

**HABITAT SELECTION AND OCCUPANCY PATTERNS OF AMERICAN MINK
(*NEOVISON VISON*) DURING WINTER IN NORTH-CENTRAL BRITISH
COLUMBIA, CANADA**

by

Dexter P. Hodder

BSc., Memorial University of Newfoundland, 1998

**A THESIS SUBMITTED IN PARTIAL
FULFILLMENT OF THE REQUIREMENTS FOR
THE DEGREE OF**

Master of Science

in

Environmental Science

Thompson Rivers University
Kamloops, British Columbia, Canada

April 2016

Thesis examining committee:

Karl Larsen (PhD),
Department of Natural Resource Sciences

Louis Gosselin (PhD),
Department of Biological Sciences

Lyn Baldwin (PhD),
Department of Biological Sciences

Eric Lofroth (MSc), Manager, BC Conservation Data Centre
External Examine

ACKNOWLEDGEMENTS

I would like to thank the Habitat Conservation Trust Foundation and the John Prince Research Forest for funding this project. I would like to recognize and thank Tl'azt'en Nation for the use of their traditional territory for this research. I specifically thank the Tom family (Stanley, Alexander, Peter and Jonathan) for their support and willingness to cease trapping activities during the time of this research so as to not impact results. Eric Stier at Guardian Aerospace provided his skill and patience during telemetry flights. Dr. Malcolm McAdie provided excellent veterinary care for captured mink and Johnny Tom provided valuable field assistance. I would like to thank my supervisor, Dr. Karl Larsen, for agreeing to work with me on this project and for his endless patience. A special thanks to committee members Dr. Louis Gosselin, Dr. Lyn Baldwin and Eric Lofroth (external) for their time and valuable feedback. I thank Chris Johnson for his advice on all things statistical and Roy Rea, Beverly John, and Steve Symes for their support. A very special thanks to my colleagues Sue Grainger and Shannon Crowley at the JPRF: Sue for her constant support and absorbing administrative burdens and Shannon for his field assistance, endless support with GIS and data analysis, and countless discussions. I especially thank my wife Cheryl for her patience, selfless support, and tolerance of my distractedness.

All handling protocols for mink during the study were approved by the Thompson Rivers University Animal Care and Use Committee (#AUP 2010-01) and permitted by the British Columbia Ministry of Environment (#PG10-62346).

Thesis Supervisor: Professor Karl Larsen

ABSTRACT

The spatial distributions of animals generally are affected by the availability of food, competition, predators, mates, and the need to communicate with conspecifics. Behavioural, physiological and morphological adaptations to these selecting agents have allowed members of the Order Carnivora (C. Mammalia) to occupy a wide range of environments, but at the same time, each combination of characteristics places constraints on the habitat a particular species is able to occupy. For example, many members of the Family Mustelidae are vulnerable to extreme temperatures as a result of their tubular body shape. The American mink (*Neovison vison*) likely faces these temperature constraints, being a smaller-bodied mustelid that ranges over a large portion of North America. Despite its large range, and its historical importance to the fur industry, the species has remained largely understudied in its native habitat. During 2011-2012, I conducted winter telemetry on 7 adult mink and used resource selection function models to assess habitat selection patterns while considering spatial scale and gender. I found that at a larger scale, the animals' use of habitat was strongly linked to riparian features, whereas this effect was less noticeable at a fine scale. The larger males selected more lakeshore habitat, whereas the smaller females generally were near streams in more forested areas. I suggest this spatial separation could be linked to an inability of females to forage aquatically in winter as a result of their smaller body size. This may make females more sensitive to competition from other forest carnivores as well as impacts from resource development activities. During winter 2013, I surveyed for mink using remote cameras (n=37) deployed in riparian habitat, including lakeshore/stream confluences. I found that fish-bearing streams positively affected mink occupancy, while the amount of older (>40yrs) coniferous forests had a negative relationship with mink occupancy. I postulate that while mink seem to occur at high densities in altered ecosystems and in areas where they are invasive, in their native range these animals are limited by environmental constraints (low winter temperatures) and competitive pressures in the system. Future work on mink and other carnivores should explore interspecific interactions in addition to habitat selection in order to develop more robust monitoring and management practices.

Key Words: American mink, body size, gender, habitat selection, native range, *Neovison vison*, occupancy, spatial scale, winter.

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CHAPTER 1

GENERAL INTRODUCTION

The spatial distribution of animals on any landscape is driven by adaptation through natural selection. These adaptations facilitate the individual's ability to forage, communicate with conspecifics, deal with competition, and avoid predators (Boyce 1988; Powell 2012). As such, spatial distributions are largely reflections of the life-history of a species and how conspecifics are able to occupy the landscape at multiple spatial scales.

Numerous ecological studies have examined space use and how spatial scale is incorporated into the decision-making process. Johnson (1980) suggested that spatial selection is a hierarchical process whereby animals make decisions as ordered selections at different scales. Through this process animals may select broad ecosystem types such as aquatic or forested areas (1st order); in turn, within this area an individual may select a home range which defines the extent of its movements (2nd order), and then within this home range an individual may select particular areas for foraging or travelling (3rd order). Finally, it may select a specific location or feature to den or nest (4th order). While this approach is widely accepted, Wheatley and Johnson (2009) demonstrated that most multi-scale wildlife studies struggle to incorporate scale in a biologically meaningful way. Generally, scale can be defined by resolution and extent (Turner et al. 2001; Wheatley and Johnson 2009), where resolution refers to the smallest unit measured and extent the size of area over which observations are measured (Boyce et al. 2003).

The manner in which competition can affect spatial distribution (Stewart et al. 2003; Darnell et al. 2014; Bianchi et al. 2014) and general body size (Ferguson and Larivière 2008) has been well studied in mammals. Competition may occur between and within species (Doebeli 2011), and in general, there is a pattern of larger body size and greater sexual dimorphism at higher latitudes (Ferguson and Larivière 2008). Intraspecific competition also can result in divergent characteristics within populations (Bolnick et al. 2003). For example, it has been suggested that when sexes compete for food, sexual dimorphism may evolve allowing males and females to specialize on different foods, thereby reducing competitive pressures (Slatkin 1984; Bolnick and Doebeli 2003; Meiri et al. 2014). This specialization,

along with concomitant adaptations, then may influence the spatial distribution of the two groups of animals across a landscape (Brown and Lasiewski 1972; Dunstone 1998).

Morphological adaptations to different hunting strategies are especially apparent in the Family Mustelidae ('weasels', Order Carnivora). Many members of this taxa have a tubular body shape (i.e. high surface area/volume ratio) and lack insulation from body fat (Dunstone 1998). The long tubular body shape allows access to burrows and confined spaces where prey occur, as well as reducing water resistance while swimming (Larivière 2003; Williams 1983). The large surface area-to-volume ratio, however, makes these species vulnerable to extreme temperatures, a limitation greatly accentuated in water (Williams 1998; Brown and Lasiewski 1972; Segal 1972). Kruuk et al. (1994) suggested that semi-aquatic mammals with a body weight less than 1 kg have limited foraging ability in cold water temperatures. Mustelids may partially compensate for this elevated heat loss by consuming foods (i.e., meat) that support a higher metabolic rate (Dunstone 1993). Still, there are clear consequences for this body design and associated hunting strategies, especially for species that are semi-aquatic. These challenges may be particularly acute in areas where frozen conditions persist for long periods of the year, which are generally challenging for many endothermic mammals (Marchand 1996).

The North American Mink

American Mink (*Neovison vison*; Figure 1.1) are semi-aquatic mustelids that occupy both marine and freshwater systems throughout a wide native range extending throughout much of North America (Figure 1.2), with the exception of northernmost arctic areas and dry deserts of the southwest (Larivière 2003). Throughout this range, the mink evolved with a diverse assortment of other mustelids and meso-predators that it continues to co-exist with. In addition, mink have an extensive distribution outside their native range (Newfoundland, Europe and South America) as a result of releases from fur farms. In some of these non-native habitats the animal has been well studied as a successful invader (e.g., Bonesi et al. 2004; Santulli et al. 2014; Fasola et al. 2009; Medina 1997). Mink exhibit striking sexual dimorphism, with males being considerably larger than females: in North America, reported mean body weights for males and females are 1154 g and 712 g, respectively (Larivière 2003).



Figure 1: Photo of American mink from the John Prince Research Forest (Photo D. Hodder).



Figure 2: Map showing the native range of American Mink (The International Union for the Conservation of Nature).

While mink are semi-aquatic, and normally associated with riparian habitats (Larivière 2003) they are incompletely adapted to aquatic foraging (Dunstone 1993). Across their range, mink consume a variety of fish, mammals, amphibians, birds and crustaceans, but mammals such as muskrat (*Ondatra zibethicus*), mice and voles appear to be the most important diet items during all seasons (Eagle and Whitman 1987). In general, the species' diet reflects whatever is available in the local prey base (Larivière 2003). Darwin (1859) in '*The Origin of Species*' used the mink to defend his evolutionary theory, citing how the animal has evolved in gradual steps from one form (terrestrial) to another (aquatic) while remaining well-adapted to its place in nature at each step. In doing so, mink demonstrate an evolutionary progression from a terrestrial to semi-aquatic life history (Estes 1989; Fish 1993). For example, though the mink is semi-aquatic in behaviour, the feet are virtually unwebbed with a relatively small surface area, thus resembling a high-speed terrestrial runner more than an animal adapted for underwater propulsion (Dunstone 1993). Also, the density of guard hairs exhibited by mink are less than those of the more aquatic river otter (*Lutra lutra*) but more than that of the strictly terrestrial polecat (*Mustela putorius*), again suggesting incomplete adaptation to aquatic life (Dunstone 1979).

Mink have been intensively harvested as a furbearer across its range, by trapping and through fur-farming, both within and outside its native range. Within British Columbia, Canada, mink are categorized as a 'Class 1' furbearer and contribute annually to the province's wild fur revenue, with most pelts coming from the northern half of the province. Class 1 furbearers are not considered particularly sensitive to harvest because seasonal home ranges of viable populations typically can be managed across an individual trapline area (Hatler and Beal 2003).

Despite the historic importance of mink as furbearers and their role as an invading species in numerous locations, there has been surprisingly little scientific investigation of the spatial ecology of mink within its native range. In particular, there is scant information available on the animal in areas where they share habitat with sympatric small to medium-sized carnivores, and/or where extreme winter conditions can influence habitat selection and behaviour. In fact, with the exception of some recent work in highly altered ecosystems (Haan and Halbrook 2014 and 2015; Wolff et al. 2015) little has changed since Larivière (2003) concluded that the ecology of mink in North America is poorly understood and that

few studies have attempted to radio-track these animals. In this thesis, I attempt to address some of the knowledge gaps regarding American Mink ecology, particularly those considering the space use patterns of mink during winter.

Research Objectives

The overarching objectives of this thesis were to explore the following in a mink population:

- The effect of spatial scale when measuring space use by mink.
- The role of sexual dimorphism on habitat selection patterns during winter.
- The applicability of different data collection and analysis techniques when examining patterns of mink habitat use.

To address these objectives, I have divided my thesis into two principle data chapters.

In Chapter 2, I used data collected from telemetered mink to test two hypotheses concerning mink habitat selection: First, I hypothesized that riparian variables (lakes, streams, wetlands etc.) would be more dominant in models when considered at a larger spatial extent (i.e. selection patterns would be different between the landscape level and at the core of mink ranges). Secondly, I predicted that males and females would select different habitats owing to the large sexual dimorphism in the species. I focused my work during winter, when thermal constraints were expected to be greatest, and I tested whether females would select less-aquatic habitats (particularly at the finer scale) than those selected by males, based on the smaller females' greater thermoregulatory challenges.

To investigate the influence of different spatial scales, I pooled all recorded telemetry locations and used two methods (minimum convex polygon (MCP) and kernel estimations) to calculate the areas used by mink at three extents: large, medium, fine. While these two methods are not directly comparable, my intent was to define three spatial extents representative of the habitat available to the study animal. The resulting areas were the large (100% MCP; 111.36 km²), medium (95% kernel; 48.23km²), and fine (50% kernel; 9.79km²) scales.

In Chapter 3, I assessed American Mink winter occupancy using remote cameras. Occupancy modeling estimates the likelihood of a space being occupied by a particular animal, where individual animals are not known (MacKenzie et al. 2006). While the outputs are somewhat similar to those from Chapter 2, noninvasive camera survey techniques eliminate the need for animal handling (Long et al. 2011). Overall, my goal was to investigate the linkages between habitat and the co-occurrence of other similar carnivores on the occupancy patterns of mink within riparian habitats. Specifically, my objectives were to (1) assess covariates that might affect the detectability of American mink, and (2) assess habitat and species co-occurrence covariates that may affect mink occupancy patterns. In Chapter 4, I summarize my overall research findings and discuss management issues and future research directions.

In the remaining portion of this chapter, I provide a more detailed sketch of the study area where I conducted my work.

