ASSESSING CUMULATIVE IMPACTS OF FOREST DEVELOPMENT ON THE ABUNDANCE AND DISTRIBUTION OF FURBEARERS

by

Michael C. Bridger

B.Sc., University of Northern British Columbia, 2012

THESIS SUBMITTED IN PARTIAL FULFILLMENT OF
THE REQUIREMENTS FOR THE DEGREE OF
MASTER OF SCIENCE
IN
NATURAL RESOURCES AND ENVIRONMENTAL STUDIES (BIOLOGY)

UNIVERSITY OF NORTHERN BRITISH COLUMBIA

April 2015

Abstract

Furbearer populations across the central-interior of British Columbia, Canada, are exposed to the cumulative impacts of landscape change, particularly as a result of forest harvesting. I elicited knowledge from furbearer experts to develop habitat models for three furbearer species: fisher (*Pekania pennanti*), Canada lynx (*Lynx canadensis*), and American marten (*Martes americana*), and applied the models to reference landscapes to quantify changes in habitat availability and quality from 1990 to 2013. Where forest harvesting was extensive, the models predicted substantial declines in habitat for each focal species. I used trapping records and negative binomial count models to investigate the relationship between habitat change and population abundance of lynx and marten. The top-ranked count models identified combinations of trapping effort, trapline area, and habitat availability and quality as having significantly positive effects on capture success. These results demonstrate the utility of expert knowledge for studying cumulative impacts of landscape change on furbearers.

Table of Contents

List of Tables

List of Figures

Acknowledgements

Funding for this project was provided by the Habitat Conservation Trust Foundation. The original concept for this research was proposed by two of my supervisory committee members, Dr. Chris Johnson and Dr. Mike Gillingham. They were instrumental in the development and implementation of this research project. I would also like to thank the third member of my supervisory committee, Eric Lofroth. His strong background in furbearer ecology was very valuable to this research, and he provided great input, enthusiasm, and time commitments throughout the study.

Chris Johnson's unwavering determination to achieve a successful research product was most greatly appreciated. As the supervisor for this study, Chris provided countless hours of support to ensure its success. From aiding in the development of appropriate research methodologies to the numerous hours of editing, Chris' contributions to this project were invaluable. His role as a mentor and confidant was equally important, and for that I am very grateful. It was an honour and pleasure to work with Mike Gillingham throughout the study. Mike has been a great mentor to me throughout my time at UNBC. His ability to think critically was instrumental in identifying research strengths and weaknesses overlooked by others. I feel very fortunate to have been able to work alongside both Chris and Mike.

I would like to thank Mike Morris and the BC Trappers Association for bringing the issue of cumulative impacts on furbearers to the attention of UNBC. The successful completion of this research could not have been achieved without the help of the amazing expert participants. I would like to thank the following experts for their input, time commitments, and patience during the tedious surveys: Biologist experts – C. Apps, S. Crowley, L. Davis, D. Hatler, D. Hodder, T. Kinley, R. Klafki, G. Mowat, K. Poole, D. Steventon, R. Weir, and Trapper experts – D. Bell, B. Frederick, B. McKay, B. Monroe, M. Richards, W. Sharpe, G. Smith, G. Tencarre, E. Voelk, D. Wilkins.

My time spent at UNBC made the completion of my research thesis that much more enjoyable. The relationships developed with friends and faculty at the university went a long way towards achieving a successful project. I will be forever grateful for the support of my family, friends and office mates. They have all been a huge support system for me, and I am thankful for their ongoing enthusiasm and encouragement.

Chapter 1: General Introduction

Background

Natural resource managers must consider the importance of the cumulative impacts of anthropogenic and natural landscape change when managing wildlife habitat and populations (Schneider et al. 2003, Johnson 2011). Cumulative impacts can be complex and difficult to understand when compared to acute, immediate changes to habitat. They can be a result of natural or anthropogenic activities at a range of temporal and spatial scales and they can be interactive, additive, or synergistic in nature (Nitschke 2008, Johnson 2011). Rapid resource extraction can result in cumulative impacts that affect economic, cultural, and ecological resources including the distribution and abundance of wildlife (Nitschke 2008). Species that are dependent on continuous tracts of late-seral habitat may be particularly susceptible to habitat loss and fragmentation associated with cumulative landscape change (Schneider et al. 2003, Nitschke 2008). Conversely, generalist species may increase as a result of landscape changes that create openings, young forests, and edge habitat.

