. Fisher track occurrence was high during the first year of the survey and showed a general decreasing trend until 2004, when no fisher tracks were observed in any forest type (4). No fisher tracks were observed in 2001 or 2003 in black spruce stands as well. Track occurrences were high in control pine stands in 2006 and were consistently higher than in thinned lodgepole stands. The mean weasel track occurrence in black spruce stands was quite variable from year to year. A distinct peak in 2002 and lower values at the beginning and end of the survey make it difficult to determine if there is an increasing or declining trend (5). Weasel track occurrence appears to have increased slightly in aspen stands, while thinned lodgepole pine stands appear to have declined. Track occurrence in the control stands varied slightly from year to year but annual means do not illustrate a clear increase or decline after the thinning harvest.



3. Marten track occurrence time series; 1998–99 represent the pre-thinned surveys and 2001–06 represent the post-thinned surveys. Stand types are represented as follows: Aw = Aspen, Pl = Unthinned pine, Plt = Thinned pine and Sb = Black Spruce.

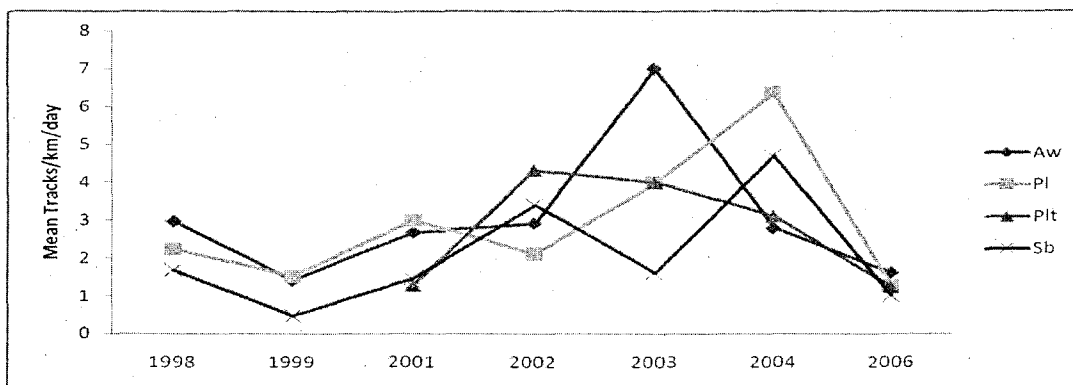


4. Fisher track occurrence time series; 1998–99 represent the pre-harvest surveys and 2001–06 represent the post-harvest surveys. Stand types are represented as follows: Aw = Aspen, Pl = Unthinned pine, Plt = Thinned pine and Sb = Black Spruce.

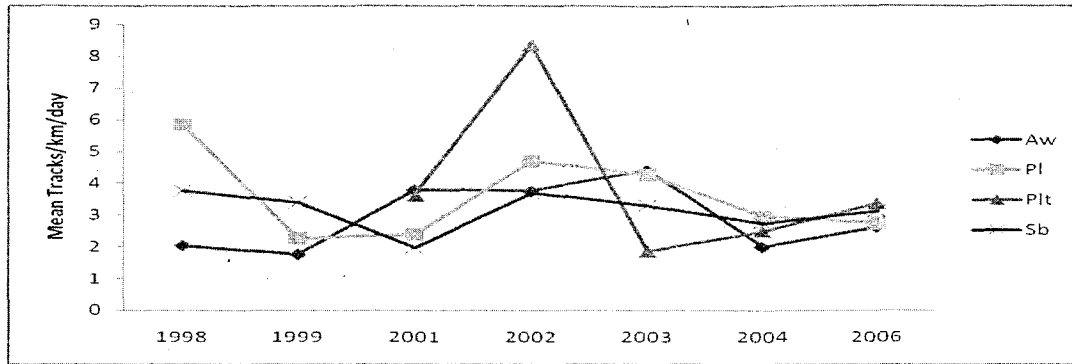


5. Weasel track occurrence time series; 1998–99 represent the pre-harvest surveys and 2001–06 represent the post-harvest surveys. Stand types are represented as follows: Aw = Aspen, Pl = Unthinned pine, Plt = Thinned pine and Sb = Black Spruce.

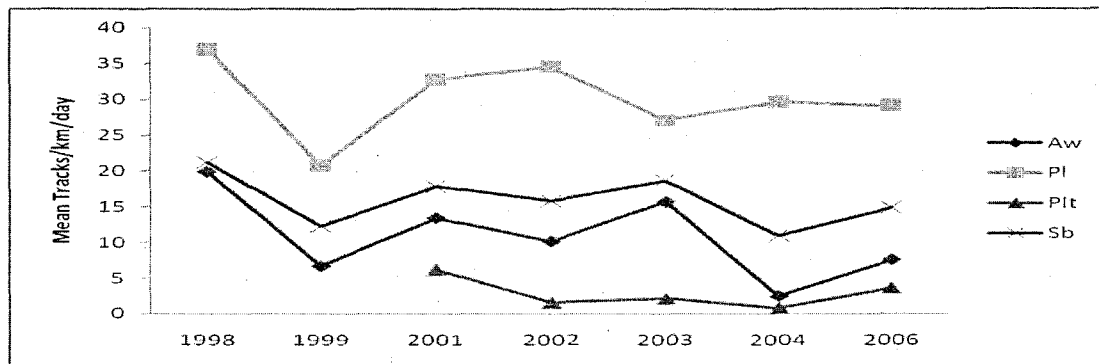
There was considerable variation from year to year in some forest types, it appears that there was an increasing trend in the occurrence of mice, vole and shrew tracks in all four forest types after the commercial thinning harvest (6). It is unclear whether squirrel track occurrence is showed an increasing or decreasing trend or if there was a change associated with thinning (7). The unthinned pine stands seem to have had a decline in track occurrences during the pre-harvest survey years, but the mean track occurrence did increase slightly after the commercial thinning took place. The annual mean snowshoe hare track occurrence was clearly very different in each of the four forest types (8). Both aspen and black spruce stands have comparatively moderate values and did not appear to decrease or increase after the thinning. The control stands had much higher mean track occurrence than any other stand type. Conversely the thinned pine stands had very low mean track occurrence compared to the other stand types. The time series clearly illustrates that the thinning harvest created a change in the habitat that ultimately led to lower relative abundance of snowshoe hare.



6. Combined mice, vole and shrew track occurrence time series; 1998–99 represent the pre-harvest surveys and 2001–06 represent the post-harvest surveys. Stand types are represented as follows: Aw = Aspen, Pl = Unthinned pine, Plt = Thinned pine and Sb = Black Spruce.