Study Area

My research was conducted in and adjacent to the co-managed (University of Northern British Columbia and Tl'azt'en Nation) John Prince Research Forest (JPRF; 54°40'14" N; 124°25'13" W; Figure 1.3). The JPRF is a 16,500-ha portion of forested crown land 45 km northwest of Fort St. James, British Columbia. The area is characterized by rolling topography with low mountains (elevation range between 700 m and 1267 m) and a high density of lakes, rivers and streams. The JPRF is located between two large lakes, Pinchi and Tezzeron, which both drain into the Stuart and Nechako River systems, but are not directly connected. The area is within the Sub-Boreal Interior ecoprovince with representation of the Babine Uplands, Manson Plateau and Nechako Lowlands ecosections. Forests of this region represent the northern extent of contiguous Douglas-fir (*Pseudotsuga menziesii* var. *glauca*) in the interior of British Columbia and are dominated by the Sub-Boreal Spruce (SBS) biogeoclimatic zone. In addition, Lodgepole pine (*Pinus contorta* var. *latifolia*), hybrid white spruce (*Picea glauca* x *engelmannii*), Trembling aspen (*Populus tremuloides*), and Paper birch (*Betula papyrifera*) are common, with Sub-alpine fir (*Abies lasiocarpa*) dominating the understory. The SBS zone within the study area is dominated by the Dry Warm (dw3), the Dry Cool (dk), and the Moist Cool (mk1) subzones (DeLong et al. 1993). During the years of

the study, the average monthly mean daily temperature during winter (December to March) was -6.4°C ($\text{SD} = 2.78$). The average minimum and maximum daily temperatures over the same time period were -12.0°C ($\text{SD} = 2.70$) and -1.1°C ($\text{SD} = 2.97$), respectively, and average annual snowfall was 114.1cm (Environment Canada). The area has a long history of fur trapping and forest management activities.

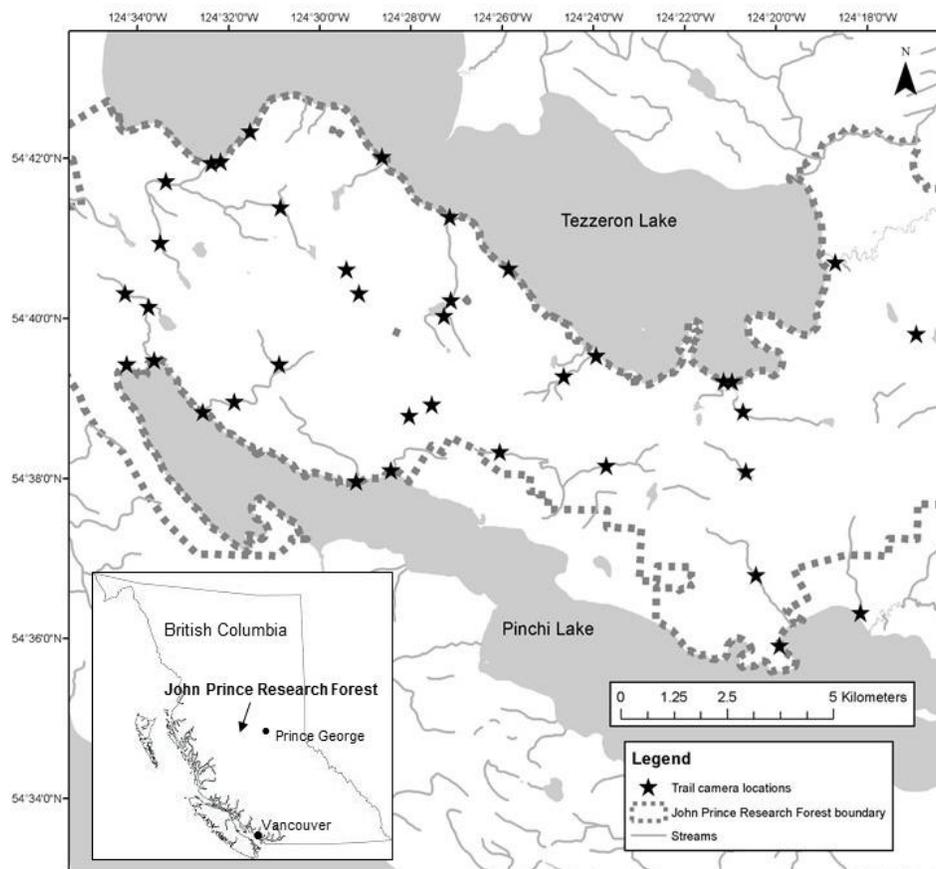


Figure 1.3. Map of study area showing location of the John Prince Research Forest in central British Columbia, Canada.

The JPRF has experienced a wide variety of logging activities over the past 70 years resulting in a mosaic of old and young coniferous forests with interspersed deciduous stands. The stands have a relatively rich understory of deciduous shrubs and regenerating conifers. While the study area is relatively undeveloped (with the exception of small scale forestry operations), the region surrounding it is facing changes in landscape composition as a result of pine beetle associated salvage logging, proposed oil and gas pipeline development, and mining exploration and development.

The area has a diverse carnivore system with 11 small to medium-sized mammalian carnivores documented during winter 2013 (Figure 1.4 and 1.5). In 2006, the JPRF initiated a project to investigate the population dynamics and spatial distributions of these carnivores. The intent of this research program is to develop a solid basis for long-term research and monitoring of these species in the north-central region of British Columbia. To date, research activities have focused on river otter (e.g. Crowley et al. 2012, Johnson et al. 2013) and mink (this study) as representatives of the aquatic environments, with marten (Aubertin et al. 2014) and lynx (Crowley et al. 2013) representing terrestrial environments.

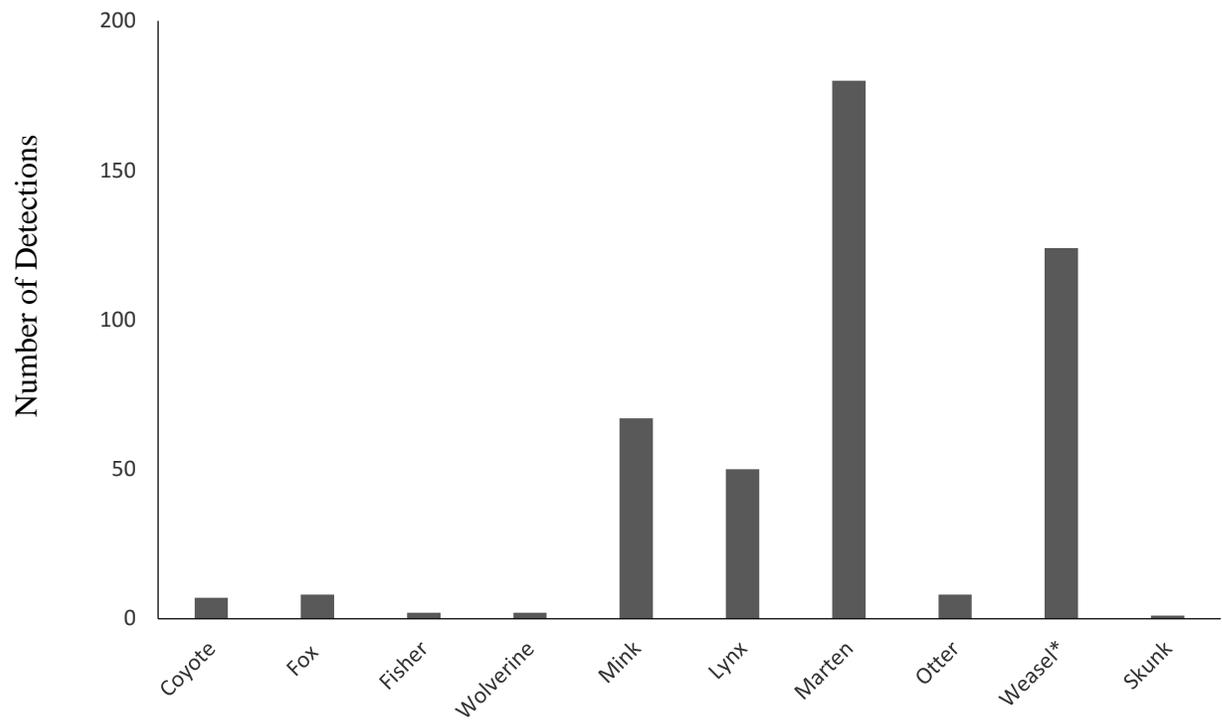


Figure 1.4: Total observations of small and medium-sized mammalian carnivores in the John Prince Research Forest during winter 2013. * Denotes Least and Short-tailed weasel detections combined.



Figure 1.5: Photos of small and medium-sized mammalian carnivores detected in the John Prince Research Forest during winter 2013. (A. *Lynx canadensis*; B. *Mustela erminea*; C. *Mephitis mephitis*; D. *Lontra canadensis*; E. *Gulo gulo*; F. *Martes americana*; G. *Vulpes vulpes*; H. *Neovison vison*; I. *Canis latrans*; J. *Mustela nivalis*; K. *Pekania pennanti*; Photos by D. Hodder except B and E (JPRF) and J (R.V. Rea)).

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CHAPTER 2

EFFECTS OF SCALE AND GENDER ON WINTER HABITAT SELECTION BY AMERICAN MINK.

INTRODUCTION

Extreme variation in behavioural, physiological and morphological adaptations have allowed some taxa to occupy a wide range of environments. However, each combination of these adaptations also places constraints on the breadth of habitat a particular species is able to occupy. Overall, the distribution of species and individuals on the landscape will be affected by the availability of food, presence of competition, predators, mates, and communication with conspecifics (Powell 2012), but also through limitations imposed by the life history of the animal. Such limitations may be revealed by patterns of resource use over different scales, such as that framed by Johnson (1980). Investigating the habitat selection of a particular species in different environments and at different scales may not only reveal important habitat associations, but also adaptive constraints in resource use. Scale can be defined by resolution and extent (Turner et al. 2001; Wheatley and Johnson 2009), where resolution refers to the smallest unit measured and extent defined as the size of area over which observations are measured (Boyce et al. 2003).

Body size of mammals has been shown to strongly influence resource selection patterns (Bonick and Doebeli 2003). Sexual dimorphism in some species may reflect differences in resource use within populations as well as between populations. Indeed, intraspecific competition (such as between sexes) may cause divergence in characteristics (Bolnick et al. 2003) that minimize overlap in resource needs (e.g. diet), allowing coexistence through niche partitioning (Slatkin 1984; Bonick and Doebeli 2003; Meiri et al. 2014). A general trend towards larger body size and greater sexual dimorphism in mammals at higher latitudes (Ferguson and Larivière 2008) suggests differences in resource use between the sexes should be particularly strong within these populations, particularly those demonstrating dimorphism.

Most members of the Family Mustelidae have a tubular body shape (i.e., high surface area/volume ratio) and little to no insulating body fat (Dunstone 1998). This body shape facilitates access to restricted spaces providing access to prey as well as reducing water resistance for those species with aquatic habits (Larivière 2003; Williams 1983). However, the resultant high surface area-to-volume ratio makes these animals vulnerable to extreme

temperatures, especially when considering aquatic forays and the relatively high thermal conductivity of water (Williams 1998; Brown and Lasiewski 1972; Segal 1972). Kruuk et al. (1994) suggested that semi-aquatic mammals with a body weight less than 1kg have limited foraging ability in cold water. Mustelids may partially compensate for elevated heat loss by consuming foods (i.e., meat) that afford a higher metabolic rate (Dunstone 1993), but this challenge may still be significant for species that are semi-aquatic and live in areas where frozen conditions persist for long periods of the year (Marchand 2013).

American mink (*Neovison vison*) are a semi-aquatic mustelid that inhabits marine and freshwater systems over a wide geographic range. The native range of this species extends throughout much of North America, with the exception of the northernmost arctic areas and dry deserts of the southwest (Larivière 2003). Also, mink are widely distributed outside their native range (Europe and South America) as a result of successful invasions following releases from fur farms (e.g., Bonesi et al. 2004; Santulli et al. 2014; Fasola et al. 2009; Medina 1997). The animal also demonstrates a striking degree of sexual dimorphism: Larivière (2003) reported contrasting average body weights for male and female mink both in North America (1154g and 712g, respectively) and in Europe (1122g and 645g, respectively).

Although mink are semi-aquatic, they are incompletely adapted to aquatic foraging (Dunstone 1993). For example, the feet are relatively small and almost unwebbed resembling that of a high speed terrestrial runner more than an animal adapted for underwater propulsion (Dunstone 1993). Also, the density of guard hairs exhibited by mink are less than those of the more aquatic Eurasian otter (*Lutra lutra*) but more than that of the strictly terrestrial polecat (*Mustela putorius*; Dunstone and O'Connor 1979). The morphological characteristics that allow mink to straddle a terrestrial and aquatic existence also may provide unique challenges during periods of extended cold weather and/or when faced with more specialized competitors.

Mink are largely understudied in their native range (Schooley et al. 2012; Larivière 2003) and while recent studies have addressed this research gap (Haan and Halbrook 2014 and 2015; Wolff et al. 2015), the present study represents one of the first detailed ecological studies of mink during winter. As a framework, I proposed two hypotheses to explore habitat selection by the animal at different spatial extents to determine the influence of scale. First, I

hypothesized that riparian variables (lakes, streams, wetlands etc.) would be more dominant in models when considered at a larger spatial scale (i.e., selection patterns would be different between the landscape level and at the core of mink ranges). Secondly, I predicted that males and females would select different habitats owing to the large sexual dimorphism in the species. I focused my work during winter, when thermal constraints were expected to be greatest, and I tested whether females would select less-aquatic habitats (particularly at the finer scale) than those selected by males, based on the smaller females' greater thermoregulatory challenges.