Furbearer populations found across the central-interior of British Columbia (BC), Canada (Figure 1.1), are exposed to the cumulative impacts of landscape change. This region has been subjected to unprecedented levels of timber harvesting following the rapid development of the forestry sector. Levels of timber harvest were historically high, but have accelerated over the past ten years in response to a mountain pine beetle (*Dendroctonus ponderosae*) epidemic that has killed 53% of merchantable pine stands province-wide (BC Ministry of Forests, Mines, and Lands 2010). Natural disturbance, including fire, insects, disease outbreak, and wind events may also reduce the availability of habitat for furbearers. The cumulative impacts of anthropogenic and natural disturbance are especially concerning for some species of furbearers thought to be sensitive to human disturbance and the loss of late successional forests.

Furbearers play important roles within the ecosystem and have significant cultural and economic importance for the fur-trapping industry throughout North America (Webb and Boyce 2009). Local trapping organizations have reported declines in the abundance of a number of furbearer species across central-interior BC (M. Bridger unpub. data), yet there is a lack of monitoring and management in response to those observations (Webb et al. 2008). There is an immediate need to investigate the long-term impacts of cumulative landscape change on the habitat and abundance of furbearer populations.

Many furbearer species act as indicators of healthy ecosystems (Buskirk 1992, Wiebe et al. 2013). American marten (*Martes americana*) and fisher (*Pekania pennanti*), for example, are often associated with intact, late-successional forests (Thompson and Colgan 1994, Payer and Harrison 2003, Weir and Harestad 2003, Proulx 2006, Proulx 2011). These forests provide structural complexity and other attributes that are vital to the persistence of furbearers and other old-growth dependent species (Buskirk 1992, Payer and Harrison 2003, Proulx 2006). Other furbearer species, like Canada lynx (*Lynx canadensis*), may thrive across landscapes where different stages of successional forests are present; old-growth forests may provide habitat for denning and resting, while regenerating forests support prey (Hoving et al. 2004).

The habitat requirements and disturbance responses of furbearers to landscape change are not well quantified, presenting challenges to natural resource professionals. Biologists and forest managers, however, recognize that many furbearer species avoid forest openings associated with industrial activity and habitat disturbance (Thompson and Colgan 1994, Hargis et al. 1999, Potvin et al. 2000, Fuller and Harrison 2005, Proulx 2009). Furthermore, fragmentation of habitat at larger spatial scales may affect population productivity (Payer and Harrison 2003). The reduction and fragmentation of old forest across landscapes may have profound long-term effects on the abundance and persistence of furbearer populations (Thompson 1994, Proulx 2000).

Expert-based wildlife studies may serve as an alternative to empirical-based research, particularly when the cryptic behaviour of many furbearer species makes them difficult to study (Ruette et al. 2003). Where empirical data are lacking, expert knowledge can provide useful insights on cumulative impacts and their influence on the distribution and abundance of furbearers. Expert-based studies have faced skepticism in the past due to the inherent difficulties in assessing the variability, uncertainty, and accuracy of expert knowledge (Drescher et al. 2013). Expert-based wildlife studies, however, can achieve scientific credibility through the application of rigorous and repeatable methods. Thus, there has been an increase in the use and acceptance of expert knowledge in ecological studies over the past 20 years (Drescher et al. 2013).

When elicited effectively, expert knowledge can be used to parameterise predictive habitat models (Store and Kangas 2001, Johnson and Gillingham 2004, O'Neill et al. 2008, Burgman et al. 2011b, Johnson et al. 2012). Additionally, expert-based approaches are effective for collecting and evaluating harvest data, such as trapping records, which can be used to quantify and explore population change over time (Erickson 1982, Raphael 1994). For example, consultations with fur trappers can allow researchers to control for factors known to influence capture success, such as trapping effort. By accounting for such factors, trapping data can be used to determine the impacts of habitat change on population abundance.

Research Objectives

The primary goal of my research was to understand of the influence of cumulative landscape change on the availability of habitat and, ultimately, the abundance of furbearer populations found across the central-interior of BC. To meet that goal, I developed and addressed the following three research objectives:

1) Develop expert-based habitat models for fisher, lynx, and marten, and map changes in habitat availability and quality from 1990 to 2013 (Chapter 2). I elicited expert knowledge from furbearer biologists and trappers that described the habitat relationships of the three focal species. I used that knowledge to develop habitat models that were applied to ten registered traplines that served as reference landscapes. The experts provided input throughout the study, including the selection of focal species and the identification and evaluation of habitat variables that were included in the models. I applied the habitat models to the reference landscapes at four time intervals (i.e., 1990, 2000, 2005, and 2013) to quantify temporal changes in habitat availability and quality. I tested the utility of the expert-based modeling approach by quantifying uncertainty and variation in the expert responses.