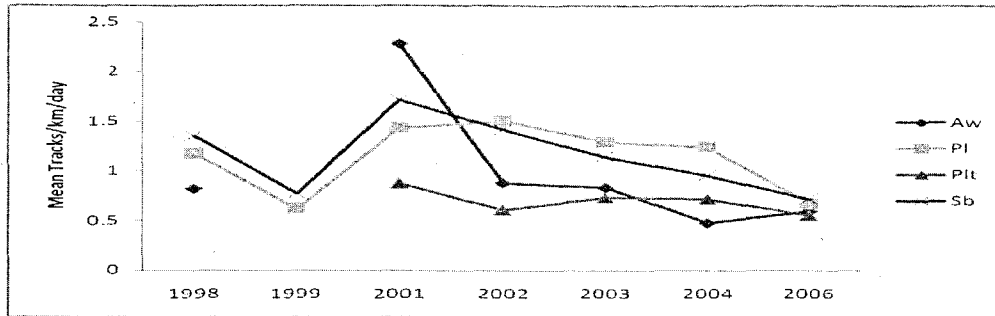
7. Squirrel track occurrence time series; 1998–99 represent the pre-harvest surveys and 2001–06 represent the post-harvest surveys. Stand types are represented as follows: Aw = Aspen, Pl = Unthinned pine, Plt = Thinned pine and Sb = Black Spruce.



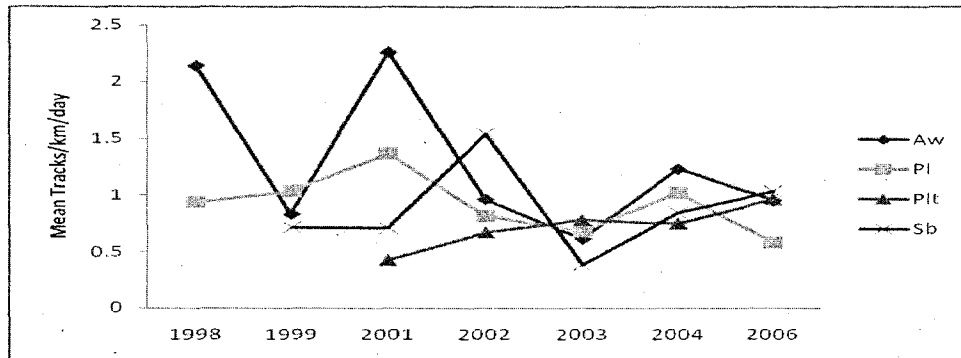
8. Snowshoe Hare track occurrence time series; 1998–99 represent the pre-harvest surveys and 2001–06 represent the post-harvest surveys. Stand types are represented as follows: Aw = Aspen, Pl = Unthinned pine, Plt = Thinned pine and Sb = Black Spruce

Lynx track occurrence was very similar in both black spruce and control lodgepole pine stands, both illustrate a declining trend after 2001 when thinning harvests began (9). Track occurrence was lower in thinned pine stands but appears to have neither increased nor decreased since 2001. The aspen stands show a declining trend. Coyote tracks in the aspen and black spruce stands showed considerable annual variation in mean track occurrence making it difficult to identify a clear increase or decline (10). Track occurrence in the unthinned pine stands had less annual variation but do not appear to be increasing or decreasing. Also coyote tracks appear to have been somewhat more

common in unthinned pine stands than in the commercially thinned stands.



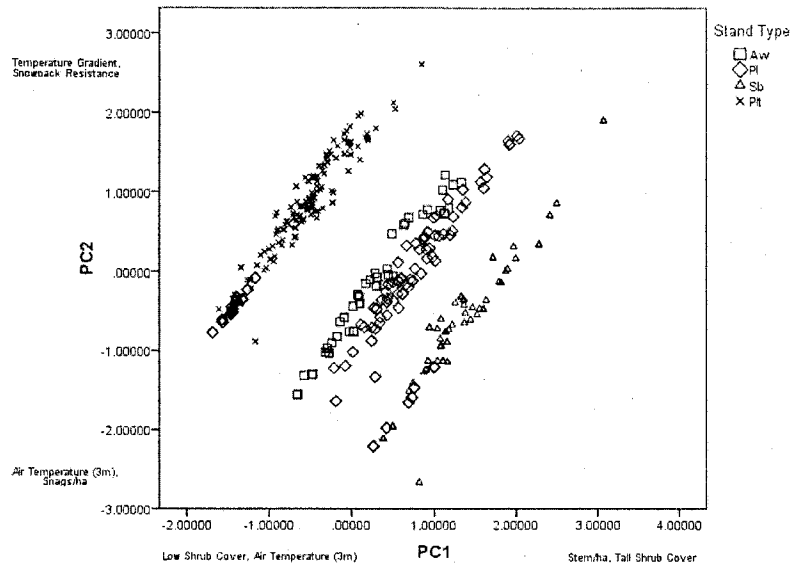
9. Lynx track occurrence time series; 1998–99 represent the pre-harvest surveys and 2001–06 represent the post-harvest surveys. Stand types are represented as follows: Aw = Aspen, Pl = Unthinned pine, Plt = Thinned pine and Sb = Black Spruce.



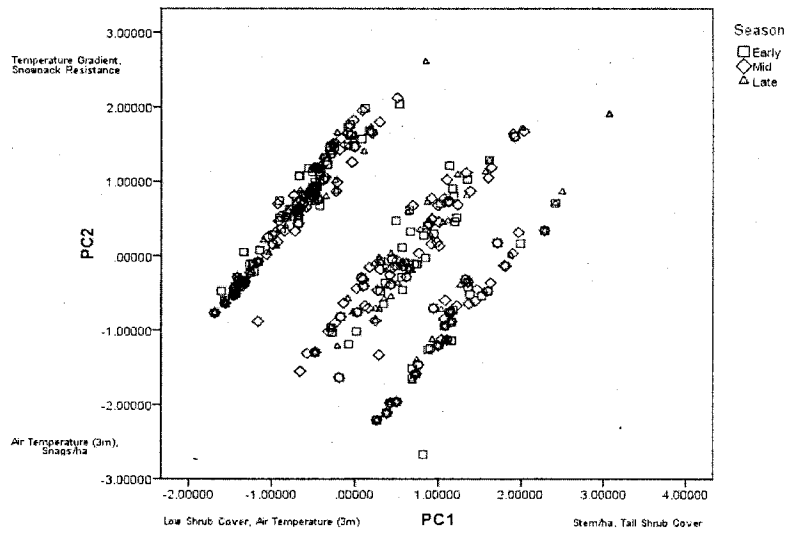
10. Coyote track occurrence time series; 1998–99 represent the pre-harvest surveys and 2001–06 represent the post-harvest surveys. Stand types are represented as follows: Aw = Aspen, Pl = Unthinned pine, Plt = Thinned pine and Sb = Black Spruce.