METHODS

Study Area

The research was conducted in the John Prince Research Forest (JPRF). The JPRF is a 16,500-ha portion of forested crown land 45 km northwest of Fort St. James, British Columbia, Canada (54°40'14"N, 124°25'13"W). The JPRF is situated between two large lakes (Tezzeron and Pinchi) and is characterized by rolling terrain with low mountains (700m to 1267m a.s.l) and a relatively high density of streams (see Chapter 1 for a more detailed description). Recent camera monitoring in the study area has revealed a community of at least ten small to medium-sized mammalian carnivores in addition to the mink (Chapter 1).

Field Methods

During the winter seasons of 2011 and 2012 I deployed live-traps (Havahart #1088) along riparian corridors and baited with a mixture of salmon, beaver, or moose meat and a commercial mink lure. Captured mink were either transported to a research station in the study area or processed in a mobile lab tent depending on trap location and environmental conditions. The animals were removed from the trap using a handling cone (Tamarack Handling cone – Lem Mayo – Corner Brook, NL) and immobilized using isoflurane gas through a mask fitted over the handling cone, followed by the surgical implantation of radio transmitters (ATS #1215 for females – 13g; ATS 1230 for males-23g) that comprised approximately 2 percent of total body weight for each gender. Mean body weights in the study area (including research animals and trapper caught samples) was 1091g (n=10) and 566g (n=5) for male and female mink, respectively. I attempted to relocate each animal 2-3 times per week during the winter period (December through April) on snowmobile and/or

foot. Telemetry points were recorded from ground-based tracking using standard triangulation and homing radio-telemetry techniques (Gorman et al. 2006) supported by periodic aerial searches to relocate animals that I was unable to locate using ground-based techniques. Mink in the study area can be active at any time of day (Chapter 3), however, telemetered mink were located only during daylight hours and all resting sites were recorded (e.g. beaver lodges, snow-pressed shrubs, squirrel middens, etc.) with a hand-held GPS unit. Mink locations could be recorded with precision as the animals would use subnivean escape cover as opposed to fleeing whilst a GPS location could be recorded. I used 'resting sites' as a general term to refer to sites where mink were located and did not move in response to the researcher. The animal could have been resting at this site or retreated to these sites as security cover in response to researcher presence. All handling protocols for mink during the study were approved by the Thompson Rivers University Animal Care and Use Committee (#AUP 2010-01) and permitted by the British Columbia Ministry of Environment (#PG10-62346).

Statistical Methods

I used resource selection functions (RSF) to quantify the influence of environmental variables on habitat selection (Mace et al. 1996; Seip et al. 2007). A RSF produces a series of coefficients that quantify the strength of avoidance or selection for specific habitat covariates. When considered additively, the series of coefficients indicate the relative probability of a mink using any location from across the study area (Johnson et al. 2006).

To investigate the influence of different spatial scales on mink habitat selection, I pooled all recorded telemetry locations (Figure 2.1) and calculated the areas used by mink at three scales: large (majority of study area based on 100% MCP; 111.36 km²; n=282), medium (based on 95% kernel; 48.23km²; n = 280), and fine (core range based on 50% kernel; 9.79km²; n = 205). For kernel estimates, a bandwidth of 1200 was used for two reasons: (1) it was considered to be the most biologically-meaningful approximation of mink home range based on the distribution of mink locations in our study area, and (2) it satisfied our objective of comparing the relative influence of habitat variables at different spatial scales. I removed lake water bodies (>100m from shore) from all estimates for two reasons: (1) there were no mink located on the lake beyond the shoreline buffer, and (2) inclusion of lake would have created excessive numbers of random points in open and deep water lake locations biasing

estimates. I then used logistic regression to estimate coefficients for the RSF model. Here, known mink locations were contrasted with an equal number of random locations. A unique set of random locations was generated at each different scale. I then categorized the data according to gender and compared models for female mink at the medium ($n = 145$) and fine ($n = 96$) scales with males at the medium ($n = 134$) and fine ($n = 109$) scales. All spatial and associated data were generated using ArcMap in ArcGIS 10.1 (Environmental Systems Research Institute, Redlands, California).

I developed a series of RSF models that served as ecologically-plausible hypotheses to explain the distribution of mink across the study region. Drawing on literature and knowledge of the study area, I predicted that patterns of mink habitat selection would be explained by three types of variables: general habitat type (e.g., riparian), specific habitat features (e.g., beaver lodge), and gender. All told, I generated or collected 8 spatial variables for inclusion with the RSF models (Table 2.1). Ecological covariates were extracted from the provincial Vegetation Resources Inventory (<http://www.for.gov.bc.ca/hts/vri/index.html>) or JPRF continuous inventory database.

I used the Akaike Information Criterion difference ($AIC_c\Delta$) for small samples and weights (AIC_cw) to select the most parsimonious model from each functional category (Anderson et al. 2000). I used the receiver operating characteristic (ROC) to assess the classification accuracy of the RSF models (Pearce and Ferrier 2000). I had insufficient sample size to withhold a percentage of the observations that would allow me to generate an independent test of classification accuracy. Instead I used a one-fold cross validation routine to withhold each record sequentially from the model building process and then calculate the probability of that withheld record being a mink location. I used these independent probabilities to conduct ROC tests. I considered a model with an Area Under the Curve (AUC) score of 0.7 to 0.9 to be a 'useful application' and a model with a score >0.9 as 'highly accurate' (Boyce et al. 2002). I used 95% confidence intervals to assess the strength of effect of each predictor covariate on the dependent variable. Poor power and inconclusive statistical inference is expected from covariates with confidence intervals that approach or overlap 0. I used tolerance scores to assess variables within each model for excessive collinearity (Menard 1995).



Figure 2.1. Map showing the distribution of raw data (telemetry locations) collected from radio-tagged American mink across the John Prince Research Forest, central British Columbia, Canada.

Table 2.1. Independent variables used for RSF models for American Mink in the John Prince Research Forest, central British Columbia, Canada. All variables except 'lake' and 'wetland' were considered continuous.

Variable Name	Coding	Description
riparian	d_rp	Distance to nearest riparian feature of any type (lake, stream, wetland etc).
beaver lodge	d_bl	Distance to nearest beaver lodge. Beaver lodge is a proxy for habitat created as a result of habitat alteration by beavers.
stream 1 to 3	d_str1to3	Distance to nearest stream classed 1 to 3 as per the British Columbia provincial classification system. These streams are potentially fishbearing year round with a defined channel for at least a 100m reach (Forest Practices Code of British Columbia, 1998).
all-streams	d_allstr	Distance to nearest stream feature.
conifer	conf	Percentage of >40 year old conifer leading forest within a 100m around each point.
stream density	str_den	Number of meters of stream within a 100m buffer of each point.
lake	lake	Whether a point was located in a buffer of 100m from the edge of a lake.
wetland	wetland	Whether a point was located in a wetland.

Predicting the distribution of suitable mink habitat

Given the paucity of empirical information on mink habitat use during winter, I used the sets of RSF models to predict the spatial distribution of habitat suitable for mink (i.e., the habitat included in the 95% and 50% kernel estimates). I used the averaged coefficients ($\beta_1 \dots \beta_i$) from the RSF models and applied that equation to the respective GIS data ($x_1 \dots x_i$). Model averaging (Anderson et al. 2000) allowed me to represent the uncertainty inherent in the model selection process. I averaged those models that constituted 95% of the AIC_w for all mink locations at the medium scale. I then replicated this effort for both males and females at the fine scale to spatially depict differences in habitat selection. Following the application of the averaged model to the study area, I grouped the continuous range of predicted RSF scores into 4 habitat classes representing a low to a very high relative probability of habitat use by mink. I used the quartiles calculated from the predicted RSF scores (w) for the observed mink and random location data to define class break points (Hodder et al. 2014).

RESULTS

I captured 7 American mink (3♂ + 4♀) over 994 trap nights. All of these animals were equipped with transmitters, resulting in a total of 262 locations being recorded and described (♂ = 136, ♀ = 126) in both upland and riparian habitats (Table 2.2). Snow-preserved shrubs were the most common resting sites for both females (35.8%) and males (51.4%). While shrubs were ubiquitous across the landscape, some features such as blown-down trees and red squirrel (*Tamiasciurus hudsonicus*) middens were clearly upland features, with female mink being associated with these features more frequently (40.4%) than males (9.3%). In comparison, features that were riparian (i.e. beaver lodge, beaver dam, snow-preserved herbs) were more frequently associated with males (36.8%) than females (19.2%). All variables were assessed for multicollinearity and were deemed acceptable with all variance inflation factor (VIF) scores less than 2.5.

Table 2.2: Percent frequency of resting sites for American mink in the John Prince Research Forest, central British Columbia, Canada.

Mink Resting Site	Female	Male
Beaver Lodge	7.3	23.9
Snow-pressed Shrubs	35.8	51.4
Beaver Dam	11.9	3.7
Blown-down Tree	20.2	8.3
Snow-pressed Herbaceous Vegetation	0.00	9.2
Red Squirrel Midden	20.2	1.0
Other	4.6	2.8

Multi-scale RSFs

Table 2.2 lists the RSF models and their associated information criteria, assessed across different spatial scales. The most parsimonious model at the large scale was ranked very high with areas closer to beaver lodges ($\beta = -3.98$, SE = 1.11) and higher stream densities ($\beta = 7.57$, SE = 0.97) positively related to mink locations. The distance to stream classes 1 to 3 ($\beta = -0.58$, SE = 0.21) and presence in lake riparian area ($\beta = 1.66$, SE = 0.35) also were significant. No other model from the set was competitive at this scale. At the medium scale, the set of models showed considerable uncertainty with the most parsimonious model showing selection for areas closer to beaver lodges ($\beta = -4.05$, SE = 1.47) with high stream density ($\beta = 5.47$, SE = 2.69) but was also influenced by distance to all stream classes ($\beta = -2.17$, SE = 0.0.83) and lake ($\beta = 1.98$, SE = 0.26). The second model was competitive ($AIC_{c\Delta i} > 2$) and considered equivalent. At the fine scale, the best model had similar variables to the medium scale models but indicated stronger selection for areas closer to beaver lodges ($\beta = -9.49$, SE = 2.40) and high stream density ($\beta = 7.62$, SE = 3.22), and areas closer to all streams ($\beta = 1.88$, SE = 1.14).

After model averaging, the coefficient values suggested mink selection at the large scale was significantly influenced by distance to beaver lodges, stream densities and lakes. Model-averaged scores at the medium scale also showed a similar relationship to beaver lodges and streams, but only the lake variable had confidence intervals that did not overlap zero. At the fine scale, beaver lodges and stream density also showed a strong trend, but no habitat variable had confidence intervals that did not overlap zero (Figure 2.1).

Gender RSFs

At the medium scale, there was considerable uncertainty for both male and female candidate models with four models for female and three for male having an $AIC_{c w_i} < 2$ (Table 2.3). All models for both females and males had high levels of precision as demonstrated by AUC scores. After model averaging, female mink exhibited significant selection for the distance to stream classes 1 to 3 and stream density, with the distance to all streams showing some influence. After averaging the models for male mink, only stream density did not have confidence intervals overlapping zero, with distances to beaver lodges and lakes showing some influence (Figure 2.2).

At the fine scale, there was much more certainty in model rankings for both female

and male candidate models. The most parsimonious model for female mink contained variables for distance to riparian, beaver lodges, stream classes 1 to 3, stream density and lake and was highly predictive. The most parsimonious model for males was more complex and included covariates for distance to riparian habitat, beaver lodges, all streams, conifer, stream density, lake and wetland and had good predictive strength. After model averaging, female mink exhibited significant selection for distance to stream classes 1 to 3, stream density and distance to beaver lodges. In contrast, averaged models for male mink demonstrated significant selection for distance to all riparian features, distance to beaver lodges and lake (Figure 2.3).

Predictive Mapping

Using GIS mapping and the averaged coefficients for the medium scale (95% fixed kernel) I predicted that 3.4% of the study area had a very high habitat suitability for mink while 2.9%, 7.1%, 66.7% had high, medium and low suitability, respectively (Figure 2.3). Using the gender specific averaged coefficients at the fine scale (50% fixed kernel), 13.2% of the study area was predicted as having attributes associated with high quality female mink habitat and 21.8% of the study area was predicted as having attributes associated with high quality male mink habitat (Figure 2.4). The areas predicted as high suitability male mink habitat had roughly twice (53.1km) the linear distance of lakeshore than those areas predicted as high for females (26.4 km).

Table 2.3. Number of parameters (K), differences in AIC_c scores (Δ), AIC_c weights (w), and Area Under the Curve (AUC) for RSF models comparing habitat selection by mink at three different spatial scales in the John Prince Research Forest, central British Columbia, Canada.