2) Use trapping records to quantify the harvest, and ultimately population changes, of two furbearer species following changes in the availability and quality of habitat across the reference landscapes (Chapter 3). I collected trapping records, dating back to 1990, from ten trappers for lynx and marten. I used negative binomial count

models to investigate the factors hypothesised to influence capture success, including habitat availability and quality, trapline size, trapping effort, and climatic variables. By controlling for confounding variables, I was able to investigate the effect of habitat change on the population abundance of lynx and marten, while examining the utility of trapping records as a measure of abundance.

3) Identify important issues and concerns, as expressed by trappers and biologists, in the management of furbearer habitat and populations, and develop recommendations to address the impacts of cumulative habitat change for those species (Chapter 4). I conducted semi-structured interviews with furbearer biologists and trappers to discuss the management of fisher, lynx, marten, and the broader group of furbearers within BC. The interviews guided experts to identify key concerns regarding the management of furbearer habitat and populations, and subsequently to provide recommendations in response to those concerns.

Taken together, results of this study provide a broader understanding of the habitat ecology of furbearers in BC, including their response to landscape change. This understanding is a prerequisite for sustaining, restoring or enhancing furbearer habitat. The study process increased the participation of stakeholders in both the extension of research results and the management of furbearer habitat. Finally, I investigated the utility of expert-based methods for understanding habitat and population change. A transparent and rigorous process, continuous expert engagement, and relatively low uncertainty in model results suggested that the methods applied throughout this study were robust and likely suitable for rapid studies of cumulative habitat change for other species.