PCA SCATTER PLOTS

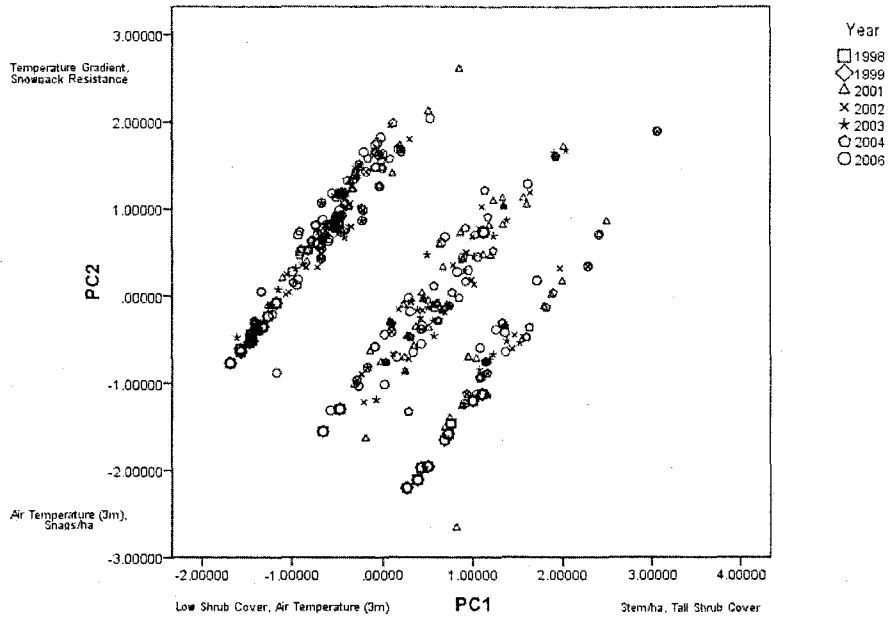
Moose



A)



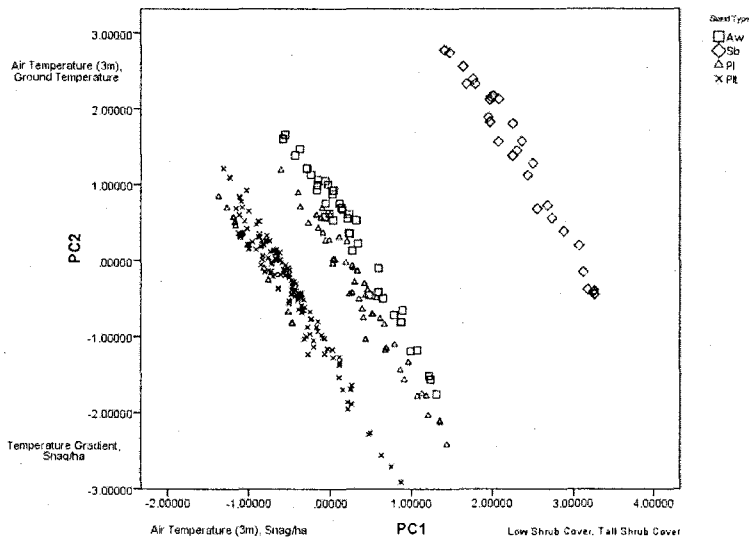
B)



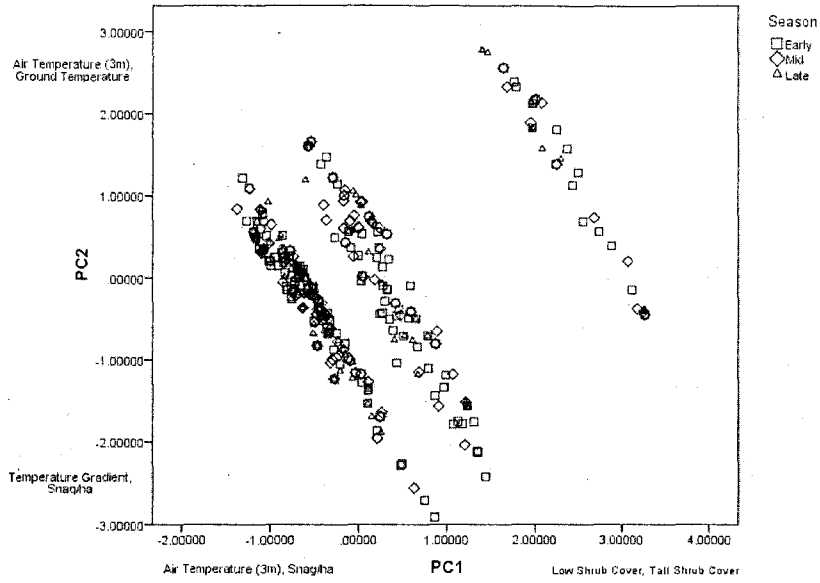
C)

Principal components scatter plots for moose based on factor loadings (A= Stand type, B= Season, C= Year).

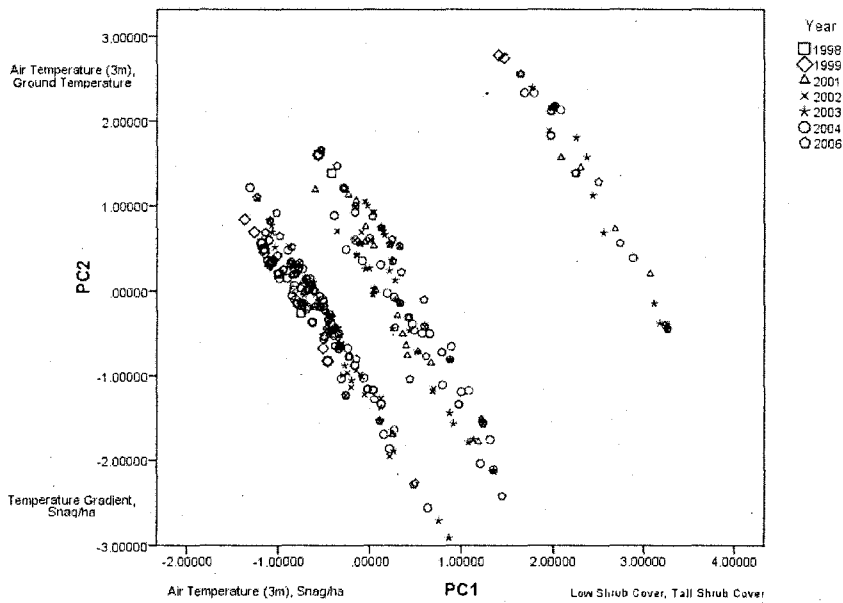
White-tailed Deer



A)



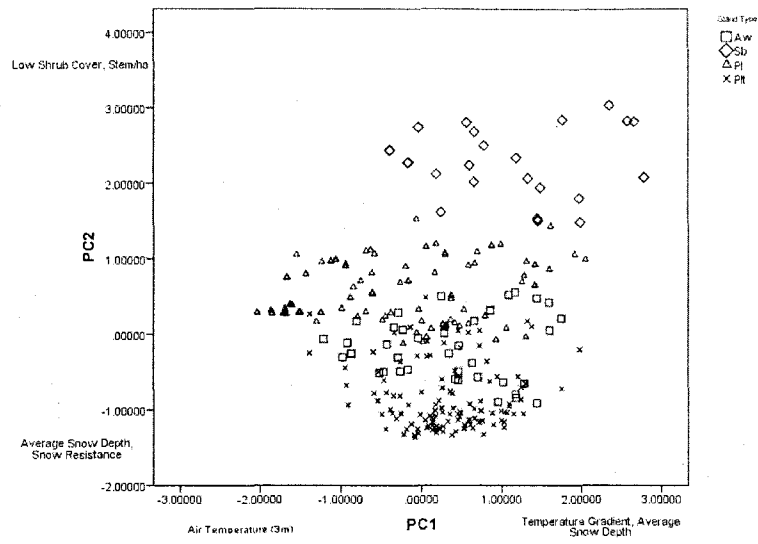
B)