Model	K	AIC_{ci}	$AIC_{c\Delta i}$	AIC_{cw_i}	AUC (SE)
100% MCP (Large)					
d_rp+d_bl+d_str1to3+str_den+lake	6	376.01	0.00	0.91	0.93 (0.01)
d_bl+ d_str1to3+str_den+lake	5	381.58	5.57	0.06	0.93 (0.01)
d_rp+d_bl+d_allstr+str_den+lake	6	382.99	6.97	0.03	0.93 (0.01)
d_rp+d_bl+d_allstr+conf+str_den+lake+wetland	8	386.87	10.90	0.00	0.93 (0.01)
d_bl+str_den+lake	4	390.64	14.63	0.00	0.93 (0.01)
d_bl+d_allstr+str_den+lake	5	390.74	14.73	0.00	0.93 (0.01)
95%_Kernel (Medium)					
d_bl+d_allstr+str_den+lake	5	458.79	0.00	0.50	0.90 (0.01)
d_rp+d_bl+d_allstr+str_den+lake	6	459.74	0.95	0.33	0.90 (0.01)
d_bl+d_str1to3+str_den+lake	5	462.52	3.71	0.08	0.90 (0.01)
d_rp+d_bl+d_allstr+conf+str_den+lake+wetland	8	462.59	3.80	0.08	0.91 (0.01)
d_rp+d_bl+d_str1to3+str_den+lake	6	464.48	5.71	0.03	0.90 (0.01)
d_bl+str_den+lake	4	470.17	11.38	0.00	0.89 (0.01)
50%_Kernel (Fine)					
d_rp+d_bl+d_allstr+str_den+lake	6	337.71	0.00	0.76	0.90 (0.02)
d_rp+d_bl+d_str1to3+str_den+lake	6	341.23	3.53	0.13	0.89 (0.02)
d_rp+d_bl+d_allstr+conf+str_den+lake+wetland	8	341.66	3.95	0.11	0.89 (0.02)
d_bl+d_allstr+str_den+lake	5	349.50	11.79	0.00	0.89 (0.02)
d_bl+str_den+lake	4	351.77	14.06	0.00	0.89 (0.02)
d_bl+d_str1to3+str_den+lake	5	353.45	15.74	0.00	0.89 (0.02)

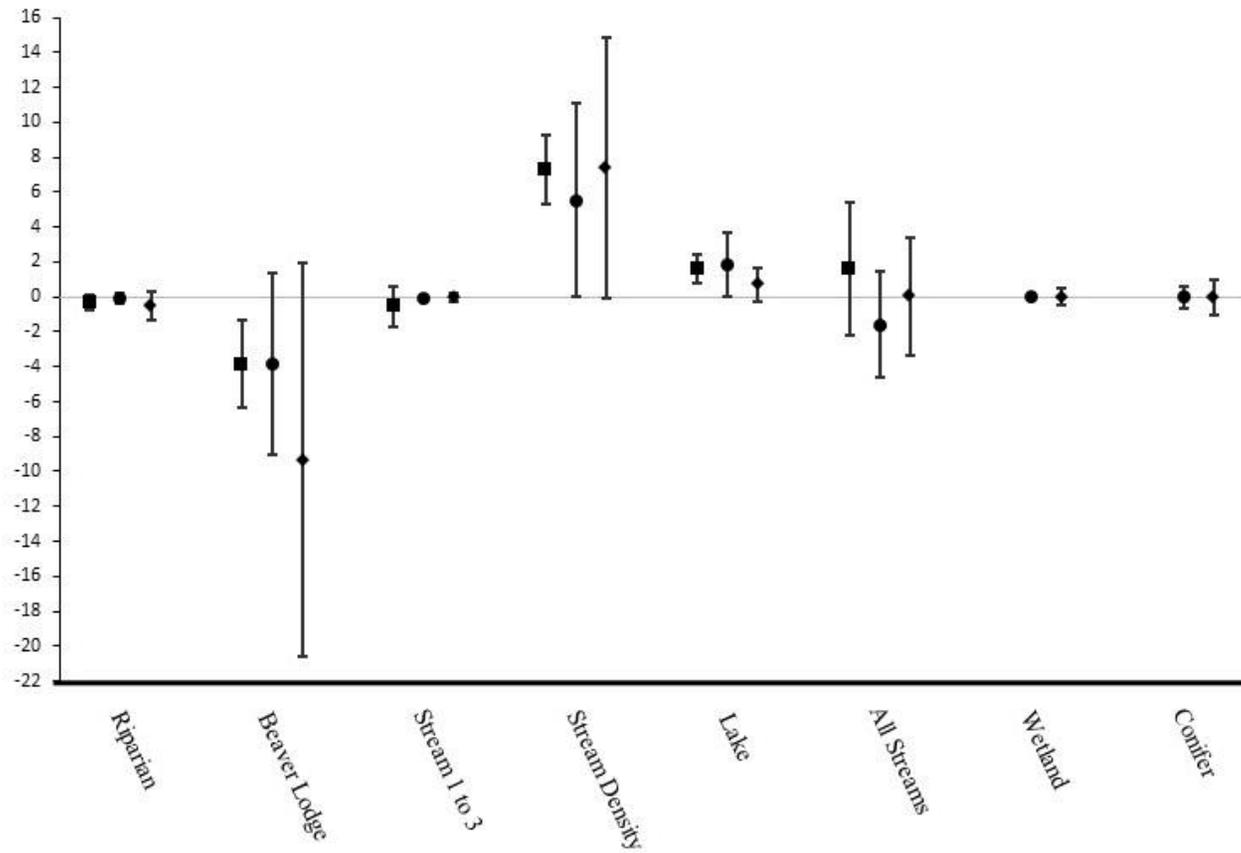


Figure 2.2. Model averaged beta coefficients (as defined in Table 2.1) and 95% confidence intervals illustrating selection of site attributes at multiple spatial scales by American Mink in the John Prince Research Forest, central British Columbia, Canada. ■ = Large Scale; ● = Medium Scale; ◆ = Fine Scale. Weighted averages and variances were corrected for model selection uncertainty using the top 95% of AIC_w (Table 2.2).

Table 2.4. Number of parameters (K), differences in AIC_c scores (Δ), AIC_c weights (w), and Area Under the Curve (AUC) for RSF models comparing habitat selection by male and female mink at the medium and fine spatial scales in the John Prince Research Forest, central British Columbia, Canada.

Model	K	AIC_{ci}	$AIC_{c\Delta_i}$	AIC_{cw_i}	AUC (SE)
95%_Kernel_female					
d_bl+d_allstr+str_den+lake	5	226.73	0.00	0.38	0.92 (0.02)
d_rp+d_bl+d_allstr+conf+str_den+lake+wetland	8	227.38	0.64	0.28	0.92 (0.02)
d_rp+d_bl+d_allstr+str_den+lake	6	228.15	1.42	0.19	0.92 (0.02)
d_rp+d_bl+d_str1to3+str_den+lake	6	228.55	1.82	0.15	0.92 (0.02)
d_rp+d_bl+str_den+lake	5	237.26	10.53	0.00	0.91 (0.02)
d_rp+d_str1to3+str_den+lake+wetland	6	237.61	10.87	0.00	0.90 (0.02)
95%_Kernel_male					
d_rp+d_bl+str_den+lake+wetland	6	174.37	0.00	0.45	0.93 (0.02)
d_rp+d_bl+str_den+lake	5	176.17	1.81	0.18	0.93 (0.02)
d_rp+d_bl+d_allstr+str_den+lake	6	176.30	1.93	0.17	0.92 (0.02)
d_rp+d_bl+d_allstr+conf+str_den+lake+wetland	8	176.89	2.52	0.13	0.93 (0.02)
d_rp+d_bl+d_str1to3+str_den+lake	6	177.99	3.62	0.07	0.93 (0.02)
d_bl+d_allstr+str_den+lake	5	191.69	17.32	0.00	0.92 (0.02)
50%_Kernel_female					
d_rp+d_bl+d_str1to3+str_den+lake	6	124.49	0.00	0.79	0.93 (0.02)
d_bl+d_str1to3+str_den+lake	5	127.10	2.61	0.21	0.93 (0.02)
d_rp+d_str1to3+str_den+lake+wetland	6	138.70	14.27	0.00	0.91 (0.02)
d_rp+d_bl+d_allstr+conf+str_den+lake+wetland	8	139.80	15.31	0.00	0.92 (0.02)
d_rp+d_bl+str_den+lake	5	144.80	20.33	0.00	0.91 (0.02)
50%_Kernel_male					
d_rp+d_bl+d_allstr+conf+str_den+lake+wetland	8	135.17	0.00	0.92	0.93 (0.02)
d_rp+d_bl+str_den+lake	5	141.65	6.49	0.04	0.88 (0.03)
d_rp+d_str1to3+str_den+lake+wetland	6	142.40	7.25	0.03	0.87 (0.03)
d_rp+d_bl+d_str1to3+str_den+lake	6	142.63	7.50	0.02	0.93 (0.02)
d_bl+d_str1to3+str_den+lake	5	196.80	61.63	0.00	0.88 (0.02)

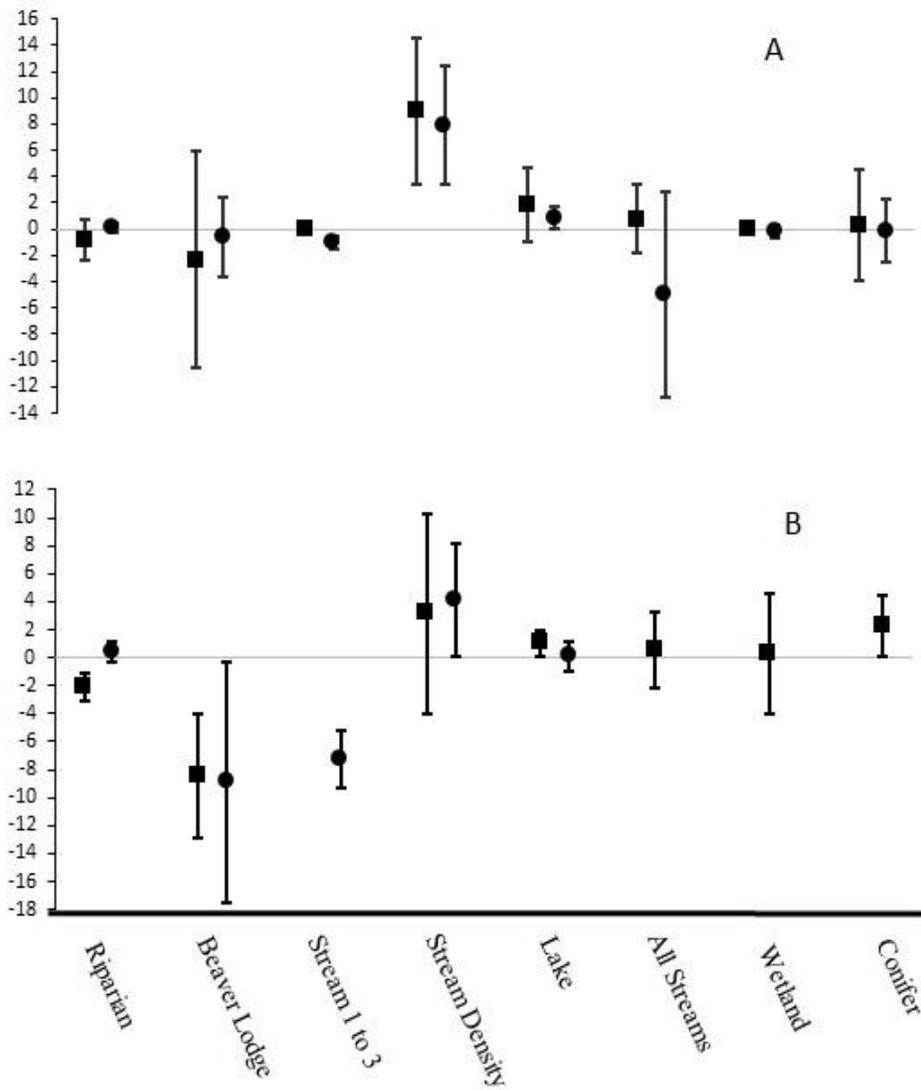


Figure 2.3. Model-averaged beta coefficients and 95% confidence intervals illustrating selection of site attributes by male and female American mink at a medium (95% fixed kernel – A) and fine (50% fixed kernel - B) spatial scale in the John Prince Research Forest, central British Columbia, Canada. ■ = Male; ● = Female. Weighted averages and variances were corrected for model selection uncertainty using the top 95% of AIC_w (see Table 2.3).