Study Area

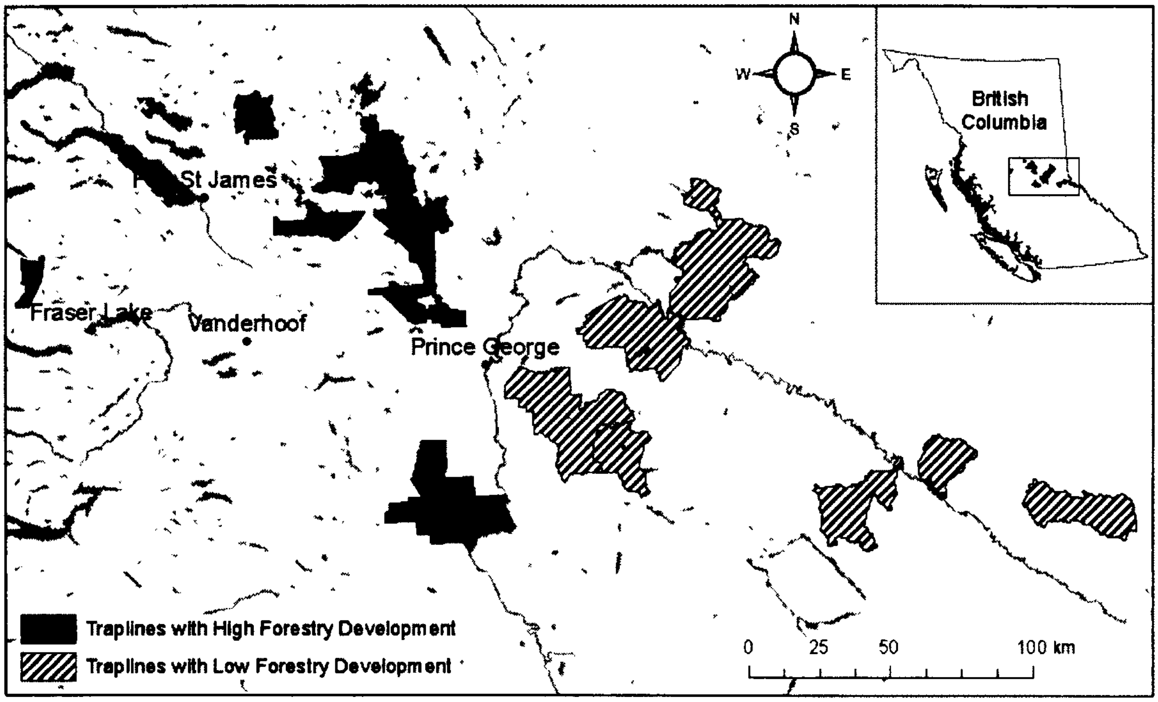


Figure 1.1. Location of reference landscapes (i.e., registered traplines) for the application of habitat models and population analysis for fisher, lynx, and marten across central-interior BC, Canada. Cumulative impacts in the form of forestry development were extensive on the dark-shaded traplines (West Study Area) during the study period, while the hash-marked traplines (East Study Area) had much less harvesting.

The application of habitat models and the population assessments for the focal species occurred across ten reference landscapes consisting of 17 registered traplines belonging to ten trappers. The reference landscapes were subjected to varying levels of industrial development: high levels of forest harvesting (up to 75% of the trapline area harvested in the past 40 years; hereafter referred to as the 'West Study Area') and minimal levels of harvesting (up to 11% of the trapline area harvested in the past 40 years; hereafter referred to as the 'East Study Area'). Intensive salvage logging that occurred in the West Study Area was in response to a mountain pine beetle epidemic that began during the early 2000's. Increased harvesting across that area resulted in reduced forestry activity in tenures that did not contain a large component of lodgepole pine (*Pinus contorta*); such areas were found in the East Study Area. There were ten traplines in the West Study Area, registered to six trappers and encompassing an area of 244,923 ha. There were seven traplines in the East Study Area registered to four trappers; these reference landscapes encompassed a total area of 357,767 ha.

The reference landscapes were approximately centered on the city of Prince George within the central-interior of BC, Canada (Figure 1.1). In the West Study Area, landscapes occurred primarily within the Sub-Boreal Spruce (SBS) biogeoclimatic zone (Meidinger and Pojar 1991). The climate of the SBS zone is characterized by severe, snowy winters with mean monthly temperatures below 0° C for the months of November to February. Summers are warm, moist and short with mean monthly temperatures above 10° C. Mean annual precipitation ranges from 440–900 mm, 25–50% of which is in the form of snow. The SBS zone is generally between 1100–1300 m, and is dominated by upland coniferous forests consisting of hybrid spruce (*Picea engelmannii x glauca*), subalpine fir (*Abies lasiocarpa*), lodgepole pine, or Douglas-fir (*Pseudotsuga menziesii*) on dry, warm sites. Trembling aspen (*Populus tremuloides*) and paper birch (*Betula papyrifera*) are common deciduous species. The extensive timber harvesting in this area has resulted in a seral distribution that is skewed towards younger age classes. The SBS zone contains ideal habitat for a variety of furbearers, including marten, fisher, lynx, wolverine (*Gulo gulo*), and beaver (*Castor canadensis*), resulting in some of the province's highest fur-harvest levels.

The East Study Area includes portions of the SBS and the Engelmann Spruce-Subalpine Fir (ESSF) biogeoclimatic zone (Meidinger and Pojar 1991). The ESSF zone generally occurs above the SBS zone at elevations ranging from 900–1700 m. Low temperatures are common with mean monthly temperatures below 0° C for the months of November to April. Mean annual precipitation may range from 500–2200 mm, with snow accounting for 50–70% of the total precipitation. Engelmann spruce (*Picea engelmannii*) and subalpine fir are the dominant climax species, but lodgepole pine is also present. Small areas of interior cedar-hemlock forests are also found within the East Study Area.

Chapter 2: Assessing the cumulative impacts of forest development on the distribution of furbearers using an expert-based habitat modeling approach

Abstract: Cumulative impacts of anthropogenic landscape change must be considered when managing and conserving wildlife habitat. Across the central-interior of BC, Canada, industrial activities are altering the habitat of furbearer species. This region has witnessed unprecedented levels of anthropogenic landscape change following rapid development in a number of resource sectors, particularly forestry. Our[1] objective was to create expert-based habitat models for three furbearer species: fisher (*Pekania pennanti*), Canada lynx (*Lynx canadensis*), and American marten (*Martes americana*) and quantify habitat change for those species. We recruited ten biologist and ten trapper experts and then used the analytical hierarchy process to elicit expert knowledge of habitat variables important to each species. We applied the models to reference landscapes (i.e., registered traplines) in two distinct study areas and then quantified the change in habitat availability from 1990 to 2013. There was strong agreement between expert groups in the choice of habitat variables and associated scores. Where anthropogenic impacts had increased considerably over the study period, the habitat models showed substantial declines in habitat availability for each focal species (78% decline in optimal fisher habitat; 83% decline in optimal lynx habitat; and 79% decline in optimal marten habitat). For those traplines with relatively little forest harvesting, the habitat models showed no substantial change in the availability of habitat over time. These results suggest that habitat for these three furbearer species declined significantly as a result of the cumulative impacts of forest harvesting. Results of this study illustrate the utility of expert knowledge for understanding large-scale patterns of habitat change over long time periods.