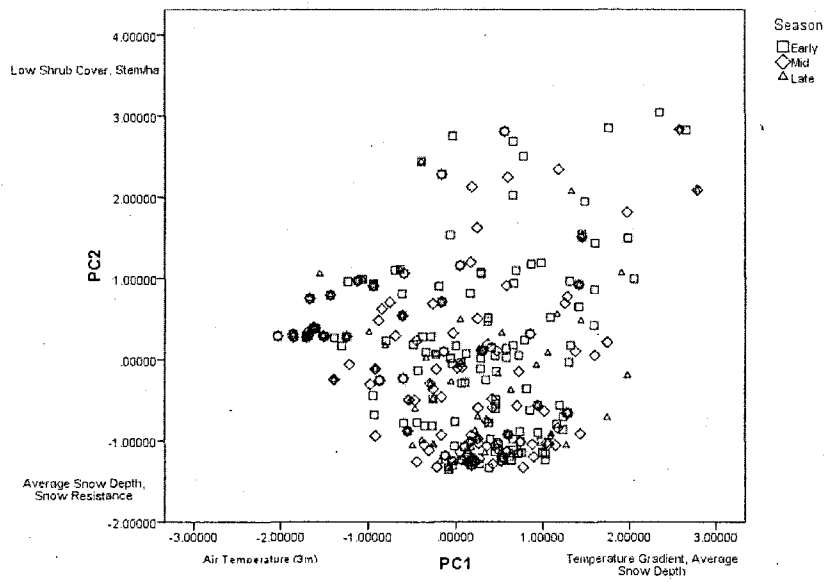
C)

Principal components scatter plots for White-tailed deer based on factor loadings (A= Stand type, B= Season, C= Year).

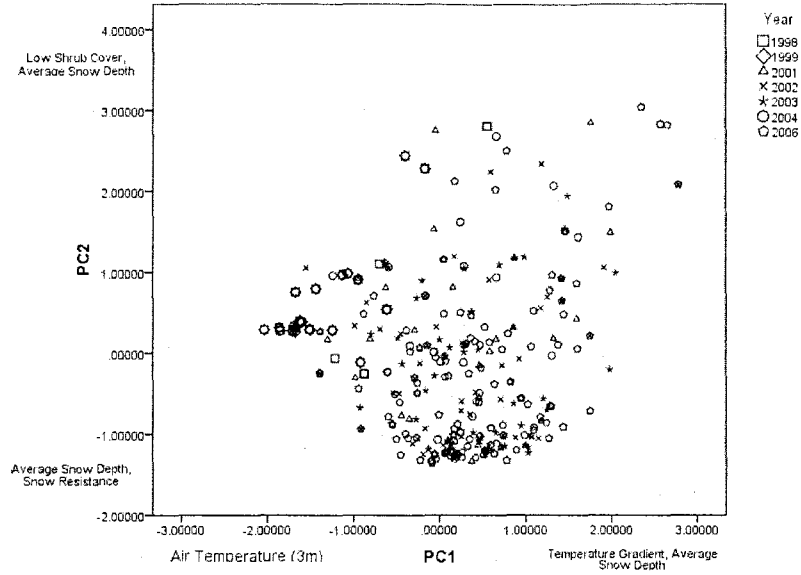
Marten



A)



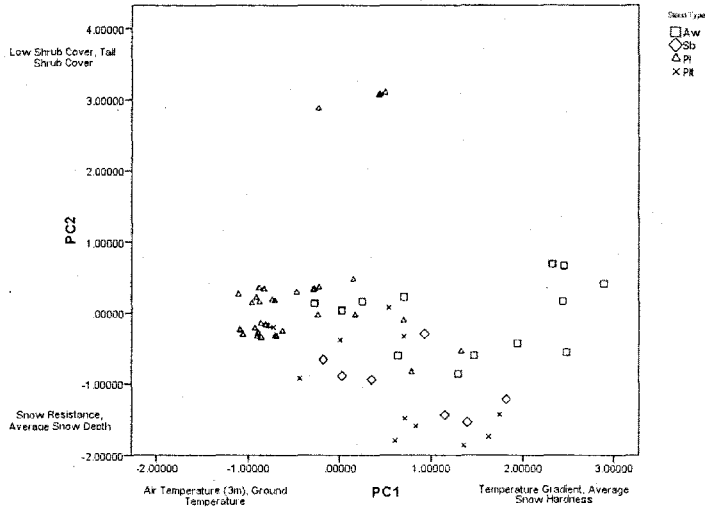
B)



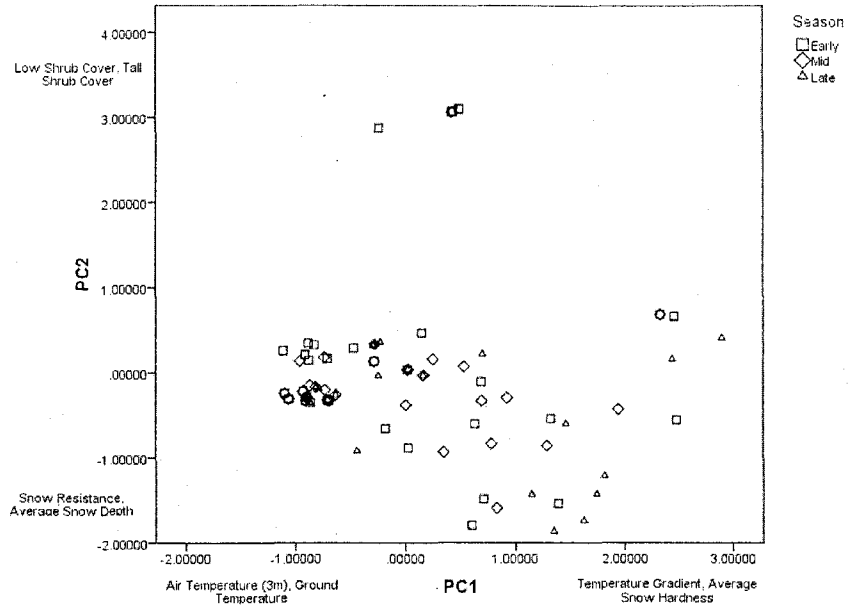
C)

Principal components scatter plots for marten based on factor loadings (A= Stand type, B= Season, C= Year).

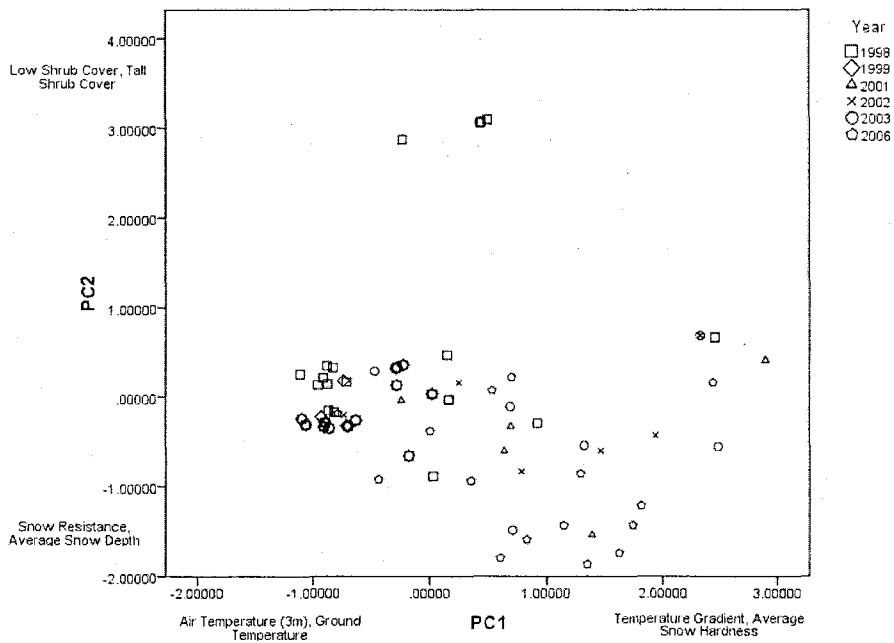
Fisher



A)