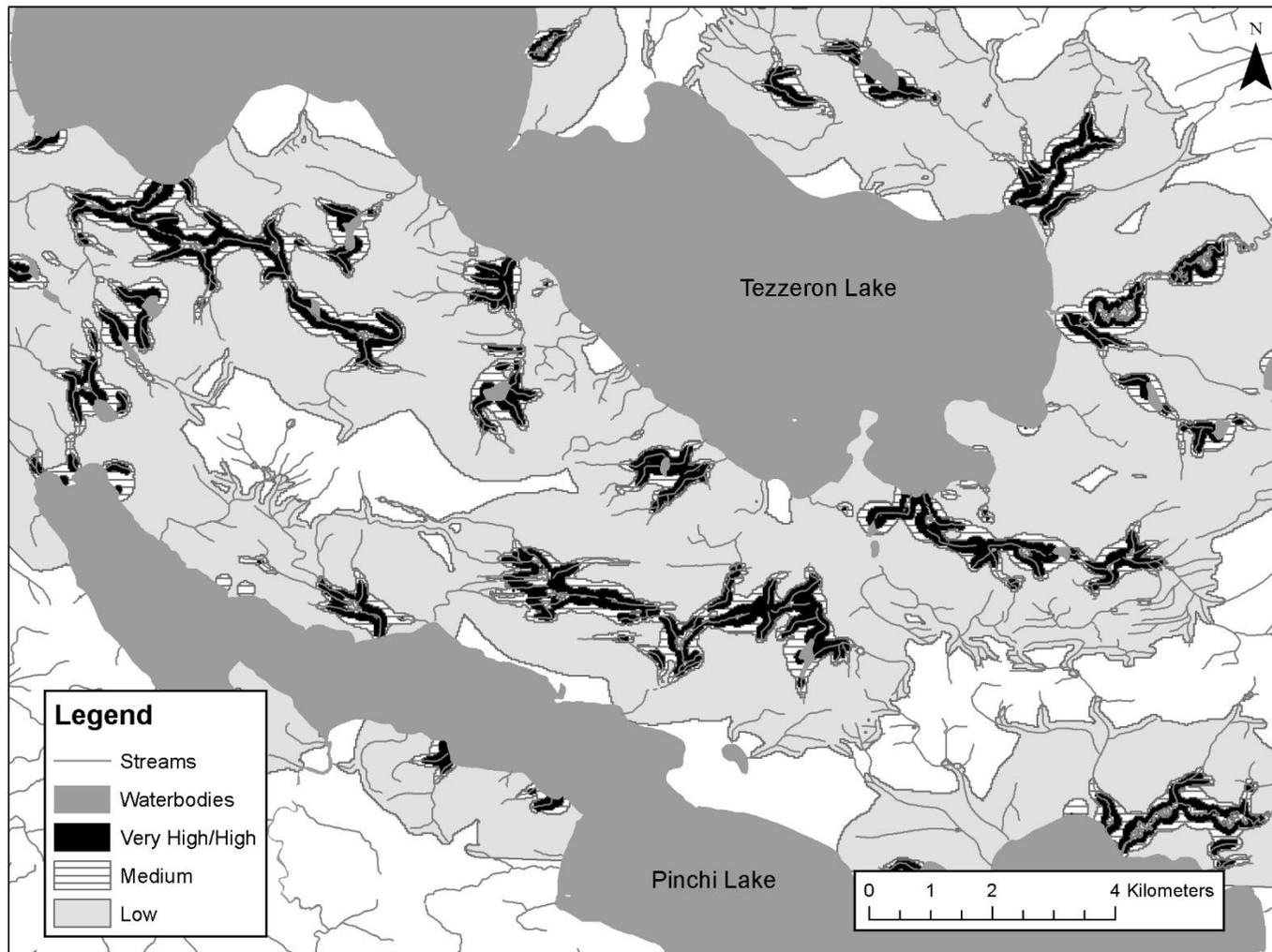


Figure 2.4. Spatial extrapolation of averaged coefficients using the quartiles calculated from top ranked RSF models predicting American mink habitat (95% fixed kernel) across the John Prince Research Forest, central British Columbia, Canada.

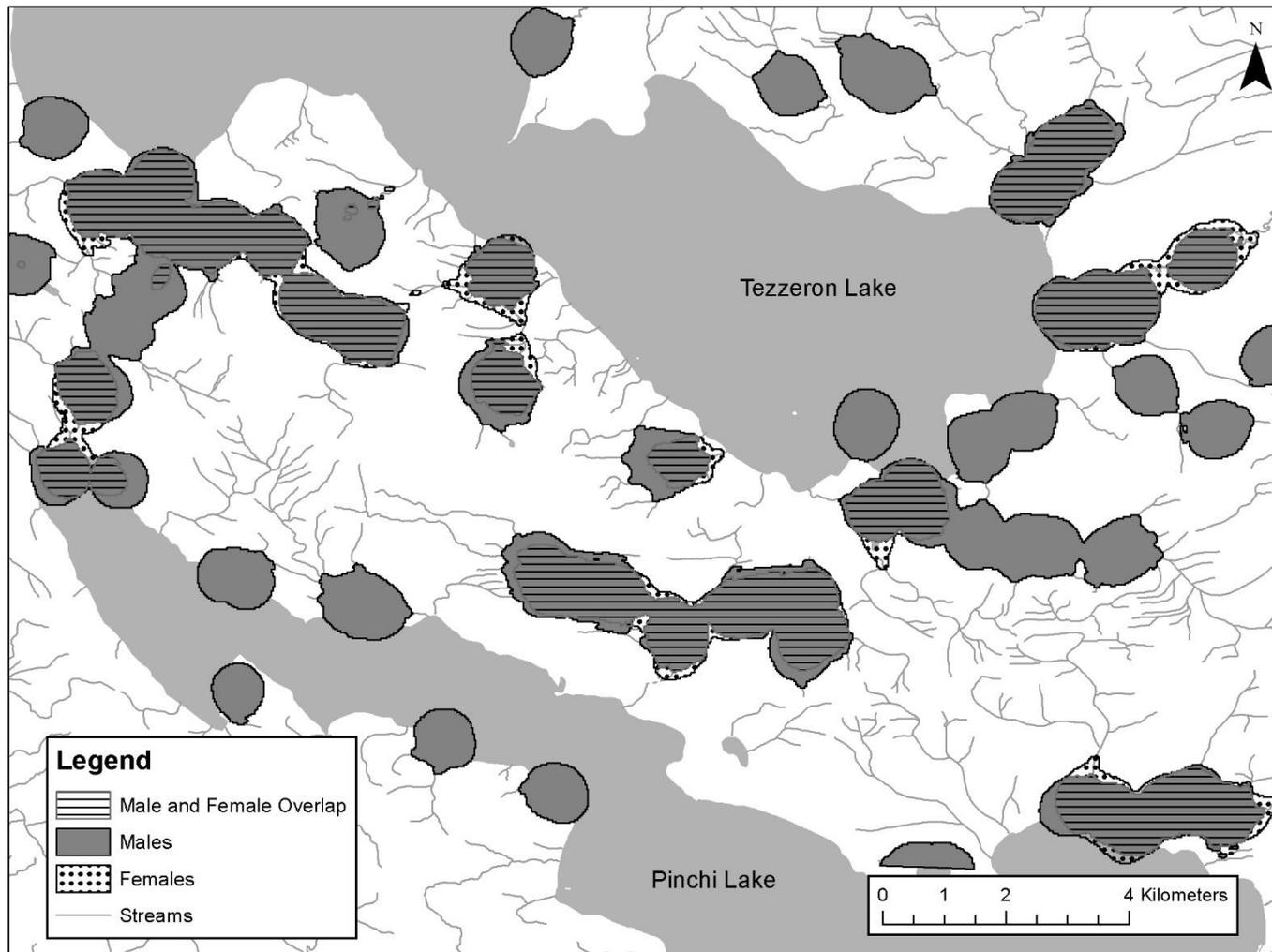


Figure 2.5. Spatial extrapolation of averaged coefficients from top ranked RSF models predicting high-quality (top two quartiles) habitat for male and female mink (50% fixed kernel) across the John Prince Research Forest, central British Columbia, Canada.

DISCUSSION

This study examined the habitat selection patterns of American mink during winter while considering differences in spatial scale and gender. My first hypothesis stated that riparian variables (lakes, streams, wetlands etc.) would be more dominant in models when considered at a larger spatial scale, based on the semi-aquatic nature of mink. My results supported this hypothesis with riparian features being selected more often by mink at the large scale. While there is no other comparable habitat selection literature for mink in its native range, several authors have demonstrated a spatial effect on habitat selection by other mammals (see Wheatley and Johnson 2009 for a review). Although significant at only the large scale, I found that trends for selection of beaver lodges and stream density were consistent across all three spatial scales. In general, I observed a pattern of decreasing selection for riparian features as scale became finer, supporting my hypothesis. This suggests that mink have strong selection for riparian features at the landscape level during winter at a relatively large scale. At the core of their range, however, mink show no significant selection for riparian features. Although mink may prefer to be in areas that are in closer proximity to riparian habitat, they appear to utilize all habitat within that area evenly. These patterns of selection may be related to the severity of winter conditions (i.e., inability to access aquatic resources) as well as the interspecific (Siderovich et al. 1999) and intraspecific (Bolnick et al. 2003) competitive pressures in the system.

The evolution of sexual dimorphism in animals has been widely studied (Ferguson and Larivière 2008; Wyman et al. 2013; Meiri et al. 2014), often being linked to a divergence in habitat at some scale. As such, I predicted the sexual dimorphism in our study population of mink would reflect sex-biased selection of different habitats during winter. My data supported this prediction, particularly at the finer spatial scale. While both male and female mink selected for some similar features, there were some scalar differences in how strongly the variables were associated with each gender. Notably, at the core of their respective ranges (finer spatial scale), both genders selected for areas closer to beaver lodges. Females, however, selected for these features in addition to streams classed 1 to 3 and higher stream density while males selected for beaver lodges in addition to all riparian features, lakes and conifer. Considering the severity of winter conditions in the study area, this suggests that females spend much of the winter period around stream habitats that are completely frozen

(i.e. aquatic habitat is restricted to deep pools and ponds) with little access to aquatic prey. Assuming that smaller mustelids (particularly those less than 1kg) have higher costs of thermoregulation (Kruuk et al. 1994) and that this is intensified by foraging in water (Williams 1983), then this spatial separation between male and female mink seems plausible.

Given a divergence in habitat selection between male and female mink, it is also possible that each gender is challenged with different competitive pressures within winter home ranges. Selection of lakeside habitat by males could result in potential competitive overlap with another mustelid, the northern river otter (*Lontra canadensis*). This competitive interaction has been observed in Europe between Eurasian otter and invasive American mink populations (Bonesi et al. 2003). However, in coastal habitats of Alaska (native mink range), Ben-David et al. (1996) showed niche separation between mink and otter. Overall, there is very little published information about real or potential interactions between river otter and mink in the freshwater systems of North America.

In my study, I found female mink showed a preference for stream habitats relative to lakeshore habitats, the latter being more associated with males. Female mink use of red squirrel middens and blown-down trees (more common in forest environments) as resting sites also provide support to this habitat selection pattern. The forests around these streams and lakes also provide habitat for other mammalian carnivores that could result in increased interspecific interactions. Indeed, the use of remote cameras to investigate mink occupancy patterns in this study area has suggested there may be avoidance by mink of sites that support American marten (*Martes americana*) and high densities of old coniferous forests (Chapter 3). Powell et al. (2003) noted that while there were exceptions, marten are generally associated with mesic, conifer-dominated forests with abundant structure across their range. If this competitive interaction exists, it did not appear to have a negative effect on the male mink in my study, as they selected for areas with more conifer cover (at the finer scale). Perhaps the relatively larger size of the male mink makes them less susceptible to these competitive pressures. Regardless, the predictive mapping demonstrates that a relatively small percentage of the total landscape is available for this generalist predator to exploit.

While I acknowledge that my sample size was small and this study was solely focused on the winter season, this work provides a novel investigation into mink spatial ecology within the species' native range. My findings suggest that overall mink habitat

selection is most clearly defined at a large spatial scale with riparian features being the most dominant variables. However, mink habitat selection is likely best assessed at more than one spatial extent as there appears to be spatial separation between male and female mink as scale becomes finer. This differentiation could have implications for maintaining both sexes on the landscape during this critical period of the year. For instance, while mink are clearly associated with riparian habitat (most significant variables can be considered riparian in nature), there is also significant use of surrounding habitat, suggesting upland forest stands may play an important role in the spatial requirements of mink during winter.

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CHAPTER 3

THE ROLE OF ENVIRONMENTAL VARIABLES AND SYMPATRIC MESO-CARNIVORES ON THE DETECTION AND OCCUPANCY OF AMERICAN MINK DURING WINTER.

INTRODUCTION

Factors affecting the distribution of a species on a landscape include food, competitors, predators, mates, and intraspecific communication (Powell 2012). Thus, understanding fully the ecology of any population (much less impacts caused by environmental change) requires knowledge of how and why the animal is spatially distributed (Chelgren et al. 2011; Walpole et al. 2012; Poley et al. 2014). However, collecting this type of information can be particularly challenging for cryptic species. Many members of the Order Carnivora fall into this category, and hence they remain poorly understood and their conservation status not well known (Boitani and Powell 2012).