[1] I used first-person plural to acknowledge co-authorship for the publication of thesis Chapters 2 and 3.

Introduction

Furbearers have significant cultural and economic importance for fur-trapping communities (Hamilton et al. 1998, Webb and Boyce 2009). Furthermore, many furbearer species act as indicators of healthy ecosystems (Buskirk 1992, Wiebe et al. 2013). For example, American marten (*Martes americana*) and fisher (*Pekania pennanti*) are often associated with intact, late-successional forests (Thompson and Colgan 1994, Payer and Harrison 2003, Weir and Harestad 2003, Proulx 2006, Proulx 2011). Other species, like Canada lynx (*Lynx canadensis*), may thrive where different stages of successional forests are present; old-growth forests may provide habitat for denning and resting, while regenerating forests support prey species (Hoving et al. 2004). Cumulative landscape change can have profound effects for furbearer habitat and populations, yet in many jurisdictions there is little to no monitoring and research to document these impacts.

Furbearers are thought to be susceptible to habitat loss and fragmentation (Soutiere 1979, Thompson and Colgan 1994, Hargis et al. 1999, Potvin et al. 2000, Proulx 2000, Fuller and Harrison 2005, Weir and Almuedo 2010, Weir and Corbould 2010). Across the central-interior of British Columbia (BC), Canada, levels of timber harvest were historically high, but have accelerated over the past ten years in response to a mountain pine beetle (*Dendroctonus ponderosae*) epidemic which has killed 53% of merchantable pine stands (BC Ministry of Forests, Mines, and Lands 2010). The magnitude of these impacts, relative to the distribution and abundance of furbearers, is unknown. Although many past studies have investigated fine-scale changes in habitat, few studies have attempted to address such questions at large spatial or temporal scales.

Anthropogenic activities, such as forest harvesting, may result in the immediate loss or fragmentation of habitat. Alternatively, the impacts of many developments accumulate over a long timeframe. Compared to acute, immediate changes to habitat, cumulative impacts can be complex and difficult to understand (Johnson 2011). These impacts are the result of natural or anthropogenic processes and events that may accumulate due to changes in environmental and socio-economic systems at varying temporal and spatial scales (Nitschke 2008). In addition to being additive, cumulative impacts can be interactive or synergistic in nature (Nitschke 2008, Johnson 2011). Cumulative landscape change may have profound impacts on the quality and distribution of furbearer habitat that persist for many years (Thompson 1994, Proulx 2000).

Species-distribution models can be an important tool for quantifying cumulative changes in the availability or quality of wildlife habitat. These models are typically empirical, relating field observations of a species' occurrence to environmental variables hypothesised to influence species distribution (Guisan and Zimmerman 2000, Guisan and Thuiller 2005, Johnson et al. 2012). When empirical data are unavailable, expert knowledge can be used to parameterise such models. Experts can formulate model structure, including the identification of important variables, and provide quantitative scores denoting the importance of each predictor. When elicited effectively, expert knowledge can be a valuable source of information and data for developing and parameterising predictive habitat models and subsequent maps (Store and Kangas 2001, Johnson and Gillingham 2004, O'Neill et al. 2008, Burgman et al. 2011b, Johnson et al. 2012). Such maps can quantify habitat change over time and space, and aid in management and planning decisions (Johnson et al. 2012).