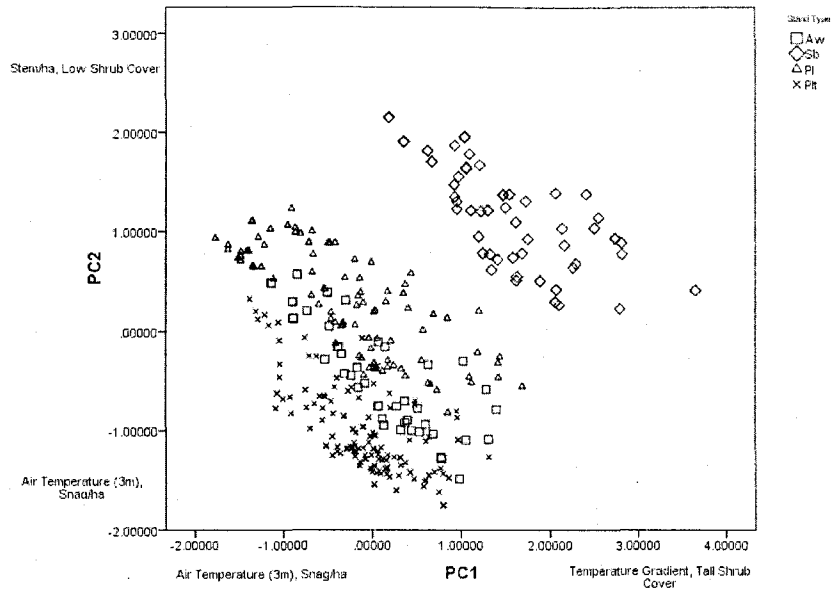
B)



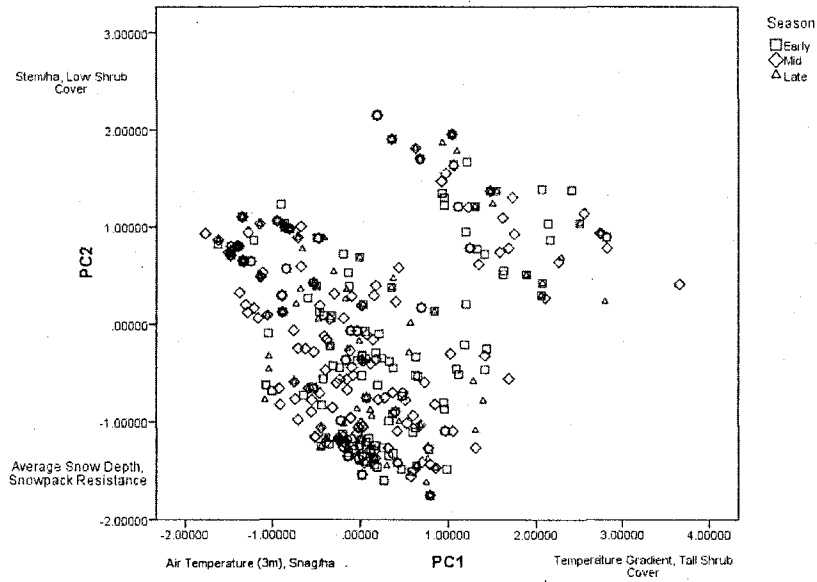
C)

Principal components scatter plots for fisher based on factor loadings (A= Stand type, B= Season, C= Year).

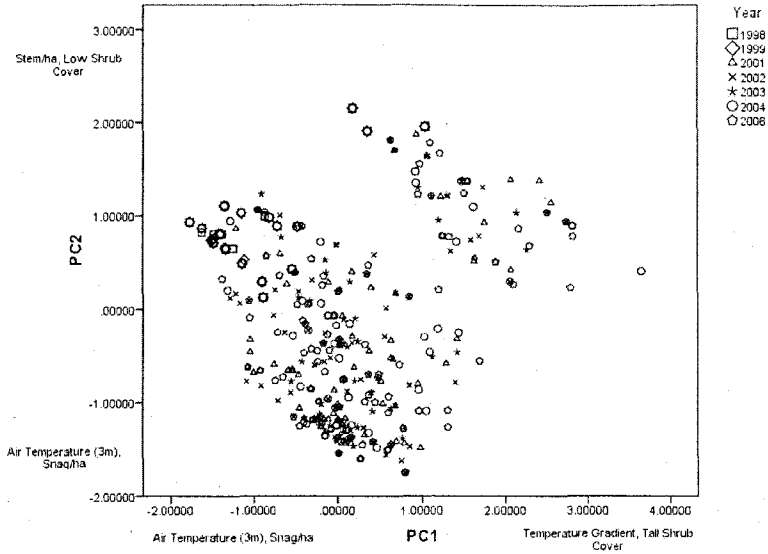
Weasels



A)



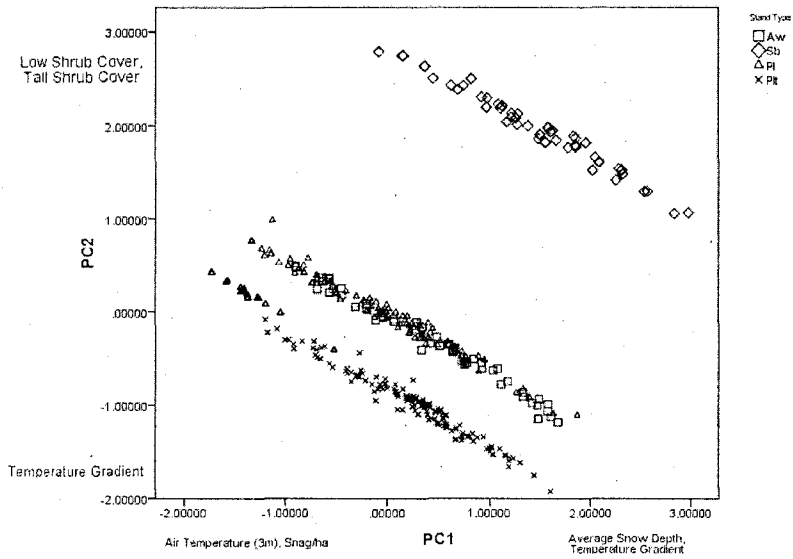
B)