Traditionally, many carnivore population assessments have focussed on understanding population abundance or density (MacKenzie and Reardon 2012). Alternatively, spatial distributions of these animals have been examined using marked animal locations and associated environmental variables to determine habitat selection patterns (Boyce et al. 2002; Johnson et al. 2006). However, these assessments are expensive and often impractical, particularly for species that have low economic value or conservation risk. Recently, more emphasis has been placed on passive detection-nondetection surveys (i.e., remote cameras, hair traps, snow tracks etc.) to determine areas that are occupied by various carnivore species (MacKenzie et al. 2006; Long et al. 2011; Schooley et al. 2012). Noninvasive survey techniques eliminate the need for animal handling, and occupancy models can provide estimates of habitat suitability without the estimation of actual population parameters (Long et al. 2011). This approach is empirically-based and uses animal detections and ecological covariates to estimate occupancy patterns. Additionally, when paired with survey methods such as remote cameras that detect multiple species, likelihood-based models can also explore the relationship between species co-occurrence and site occupancy (MacKenzie et al. 2006; Burton et al. 2015). Although the consideration of other species (especially predator-prey relationships) is not new in resource selection models (Johnson et al. 2002; Anderson

and Johnson 2014; DeCesare et al. 2014) the incorporation of carnivore co-occurrence data in occupancy models using passive data collection techniques is relatively novel and has not been applied widely in field ecology studies.

American mink are cryptic, semi-aquatic carnivores (F. Mustelidae) and poorly understood across their native range (Schooley et al. 2012). Despite a long history of harvest and management, little is published about mink ecology or population dynamics in North America (Schooley et al. 2012; Larivière 2003). What is known is that the animals typically have distributions that are linear and near water (Larivière 2003). Across their range, mink consume a variety of fish, mammals, amphibians, birds and crustaceans but mammals such as muskrat (*Ondatra zibethicus*), mice and voles appear to be the most important diet items for mink during all seasons (Eagle and Whitman 1987) and in general, the species' diet reflects whatever is available in the local prey base (Larivière 2003). Despite its semi-aquatic nature, mink are not particularly agile in water and are limited to foraging for small or slow-moving prey in shallow water (Dunstone and Birks 1987). In Illinois, however, Wolff et al. (2015) demonstrated that mink occupancy during summer in a largely agricultural landscape was influenced by the availability of preferred prey (crayfish). Other information on mink ecology is derived from research outside of their native range, where there has been substantial research on mink as an introduced species (e.g. Bonesi et al. 2004; Santulli et al. 2014; Fasola et al. 2009; Medina 1997).

In this study, I assessed American mink winter occupancy in a northern part of its native range where ecosystems are relatively undisturbed, flow of natural waterways are not regulated, and the only major landscape disturbance is ongoing forestry activities. Overall, I sought to investigate the linkages between habitat and species co-occurrence on the occupancy patterns of mink within riparian habitats. Specifically, my objectives were to (1) assess covariates that affect the detectability of American mink in non-invasive surveys, and (2) assess habitat and species co-occurrence covariates that affect mink occupancy patterns.

METHODS

Study Area

The research was conducted in the John Prince Research Forest (JPRF; Figure 3.1), a 16,500- ha portion of forested public land 45 km northwest of Fort St. James, British

Columbia, Canada. The JPRF is characterized by rolling terrain with low mountains (700m to 1267m a.s.l) and is within the Sub-Boreal Interior ecoprovince. The JPRF is situated between two large lakes, Tezzeron (8079ha) and Pinchi (5586ha), and has a relatively high density of streams. The area has experienced a wide variety of logging activities over the past 70 years and contains a mosaic of old and young forests with interspersed deciduous stands. The stands have a relatively rich understory of deciduous shrubs and regenerating conifers (see Chapter 1 for a more detailed description).

Camera Surveys

In winter 2013, I monitored mink with remote cameras now commonly used to monitor wildlife species (Burton et al. 2015). Specifically, I used Bushnell Trophy Cam (Model 119467) and Bushnell Trophy Cam HD Max (Model 119477) passive infrared cameras (Bushnell Outdoor Products, Kansas, USA). I deployed 37 cameras in riparian habitat along streams including lakeshore/stream confluences throughout the JPRF. Camera stations were active for three 15 day sessions: January 26-Feb 9, March 5-19, and April 2-16. Riparian corridors were chosen for camera placement due to the semi-aquatic nature of mink and subsequent selection for habitats near riparian features (Chapter 2, Burton et al. 2015). I stratified camera locations by streams that were “fish bearing” (n=16) and “non-fish bearing” (n=21) with representation at junctions with lakeshore and upland habitats. The study area has a complete stream classification inventory as per the provincial standards in British Columbia (Forest Practices Code of British Columbia, 1998). My cameras were not spatially independent in terms of a minimum distance between stations but instead were monitoring different sub-watersheds, an approach I feel appropriate given the linear nature of mink home ranges (Larivière 2003). This method notwithstanding, 26 of the 37 sites were >1km apart. At each site, a camera was set 0.5-1m above the snow on a tree or fallen log. Bait and lure were set near the ground 2-3 meters from the camera. Bait was a combination of salmon paired with either beaver or moose meat and hung 0.5-1m from the ground. During the last two surveys, a small diameter log (<15cm diameter) was added to the set and secured in the snow with one end pointing out directly below the bait (~30-40 cm below bait). The addition of this log served as a platform for mink to use as they approached the bait, allowing for better video captures and in turn, better verification of species and even individual markings. Commercial mink lure and beaver castor were placed directly above the bait as well as on the

log or ground below the bait. Bait was replaced and additional lure added approximately mid-way through each session. Cameras were set to take 30 seconds of video with a 1 second delay between videos. This video schedule allowed for near continuous recording for the time the animal was in view. Sensor level was set to normal, LED control for night vision was set to medium, and video sound recording was turned on.

Statistical Methods

I used likelihood-based occupancy modelling to evaluate the influence of covariates (Table 3.1) on detection and occupancy of American mink (Mackenzie et al. 2006; Long et al. 2011; Shannon et al. 2014). Specifically, I used single-season occupancy models in PRESENCE (Version 7.1 USGS-PWRC. <http://www.mbr-rc.usgs.gov/software/presence.html>; Hines 2006) to estimate detection rates (P ; probability that a mink was detected if present) and site occupancy (Ψ ; probability that a mink occupied the site) for multiple surveys of the same site (Mackenzie et al. 2006; Schooley et al. 2012). Estimation in PRESENCE assumes that there are no false positives (unlikely with camera data) and effectively copes with missing data (Mackenzie et al. 2006). I used single-season, single-species models (instead of multi-species models) because the original study design was stratified to survey mink habitat (i.e. riparian areas) and would not necessarily be representative of other species' habitats (e.g. marten).

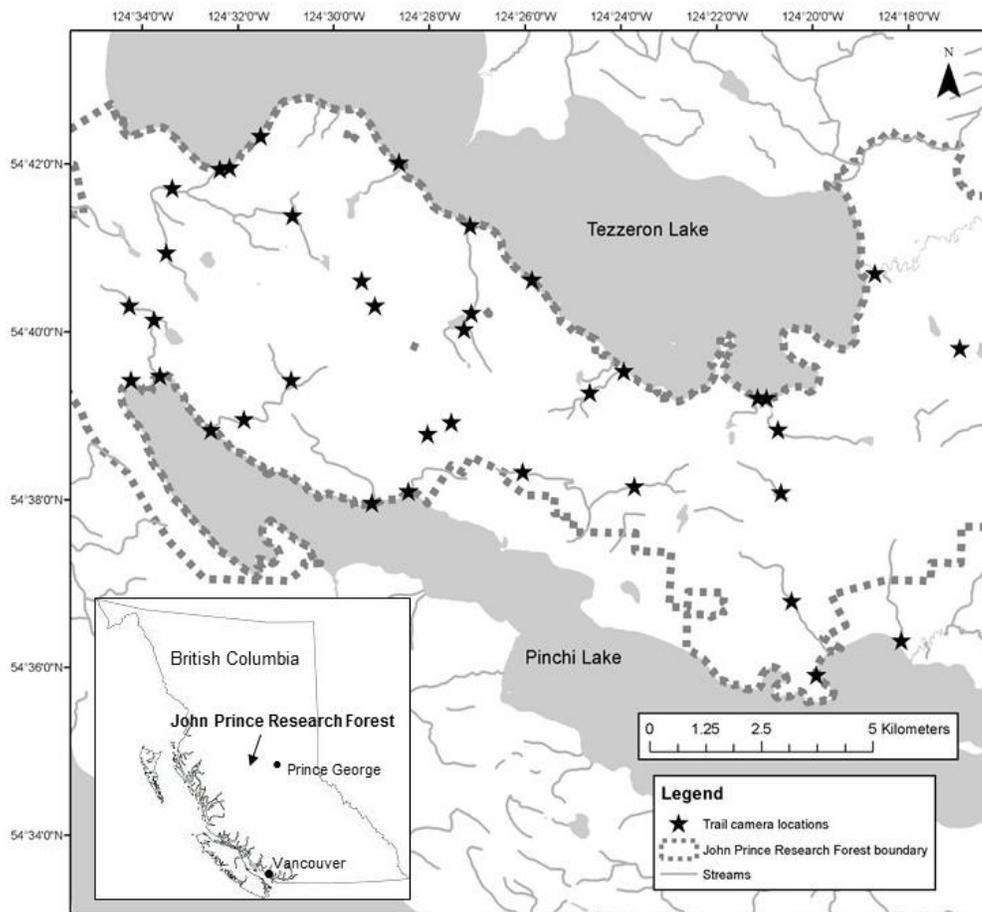


Figure 3.1. Map of study area showing remote camera locations ($n = 37$) in the John Prince Research Forest in central British Columbia, Canada.

Table 3.1. Variables used for detection and occupancy models for American mink in the John Prince Research Forest, central British Columbia, Canada.

Variable Name	Coding	Description
temperature	continuous	Mean temperature during 15 day trapping session.
Julian	continuous	Julian date to mid-point of survey
conifer	continuous	Percentage of forests in 100m radius of camera trap location that was conifer leading and >40yrs old.
deciduous	continuous	Percentage of forests in 100m radius of camera trap location that was deciduous leading.
riparian	continuous	Amount of linear riparian habitat (including lakeshores, streams, wetlands etc.) in 100m radius of camera trap location.
fishbearing	categorical	Stream at camera trap location was fish bearing.
American marten	categorical	Marten present at site during all three trap sessions.
weasel	categorical	Weasel present at site during a trap session.
Canada lynx	categorical	Lynx present at site during a trap session.

For detection models, I used a constant occupancy probability while varying detection covariates paired with differences in survey period [$\Psi(\cdot), P(\text{survey})$]. For occupancy models, I let the probability of detection (P) differ between surveys but otherwise remain constant (without covariates) while varying habitat and carnivore co-occurrence covariates that may influence species occupancy (Ψ). I used the Akaike information criterion difference ($AIC_{c\Delta i}$) and associated weight ($AIC_{c w_i}$) for small sample sizes to rank the most parsimonious models (Anderson et al. 2000). I used parametric bootstrapping with 1000 permutations in PRESENCE to assess goodness-of-fit for detection and occupancy models (Kaiser and O’Keefe 2015). I used \hat{c} as a measure of overdispersion and considered a value between 0.5 and 1 as having acceptable model fit and any model having a value less than 0.5 or greater than 1 as having poor fit (MacKenzie and Bailey 2004; Kaiser and O’Keefe 2015). For those models with poor fit I used QAICc (Quasi-AIC) as a correction to more accurately portray covariates in model rankings (MacKenzie and Bailey 2004). I used model averaging (Anderson et al. 2000) to help represent the uncertainty inherent in the model selection process. I considered the 85% confidence intervals as a measure of significance for averaged beta coefficients of all models in the *a priori* set (Arnold 2010).

While my sample size was insufficient to withhold portions of the data to further investigate trends using occupancy models, I compared percent overlap between mink and marten at ‘lake’ and ‘non-lake’ sites as a way to further explore the potential relationship between mink and marten co-occurrence.

RESULTS

During the winter of 2013, there was a naïve occupancy rate (i.e., proportion of sites with detections of mink) of 0.65 based on remote camera surveys of riparian habitats in the study area. Mink were active during all times of day with detections being classed as “night” and “day” (based on light conditions observed in videos) during 49 and 51 percent of detections, respectively. I used mink occurrence data from these detections to construct 22 models in PRESENCE. Models were constructed for detection ($n=7$; Table 3.2) and occupancy using habitat and species occurrence data ($n=15$; Table 3.3). For the detection models, all *a priori* models had poor fit with \hat{c} values all greater than 1, suggesting some degree of overdispersion. As a result, I corrected the model rankings by using the QAIC

scores. After this correction, the best model of detection probability ($QAIC_c w_i = 0.86$) had no covariates and suggested that detection varied among survey periods. Overall, the detection probabilities for mink during the study were 0.61 (95% CI = 0.37 – 0.81), 0.24 (95% CI = 0.12 – 0.44), and 0.48 (95% CI = 0.29 – 0.69) for Sessions 1, 2, and 3, respectively. The average detection rate for mink throughout the study was 0.44.