There has been an increase in the use of expert knowledge in ecological studies in the last 20 years (Drescher et al. 2013). Expert knowledge, however, may still face skepticism when compared to empirical research (McBride and Burgman 2012). When developed or implemented poorly, such studies may be biased by the methods used to acquire the expert knowledge (Martin et al. 2011, McBride and Burgman 2012). Furthermore, there are inherent difficulties when assessing the variability, uncertainty, and accuracy of expert knowledge (Drescher et al. 2013). Wildlife studies incorporating expert knowledge can achieve scientific credibility by adopting rigorous methods that include an unbiased sample of experts, transparent and repeatable elicitation of knowledge, and the quantification of uncertainty (Burgman et al. 2011a, Johnson et al. 2012, McBride and Burgman 2012, Drescher et al. 2013). When conducted effectively, expert knowledge can serve as an excellent source of information for studying cumulative impacts at a large spatial scale, particularly when empirical data are limited.

The objective of this study was to use expert knowledge to quantify the cumulative impacts of landscape change relative to the availability and quality of furbearer habitat. We elicited expert knowledge and parameterised species-distribution models representing the habitat of fisher, lynx, and marten. The models were used to develop a chronology of maps displaying habitat change since 1990 across traplines subjected to high levels of forestry development (hereafter referred to as the 'West Study Area') and traplines subjected to minimal levels of forestry development (hereafter referred to as the 'East Study Area'; Figure 1.1). We evaluated the utility and consistency of knowledge from two groups of experts with different domains of expertise: trappers with intimate knowledge of their trapping areas and furbearer biologists with a potentially broader perspective on the habitat ecology of the focal species. We hypothesised that the distribution and quality of furbearer habitat would decline following rapid and extensive cumulative landscape changes.

Methods

We used expert-based habitat models to map and quantify habitat change for three focal furbearer species. We recruited experts from two distinct groups and elicited expert knowledge that would aid in the development of habitat models for each species. The models were applied spatially to ten trapline areas that served as reference landscapes and at four time intervals (i.e., 1990, 2000, 2005, and 2013), which represented increasing levels of forest harvesting. Using this approach, we quantified cumulative habitat change over time as well as the uncertainty in those predictions.

Identification of Experts

We recruited 21 experts from two general categories: professional experts in the form of furbearer biologists, and expert practitioners in the form of furbearer trappers. Although there are no specific criteria to identify the appropriate number of experts for such studies, it is important that the participants represent the knowledge bounds relative to the study objectives and that the sample is large enough to prevent significant bias or error from any one expert (McBride and Burgman 2012). We used peer-referral techniques to identify a collection of potential candidates from both categories of experts. Where a population of experts may be difficult to enumerate, peer-referral techniques provided a practical method for identifying appropriate individuals to represent the expert community.

Identification of Biologist Experts

We used three rounds of peer-referral to identify three seed experts, eight subsequent experts, and an advisory expert. The role of the seed experts was to recommend additional experts, who in turn, were asked to nominate further experts. The role of the advisory expert was to review the suitability and appropriateness of the research surveys, and provide feedback or possible revisions before submission to the expert groups.

We conducted a thorough literature review of furbearer research in BC to identify a group of candidate biologist experts. We identified one seed expert from each of the following disciplines: government biologists, academic researchers, and private-consulting biologists. They were selected based on their expertise in the field of furbearer ecology, including their knowledge of, and access to, further experts.

We established a set of criteria to ensure candidate experts were credible and qualified (Table 2.1). Drawing from these criteria, the seed experts were asked to provide a list of furbearer biologists currently working within BC, and subsequently rank the candidates in terms of suitability for the study. We then contacted the top four ranked candidates and invited them to participate in the study. They were then asked to submit a further list and ranking of candidate furbearer biologists (using the set of criteria for guidance). We recruited the top four ranked experts in the second round of referral, providing us with a total of ten professional experts (including two of the seed experts; Figure 2.1). We then identified the advisory expert from the list of candidates.

Table 2.1. Criteria for the recruitment of suitable biologist and trappers experts for the development of expert-based habitat models. These criteria served as a guide during the peer-referral phase of expert identification.

General Criteria	Thresholds	Explanation of Criteria
Biologist Experts		
Years of direct experience with furbearer ecology	$\geq$5 years	General research experience with furbearer species including habitat use, behaviour, and/or landscape change.
Number of relevant publications/reports	$\geq$3 publications	Peer-reviewed or relevant grey literature.
In-depth knowledge of specific species biology	$\geq$1 species	Focused research on one or more furbearer species.
Location of past research	BC	Knowledge specific to British Columbia; ideally, knowledgeable of furbearer habitat and populations found in central-interior BC.
Trapper Experts		
Number of years trapping	$\geq$15 years	Total years of trapping furbearers native to North America.
Number of continuous years trapping on current trapline	$\geq$10 years	Specific local knowledge of trapping landscape, habitat features, habitat use, habitat change, etc.
Location of current trapline	Central-interior BC	Current trapline located in north-central BC.
Extent of personal trapping records	$\geq$10 years	Detailed records of captures, effort level, etc.
Levels of landscape change on trapline	Case-dependent	Forms and extent of past or present landscape change; may range from very little to extensive change across trapline.