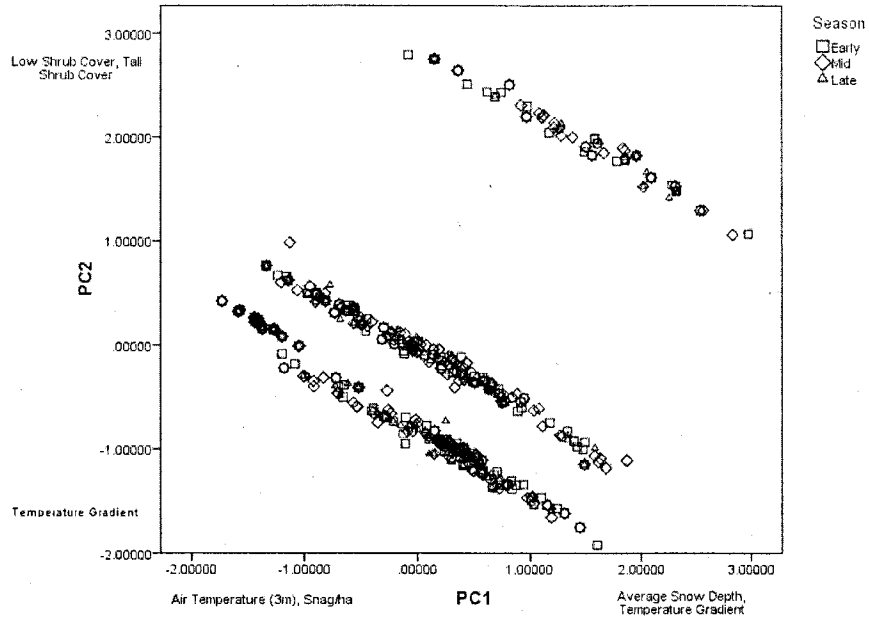
C)

Principal components scatter plots for weasels based on factor loadings (A= Stand type, B= Season, C= Year).

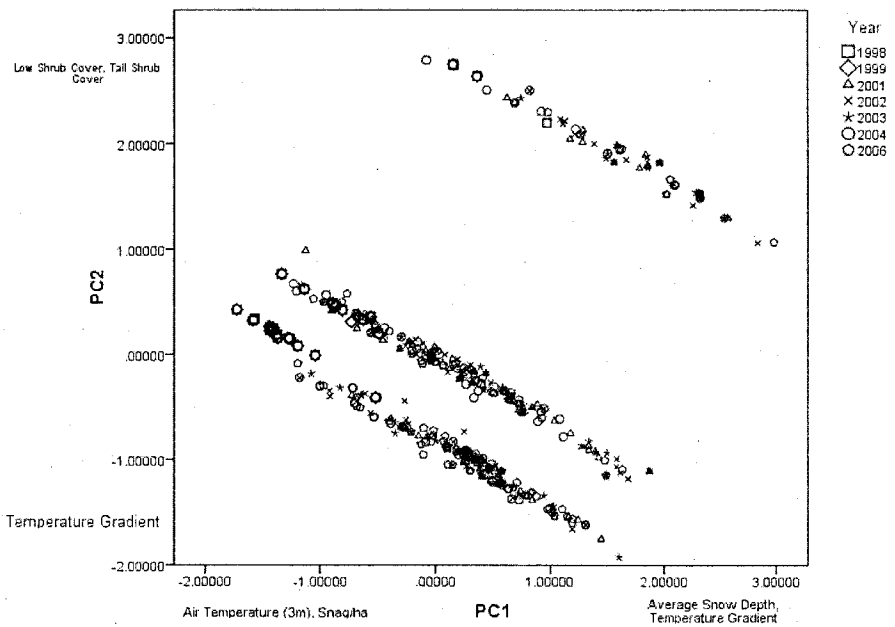
Mice, Voles and Shrews



A)



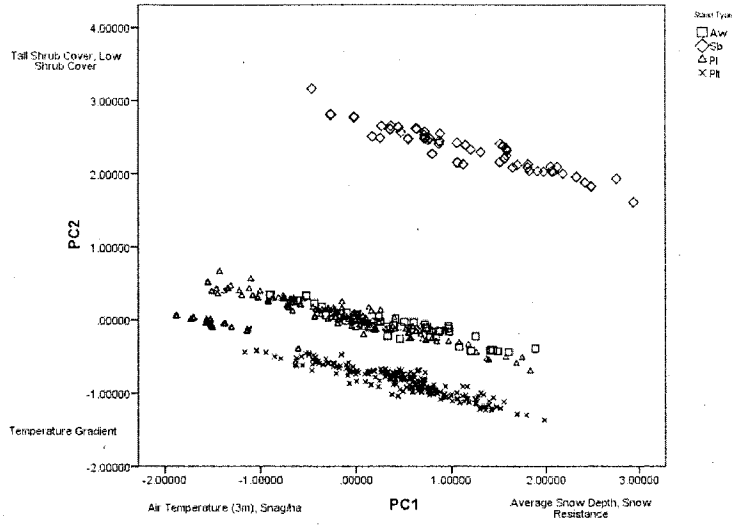
B)



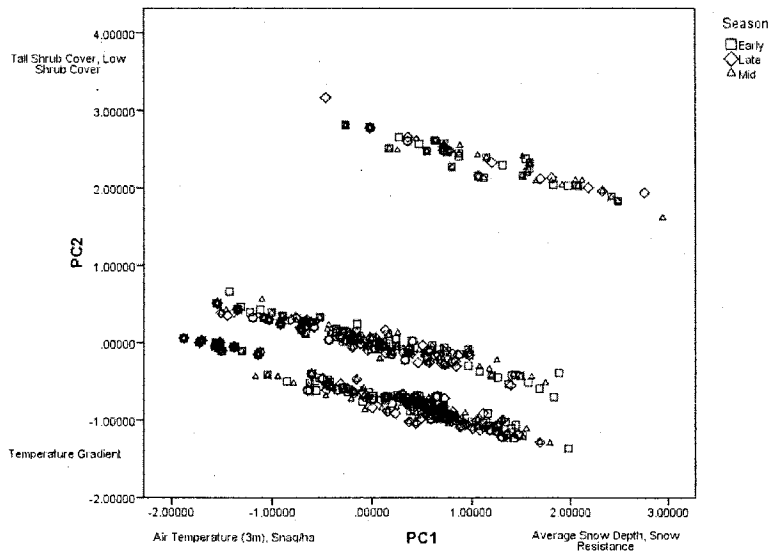
C)

Principal components scatter plots for mice, voles and shrews based on factor loadings (A= Stand type, B= Season, C=Year).