For the set of models testing the influence of habitat covariates and species co-occurrence on mink occupancy, all models were deemed to have acceptable fit with \hat{c} values greater than 0.5 and less than 1. There was considerable uncertainty in model selection with the top model having a low model weight ($AIC_c w_i = 0.21$). Another 3 additional models had an $AIC_c \Delta_i < 2$ and therefore were considered equivalent models (Table 3.3). Of these top models, the conifer variable was included in all, with the variables fish-bearing, beaverlodge, and marten also exhibiting influence. After model averaging, the coefficient values suggested that mink occupancy had a negative relationship with conifer habitat and was positively associated with fish-bearing streams (Table 3.4). However, only the fish-bearing variable was significant with confidence intervals not overlapping zero. Using the model-averaged results the mean occupancy within riparian habitat across the study area for mink was 0.77 (95% CI = 0.73 – 0.80, see Table 3.5). When comparing “lake” versus “non-lake” sites, I found that 81.25% of sites in the lakeshore zone had both marten and mink detections, but the sites that were non-lakeshore detected both species at only 19.05% of sites (Figure 3.1).

DISCUSSION

My surveys of riparian areas for the presence of mink yielded relatively modest detection rates that varied between survey periods, with higher rates occurring earlier and later in winter. Naïve occupancy within riparian habitats was relatively high, which is consistent with findings of similar work using track surveys for mink in Illinois during summer (Schooley et al. 2012). However, a lack of comparable data are available that explore mink detection and occupancy during winter in its native range.

In terms of occupancy patterns, I found cameras located at fish-bearing streams were more likely to detect mink. These results are comparable to my results in Chapter 2, where I monitored telemetered mink in the same study area. It must be noted, however, that many of the streams in my study area are completely frozen during winter, so it may not be fish *per*

se that are bringing mink into this riparian area, but rather the habitat structure or other characteristics. However, I also observed a negative trend (though not significant) between mink occupancy and the amount of older (>40yrs) coniferous forests which could represent high-value marten habitat (Powell et al. 2003). Considering the differences in percent overlap between the lakeshore and non-lakeshore zones, this could support the negative association detected between marten presence and conifer habitat in the models. Males appear to preferentially select areas around lakeshores, whereas females favour areas near forest streams (see Chapter 2), suggesting a potential avoidance of marten habitat by female mink. To my knowledge there is no literature investigating the potential for competitive interactions between mink and marten. Despite my focus on monitoring mink activities in riparian habitats, there was still higher naïve occupancy for forest dwelling marten (0.77) than for the more riparian mink (0.65), suggesting considerable spatial overlap. Given that marten and mink are of similar size (400-1400 g vs. 500-1500g, respectively), the potential for interactions between these two species is high, a potential effect that should be considered when studying either species in areas of sympatry.

While no reliable data exist for mink diet in my region, an overlap with marten possibly could explain some of the indirect association between the two species, given that the latter primarily feeds on small mammals such as voles (Powell et al. 2003) while mink diet also can be dominated by mice and voles during all seasons (Eagle and Whitman 1995). Additionally, mink (as with several other mustelids) are poorly adapted for extreme temperatures due to their elongated, fusiform body shape (Kruuk et al. 1994). This likely further restricts the diet and habitats accessible to mink in winter due to thermoregulatory limits on their ability to forage in aquatic environments (Kruuk et al. 1994). In Chapter 2 I suggested this may be particularly critical for females due to their smaller body size. In addition to this constraint, much of the aquatic habitat available to mink in summer is unavailable during winter as a result of complete ice cover. I postulate that while mink seem to occur at high densities in altered ecosystems (Larivière 2003) and in areas where they are invasive (Bonesi and Macdonald 2004; Bonesi and Palazon 2007), in their native range these animals are restricted by environmental extremes (low winter temperatures) and competitive pressures in the system.

Interspecific interactions have been documented between American mink and other mustelid species. Ben-David et al. (1996) demonstrated that there was niche partitioning between mink and the North American River Otter (*Lontra canadensis*) in Alaska while mink appeared to be negatively affected by competition with Eurasian Otter (*Lutra lutra*) in Europe (Erlinge 1972; Bonesi et al. 2004). It also has been well documented that introduced American mink have had serious impacts on their European counterpart (Maran and Henttonen 1995; Santulli et al. 2014). However, Lodé (1993) reported no competitive overlap in diets between mink and the more terrestrial European Polecats (*Mustela putorius*) while Harrington and Macdonald (2008) found that mink and polecats overlapped home ranges but avoided simultaneous use of areas. Unfortunately, I had insufficient detections of river otter at our camera stations to use in our analyses, despite the species occurring in relatively abundant numbers in the study area (Johnson et al. 2013).

Table 3.2. Overall QAIC_c model rankings with K (number of parameters), QAIC_{c Δ i} (difference from top model score), QAIC_{c w i} (model weight), $-2\text{Log}(L)$ (negative 2 log likelihood), χ^2 (Chi square value), p (χ^2 associated p-value), and \hat{C} (measure of dispersion) for detection models of American mink in the John Prince Research Forest, central British Columbia, Canada.

Model	K	QAIC _{c$\Delta$$i$}	QAIC _{c$w$$i$}	$-2\text{Log}(L)$	χ^2	p	\hat{C}
$\Psi(\cdot), P(\text{survey})$	4	0.00	0.86	129.13	6.70	0.36	1.10
$\Psi(\cdot), P(\text{julian}+\text{survey})$	5	3.90	0.12	129.13	6.70	0.33	1.10
$\Psi(\cdot), P(\text{temp}+\text{survey})$	5	9.19	0.01	129.13	6.70	0.37	1.05
$\Psi(\cdot), P(\text{marten}+\text{julian}+\text{survey})$	6	9.54	0.01	129.13	6.42	0.37	1.09
$\Psi(\cdot), P(\text{marten}+\text{survey})$	5	12.6	<0.01	129.06	6.43	0.39	1.03
$\Psi(\cdot), P(\text{temp}+\text{julian}+\text{survey})$	6	13.7	<0.01	129.06	6.70	0.36	1.09
$\Psi(\cdot), P(\text{marten}+\text{temp}+\text{survey})$	6	17.5	<0.01	129.06	6.43	0.39	1.02

Table 3.3. Overall QAIC_c model rankings with K (number of parameters), AIC_{cΔi} (difference from top model score), AIC_{cwi} (model weight), $-2\text{Log}(L)$ (negative 2 log likelihood), χ^2 (Chi square value), p (χ^2 associated p-value), and \hat{C} (measure of dispersion) for occupancy models of American mink in the John Prince Research Forest, central British Columbia, Canada.

Model	K	AIC _{cΔi}	AIC _{cwi}	$-2\text{Log}(L)$	χ^2	p	\hat{C}
$\Psi(\text{conifer+beaver}), P(\text{survey})$	6	0.00	0.21	117.65	6.29	0.74	0.62
$\Psi(\text{conifer}), P(\text{survey})$	5	0.79	0.14	120.78	6.22	0.50	0.91
$\Psi(\text{fish+conifer}), P(\text{survey})$	6	1.50	0.10	119.15	6.09	0.49	0.90
$\Psi(\text{marten+fish+conifer}), P(\text{survey})$	7	1.92	0.08	117.17	6.01	0.53	0.89
$\Psi(\text{conifer+marten}), P(\text{survey})$	6	2.07	0.07	119.72	6.17	0.48	0.92
$\Psi(\text{lynx+conifer+beaver}), P(\text{survey})$	7	2.33	0.06	117.58	6.20	0.47	0.94
$\Psi(\text{marten+beaver+conifer}), P(\text{survey})$	7	2.38	0.06	117.63	6.27	0.47	0.93
$\Psi(\text{weasel+beaver+conifer}), P(\text{survey})$	7	2.38	0.06	117.63	6.30	0.45	0.96
$\Psi(\text{fish+beaver+conifer}), P(\text{survey})$	7	2.40	0.06	117.65	6.29	0.76	0.60
$\Psi(\text{riparian+conifer}), P(\text{survey})$	6	3.23	0.04	120.88	6.19	0.69	0.69
$\Psi(\text{fish+weasel+conifer}), P(\text{survey})$	7	3.47	0.04	118.72	6.12	0.50	0.91
$\Psi(\text{lynx+fish+conifer}), P(\text{survey})$	7	3.77	0.03	119.02	6.10	0.50	0.89
$\Psi(\text{marten+beaver+conifer+fish}), P(\text{survey})$	8	3.95	0.03	116.72	5.96	0.52	0.86
$\Psi(\text{beaver}), P(\text{survey})$	5	6.09	0.01	126.08	6.18	0.75	0.62
$\Psi(\text{riparian+beaver}), P(\text{survey})$	6	6.38	0.01	124.03	6.21	0.71	0.64

Table 3.4. Model averaged beta coefficients ($\bar{X}\beta$) and associated confidence intervals (85%) for covariates included in occupancy models of American mink in the John Prince Research Forest, central British Columbia, Canada.

Covariate	$\bar{X}\beta$	Lower 85% CI	Upper 85% CI
Riparian	0.03	-0.10	0.16
Conifer	-8.46	-21.4	4.43
Fishbearing	0.57	0.42	1.10
Beaverlodge	-0.13	-0.44	0.18
Weasel	0.02	-0.04	0.09
Lynx	-0.05	-0.39	0.28
Marten	-0.54	-1.57	0.54

Table 3.5. Overall AIC_c model rankings with $\bar{X}\Psi$ (SE) (average occupancy for model with standard error), $AIC_{c w_i}$ (model weight), and $\bar{X}\Psi_{w_i}$ (SE) (weighted average occupancy for model with standard error) for occupancy models of American mink in the John Prince Research Forest, central British Columbia, Canada.

Model	$\bar{X}\Psi$ (SE)	$AIC_{c w_i}$	$\bar{X}\Psi_{w_i}$ (SE)
$\Psi(\text{conifer+beaver}), P(\text{survey})$	0.74 (0.07)	0.21	0.16 (0.003)
$\Psi(\text{conifer}), P(\text{survey})$	0.82 (0.06)	0.14	0.12 (0.002)
$\Psi(\text{fish+conifer}), P(\text{survey})$	0.75 (0.07)	0.10	0.08 (0.002)
$\Psi(\text{marten+fish+conifer}), P(\text{survey})$	0.77 (0.06)	0.08	0.06 (0.001)
$\Psi(\text{conifer+marten}), P(\text{survey})$	0.81 (0.06)	0.07	0.06 (0.001)
$\Psi(\text{lynx+conifer+beaver}), P(\text{survey})$	0.74 (0.07)	0.06	0.04 (0.001)
$\Psi(\text{marten+beaver+conifer}), P(\text{survey})$	0.74 (0.07)	0.06	0.04 (0.001)
$\Psi(\text{weasel+beaver+conifer}), P(\text{survey})$	0.73 (0.07)	0.06	0.04 (0.001)
$\Psi(\text{fish+beaver+conifer}), P(\text{survey})$	0.73 (0.07)	0.06	0.04 (0.001)
$\Psi(\text{riparian+conifer}), P(\text{survey})$	0.79 (0.06)	0.04	0.03 (0.001)
$\Psi(\text{fish+weasel+conifer}), P(\text{survey})$	0.76 (0.06)	0.04	0.03 (0.001)
$\Psi(\text{lynx+fish+conifer}), P(\text{survey})$	0.78 (0.06)	0.03	0.02 (<0.001)
$\Psi(\text{marten+beaver+conifer+fish}), P(\text{survey})$	0.79 (0.06)	0.03	0.02 (<0.001)
$\Psi(\text{beaver}), P(\text{survey})$	0.77 (0.06)	0.01	0.01 (<0.001)
$\Psi(\text{riparian+beaver}), P(\text{survey})$	0.78 (0.06)	0.01	0.01 (<0.001)

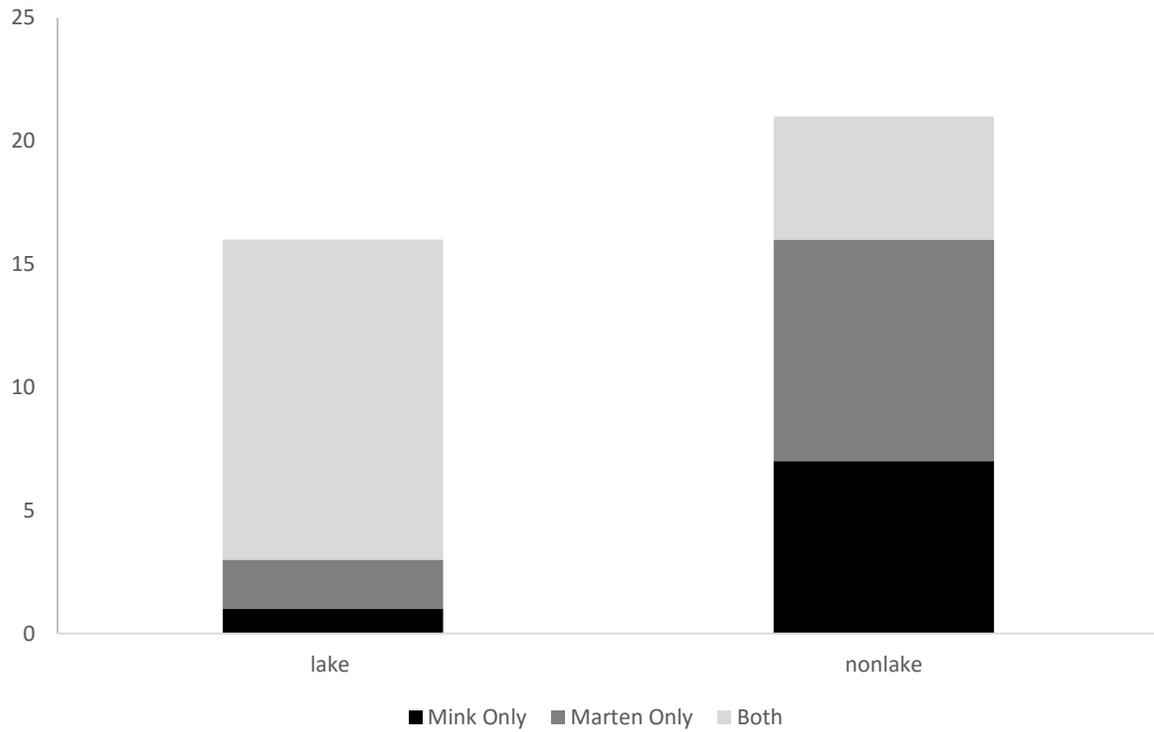


Figure 3.2. Spatial overlap of American marten and American mink detections at camera stations representing “lake” and “non-lake” locations in the John Prince Research Forest, central British Columbia, Canada.