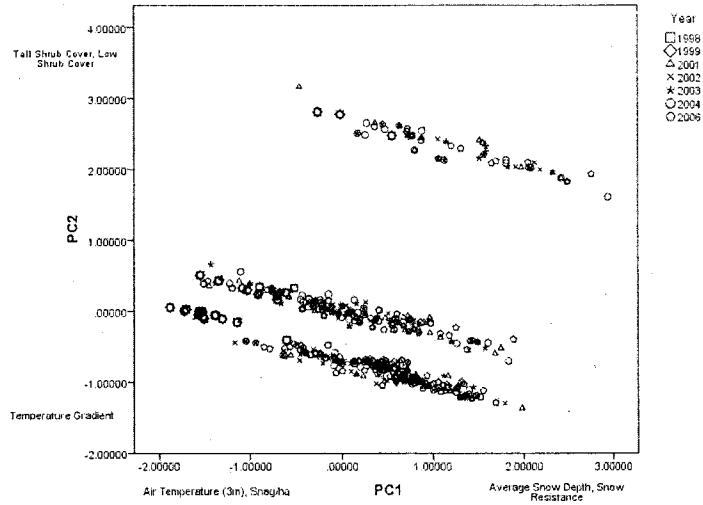
Squirrels



A)



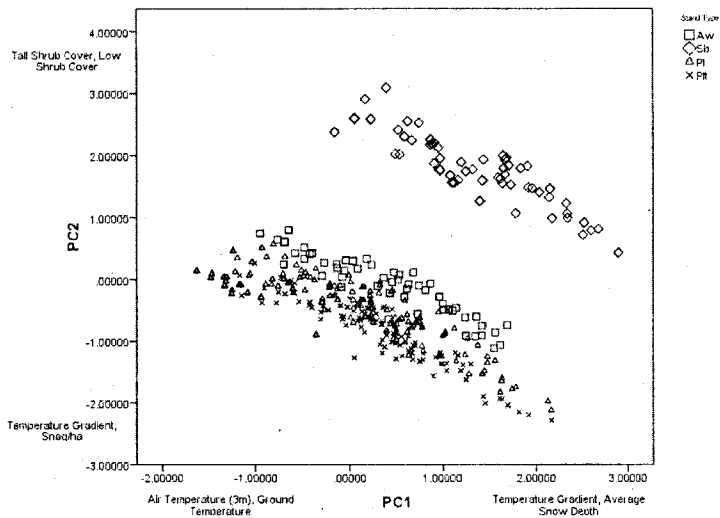
B)



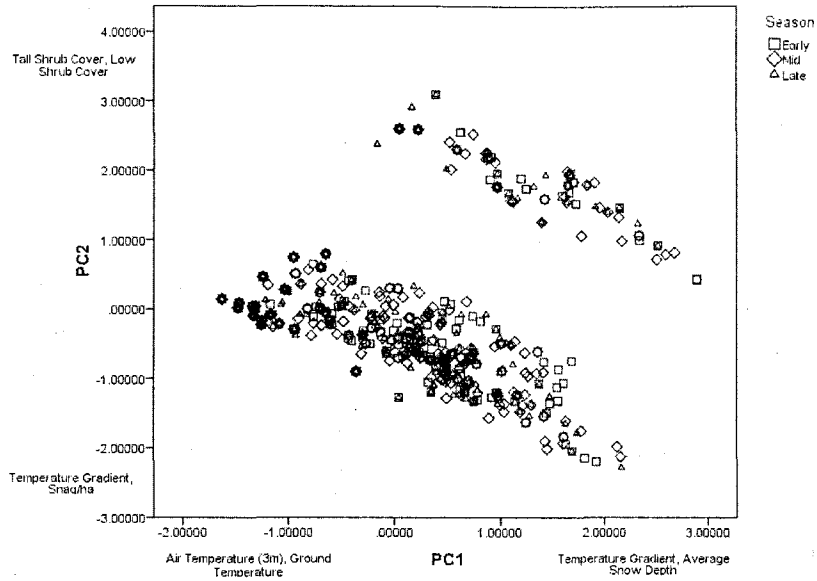
C)

Principal components scatter plots for squirrels based on factor loadings (A= Stand type, B= Season, C= Year).

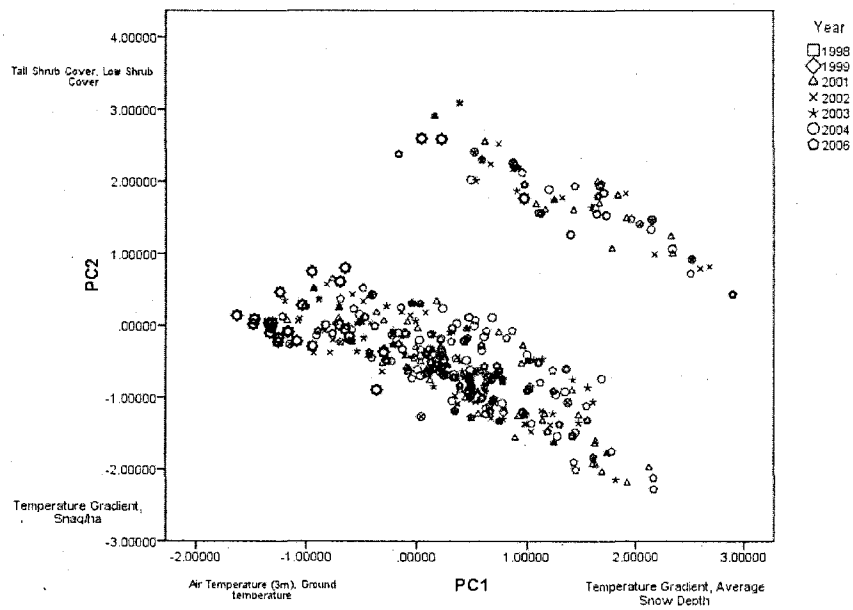
Snowshoe Hare



A)



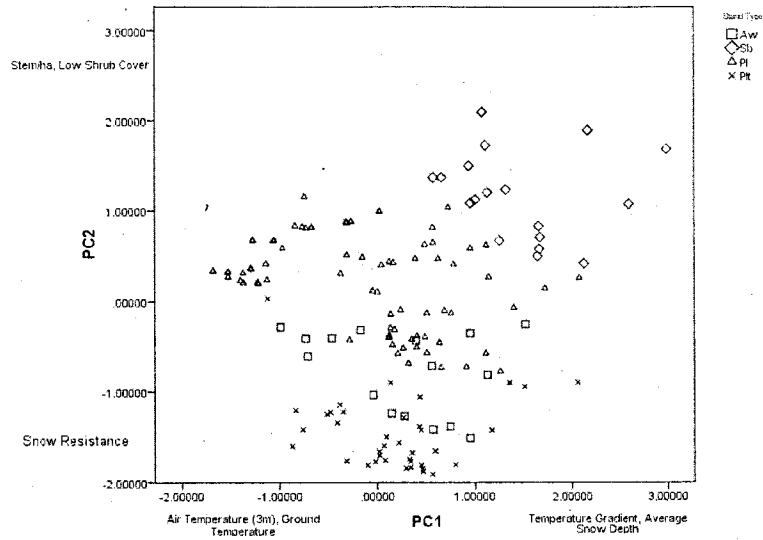
B)



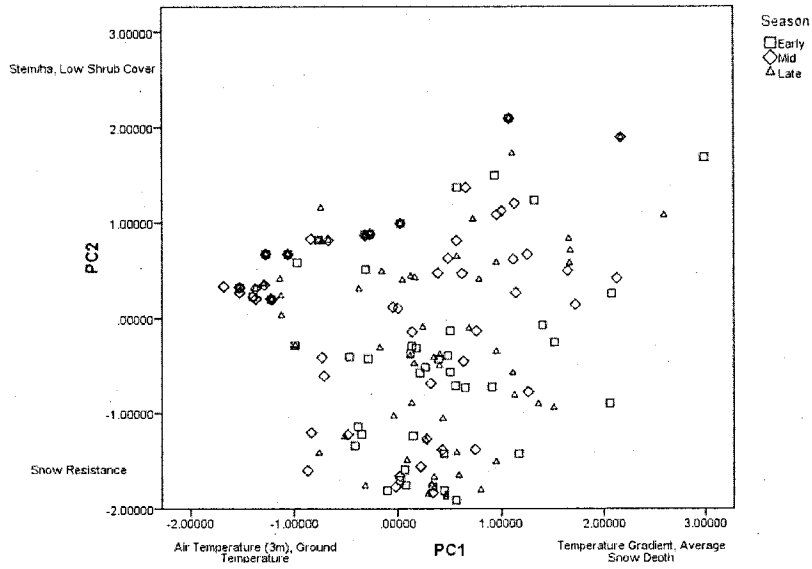
C)

Principal components scatter plots for snowshoe hare based on factor loadings (A= Stand type, B= Season, C=Year).

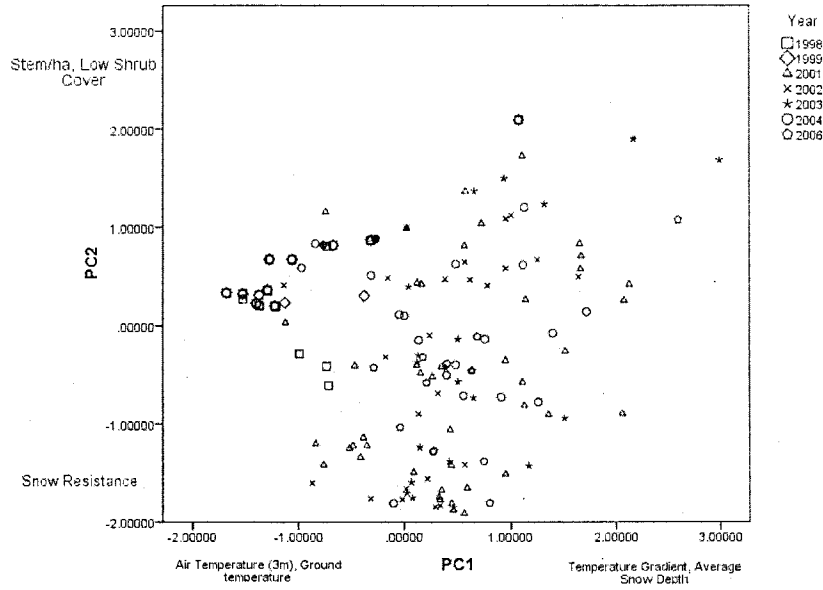
Lynx



A)



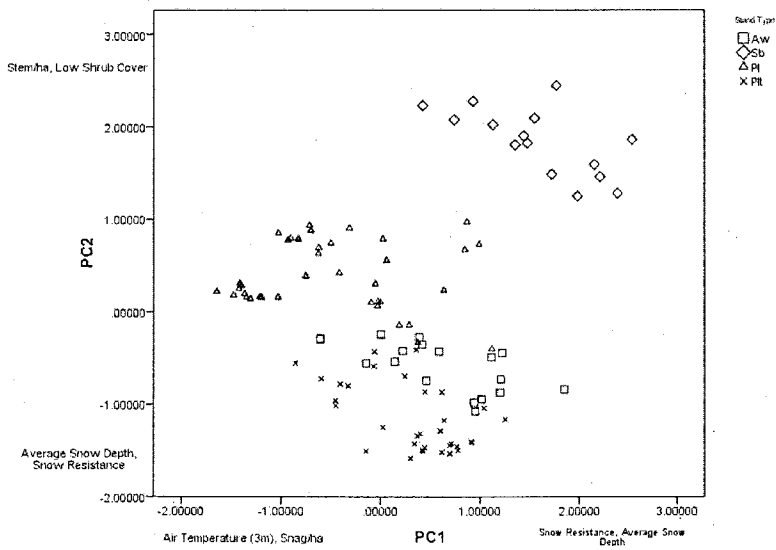
B)



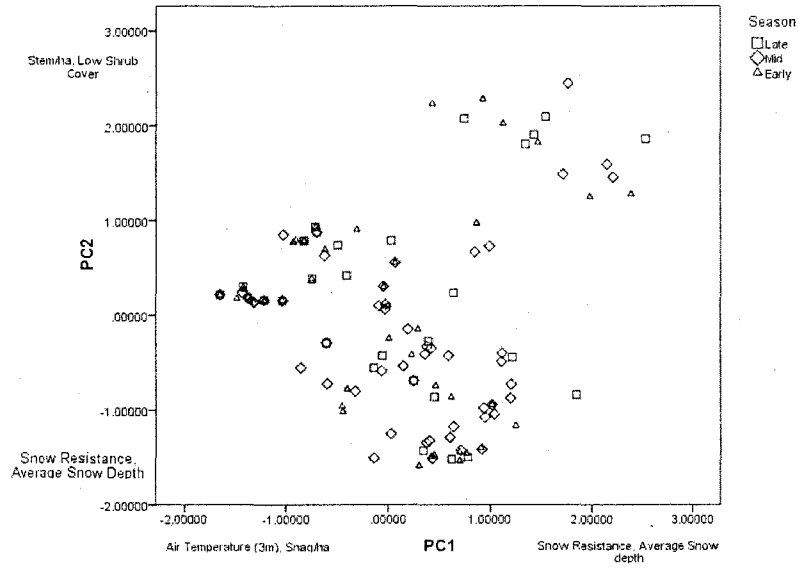
C)

Principal components scatter plots for Lynx based on factor loadings (A= Stand type, B= Season, C=Year).

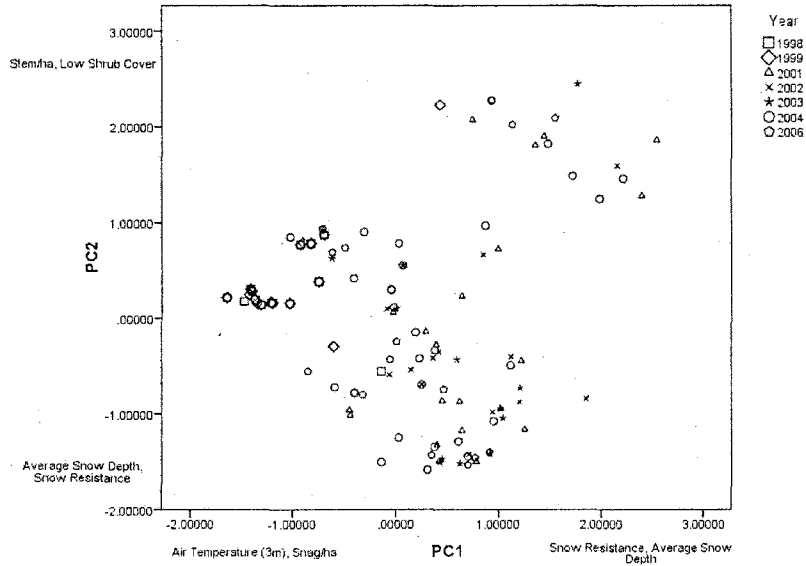
Coyote



A)



B)



C)

Principal components scatter plots for coyote based on factor loadings (A= Stand type, B= Season, C= Year).