There are limitations to this study that should be recognized. My sample size of camera stations (n=37) was relatively small and may have produced larger coefficients and associated confidence intervals. A single-season analysis is a snapshot in time and may be influenced by conditions in that single year. Also, other species (e.g. river otter) that are abundant and could influence mink occupancy may not have been attracted to the bait and thus would be under-represented. Lastly, there may be spatial autocorrelation between sites that cause marten detections to be over-represented in the models. However, this is less of a concern in light of the associations found with habitat variables (e.g., conifer), and the relatively small scale of measurement (100 m radius) used around the camera sites. One or a combination of these factors may possibly account for some of the model uncertainty found in this study. Notwithstanding, this study provides an important initial data set on a relatively unstudied furbearer in its native habitat.

Large-scale alterations to forest landscapes, including commercial forestry or the recent unprecedented changes caused by forest pests (e.g. pine beetle outbreaks in western Canada) will undoubtedly impact carnivore communities in various ways, including alterations to the coexistence and interaction of species such as those included in this study. Knowledge of these interactions, and how changes to habitat influences the community, are needed to augment more traditional habitat selection studies. Ultimately, understanding the long-term spatial distribution and population dynamics of carnivore communities will be required to craft meaningful management and conservation programs for the taxa.

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CHAPTER 4

IMPLICATIONS, LIMITATIONS, FUTURE RESEARCH DIRECTIONS, AND CONCLUSIONS

IMPLICATIONS

This study explored aspects of North American mink ecology within a freshwater ecosystem during winter within the native range of the species. More specifically, I investigated habitat selection and occupancy patterns of mink in a northern climate where it occurs in sympatry with numerous other meso-carnivores (see Chapter 1). To this end, I assessed (1) patterns of habitat selection across multiple spatial extents, (2) the influence of gender on habitat selection patterns, and (3) the use of remote cameras and occupancy modeling to determine the influence of ecological covariates and species co-occurrence on occupancy patterns.

The following points represent the major findings of my thesis:

- It was beneficial to assess mink space use at multiple spatial extents. This was important because, due to the semi-aquatic nature of mink, riparian features dominate models at a landscape level but at a finer scale more variables/features contribute to explaining selection patterns.
- There was niche separation between male and female mink during winter. While both genders ultimately selected for riparian areas, males tend to select for areas nearer lakeshores while females selected for areas near smaller forest streams.
- Further to the niche separation argument, female mink were located more often at terrestrial resting sites than were males.
- Remote cameras were a useful tool for monitoring mink during winter. However, challenges with small sample sizes can restrict the predictability of occupancy models.
- Mink occupancy was positively associated with fish-bearing streams and had a negative association (though not significant) with the amount of older (>40yrs) coniferous forest surrounding the camera station.

One of the strengths of my investigation is that I used two different techniques to

investigate habitat relationships in the mink population; (1) radio-telemetry paired with resource selection functions (RSF), and, (2) remote cameras paired with occupancy modeling. It is encouraging that I obtained results using the passive technique (i.e. remote cameras) comparable to what the more invasive radio-telemetry methods provided. It is important to note, however, that while the outputs of these methods are comparable, the results and interpretations must be done in context. Resource selection functions are empirically-based, allowing me to identify the strength of mink-resource relationships contingent on selection being related to the life history and fitness requirements of mink (i.e., RSFs are a measure of individual animal selection; Johnson et al. 2006; Johnson and Seip 2008). Occupancy modeling, also empirically based, estimates the likelihood of a space being occupied by a particular animal, even though individual animals in the data set are not known (MacKenzie et al. 2006). Noninvasive camera surveys eliminate the need for animal handling, and occupancy models can provide estimates of habitat suitability (Long et al. 2011). Recently, more emphasis has been placed on these passive detection-nondetection surveys to determine areas that are occupied by various carnivore species (MacKenzie et al. 2006; Long et al. 2011; Schooley et al. 2012) and often these are the only logistically-feasible methods for monitoring elusive and cryptic animals. Additionally, when occupancy modeling is paired with survey methods such as remote cameras that detect multiple species, likelihood-based models can also explore the relationship between species co-occurrence and site occupancy (MacKenzie et al. 2006; Burton et al. 2015). My thesis research demonstrates that these types of passive methods for monitoring animals can provide new, relevant information that will allow researchers and managers to more actively assess the status of mink populations.

The models presented in Chapter 2, derived from radio-telemetry data and RSFs, showed mink habitat selection was related to different variables at different spatial extents. Specifically, riparian features dominated models at larger spatial scales but less so at the finer scale. It is important to make this assessment for organisms that are understudied so that one can be confident the questions about space use are adequately applied (Wheatley and Johnson, 2009). Overall, the presence of features such as beaver lodges and higher stream density best described mink habitat selection. The analyses considering gender demonstrated a divergence in habitat selection between males and females, particularly at the fine scale.

While both male and female mink selected for similar features (i.e. beaver lodges and stream density), these features were selected more often by males in lakeshore areas while females selected these features in forest stream environments. I suggest that these findings could be explained by the large degree of sexual dimorphism and associated challenges with thermoregulation in winter (Kruuk et. al. 1994, Williams 1983). My results support the theory suggesting that largely dimorphic animals should exhibit niche separation in their respective life history strategies.

In Chapter 3, I used remote cameras to assess the influence of ecological covariates and species co-occurrence on occupancy patterns. I found that sites that were located near fish-bearing streams positively affected mink occupancy. I also found a negative association between mink occupancy and the amount of older (>40yrs) coniferous forests (high value marten habitat; Powell et al. 2003). To my knowledge there is no literature investigating the potential for competitive interactions between mink and marten. My research, at least, demonstrates the potential importance of this interaction and provides some context for further investigations.

Although the noticeable difference in sizes between the sexes implies niche separation in this species, this study provides some of the first data supporting this assumption. This differentiation could have implications for maintaining both sexes on the landscape during this critical winter period. Also, while mink are clearly associated with riparian habitat, the notion that mink are rarely found more than a few meters from water (Larivière 2003) has been challenged with my findings. Mink (particularly females) clearly use surrounding forested habitat, suggesting upland forest stands may play an important role in the spatial requirements of mink during winter. These results could have conservation value in that female mink may be at higher risk of disturbance and displacement from resource development in more terrestrial environments during winter. In addition, results from the camera monitoring demonstrated that there are also several other sympatric mammalian carnivores utilizing these sites. For example, despite the fact I focused my monitoring activities on riparian habitats, there was still higher naïve occupancy for forest dwelling marten (0.77) than for the more riparian mink (0.65), suggesting considerable spatial overlap. Given that marten and mink are of similar size (mink: 500-1500g; marten: 400-1400g) it is important to understand these potential interactions and its implications for studies that

investigate the influence of landscape alterations on one or both of these species. While these trends in space use by mink may not be applicable across its range, these results do provide a foundation for initiating future investigations.

The central interior plateau of British Columbia is managed largely as an industrial forestry landscape. My study area in the JPRF, though relatively small, represents this broad area fairly well in terms of ecological classification and wildlife community (see Chapter 1). The results of my thesis work have identified techniques that can be effectively used to monitor mink populations and how they occupy the landscape. Currently, in British Columbia, there is no direct management guidance specifically for American Mink and populations are not monitored, with the exception of trends in trapper fur harvest. As noted in Chapter 1, Class 1 furbearers are not considered sensitive to harvest because seasonal home ranges of viable populations typically can be managed across an individual trapline area (Hatler and Beal 2003). All told, management of these animals remains somewhat passive unless issues are highlighted by trappers or demonstrated in fur harvest returns. Hatler et al. (2008) noted that trappers across northern BC reported a steep decline in mink populations during the 1980s to 1990s yet no tangible explanation has been offered as to why this occurred, and no investigations were initiated. While wild animal populations are well known to fluctuate over time, with increasing development pressures on the landscape we need to try and understand whether these cumulative pressures can be absorbed by populations. In addition, if populations of mink were of concern, the results of this work could be used to tailor trapping efforts such that they minimize risks to reproductive females. These same principles could be applied to forest harvesting to provide more space around riparian areas, thus facilitating the life history needs of female mink. Currently, it is possible that riparian management guidelines do provide enough habitat considerations to accommodate the needs of mink. However, if we consider the potential interactions of multiple competing carnivores occupying the same spaces, the recent intensive salvage logging may not provide enough total habitat. This could become very important in the context of a quickly changing landscape.

LIMITATIONS AND FUTURE RESEARCH DIRECTIONS

This study explored patterns of habitat selection and occupancy, which are limited by the habitat data available for comparisons to movements or detections of animals. As a result,

these approaches cannot assess the role of other resources such as food, which is undoubtedly important, as these data were not available. It is assumed, however, that habitat can be used as a proxy to infer whether a particular area has resources available to support a particular animal.

As with most radio-telemetry studies, my work following individual mink was challenged with logistical constraints and finite resources. Mobility in winter for field staff is challenging in undeveloped areas where free-ranging carnivores move large distances and typically occur at low densities. The range on radio implants for these animals was approximately 500m and average daily movements were as much as 7km. I did not have population density estimates available for mink in my study area and while I acknowledge that my sample size ($n=7$) of telemetered animals was relatively small, I do believe it was a significant proportion of the local population. For example, my study area was approximately 185 km², and according to the predictive models about 13.5% of this total was rated as moderate to high habitat suitability for mink (about 25km²). If the average home range for a mink is 6.5km² and even if there is considerable range overlap, this still suggests a low population density (perhaps as few as 20 animals in total). In addition to sample size, this study was solely focused on the winter season which can be challenging for many animals but does not consider some of the important aspects of mammal life history.

With respect to the camera monitoring, there also were limitations to this study: my sample size of camera stations ($n=37$) was relatively small, and this is reflected in the larger coefficients and associated confidence intervals. Further, a single-season analysis is a snapshot in time that is likely influenced by conditions in that single year. Also, other species (e.g. river otter) that are abundant and could influence mink occupancy may not be attracted to bait and thus be under-represented. Lastly, there may be spatial autocorrelation between sites that cause marten detections to be over-represented in the models. However, this is less of a concern in light of the relationship found with habitat variables (e.g. conifer) given the scale (100m radius) of measurement used around our camera sites and the demonstrated association between marten and older coniferous forests (Powell et al. 2003). Combinations of these factors could possibly account for some of the model uncertainty found in this study.

As noted in Chapter 1, the John Prince Research Forest has initiated a broad project to

investigate the population dynamics and spatial distributions of meso-carnivores in the north-central region of British Columbia. The intent of this program is to develop a solid basis for long-term research and monitoring of these populations in the north-central region. The results of this research has been fully utilized in the continued development of this program. In particular, the development and verification of passive methods for monitoring mink (and other carnivores) has been valuable.

In terms of research needs, there are several remaining gaps in our knowledge of mink ecology that could not be addressed within the scope of this study. From my perspective, there are four research priorities that should be addressed to more completely understand the role of mink in these ecosystems. These are:

1. An investigation into space use and movements during the non-winter seasons.
2. An analysis of diet content and foraging behaviour during all seasons.
3. An examination of the interactions between mink and the other (potentially competing) meso-carnivores in the ecosystem. And specifically, how are the current changes in landscape composition affecting these relationships?
4. An exploration of mark-recapture techniques to quantify mink population densities.

CONCLUSIONS

The forested landscape in north-central British Columbia is undergoing unprecedented changes as a result of high levels of mountain pine beetle associated salvage logging, pipeline development, and mineral exploration and development. It is critical for us, as researchers and managers, to have some basic understanding of how ecological communities function if we are to adequately manage the impacts of these developments and maintain some vestige of carnivore populations. This study has investigated a species that has been understudied in its native range, much less in a similar forest type to that of my research site. I also tested novel questions about a very interesting animal and have shed light on a complex meso-carnivore community that has never been studied as a complete system. I believe this knowledge provides context for mink management while establishing a framework for addressing many more meaningful questions.

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