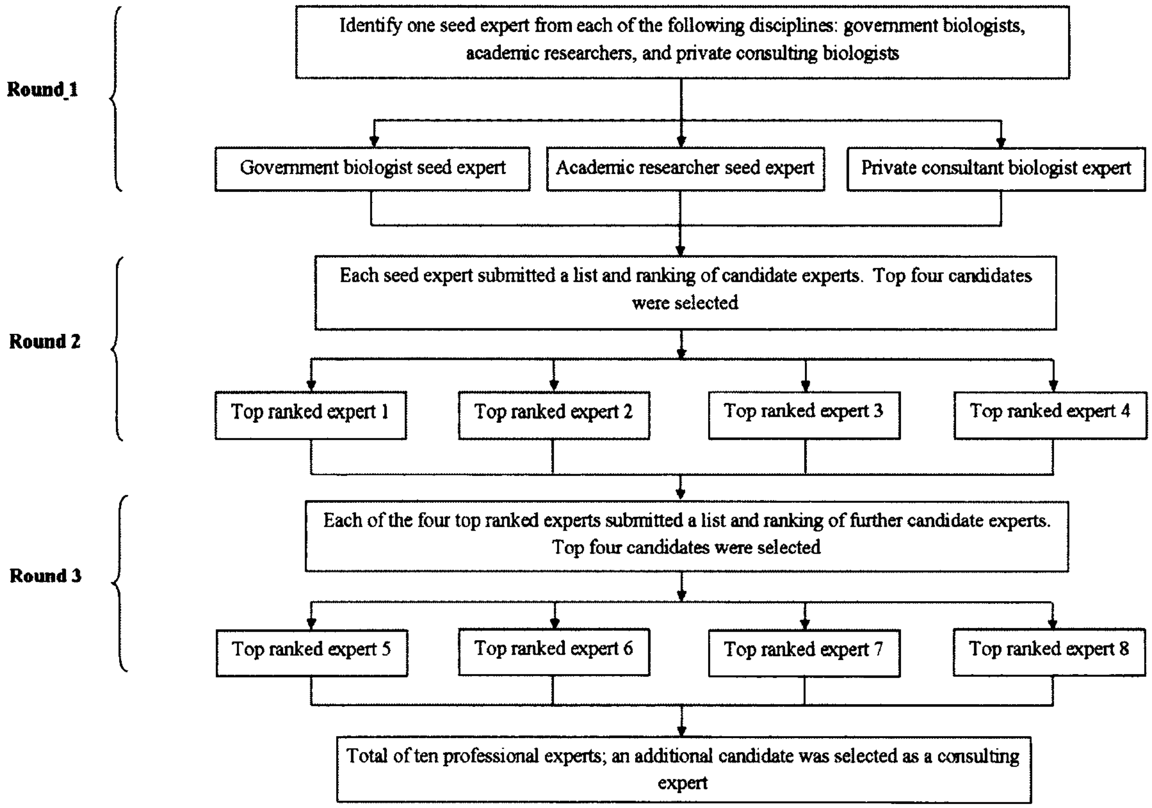


Figure 2.1. The peer-referral method used for identifying biologist experts for the development of expert-based habitat models. The first round of peer-referral required the identification of seed experts, followed by two rounds of further nominations of experts.

Identification of Trapper Experts

We sought guidance from the former president of the British Columbia Trappers Association who identified two seed experts that had knowledge of, and access to, many suitable candidate experts, in this case local experts. As with the biologists, we established a set of criteria (Table 2.1) to be used as a reference when selecting trappers. Applying these criteria, the seed experts submitted a list of qualified trappers to participate in the study. Because traplines were to be used as reference landscapes for modeling habitat, it was critical to identify trappers with traplines that were located within the proposed study area. We conducted a short survey (Appendix A) and ranked each trapper in terms of their ability to meet the study objective. Of the eight top-ranked candidates, all agreed to participate (Figure 2.2).

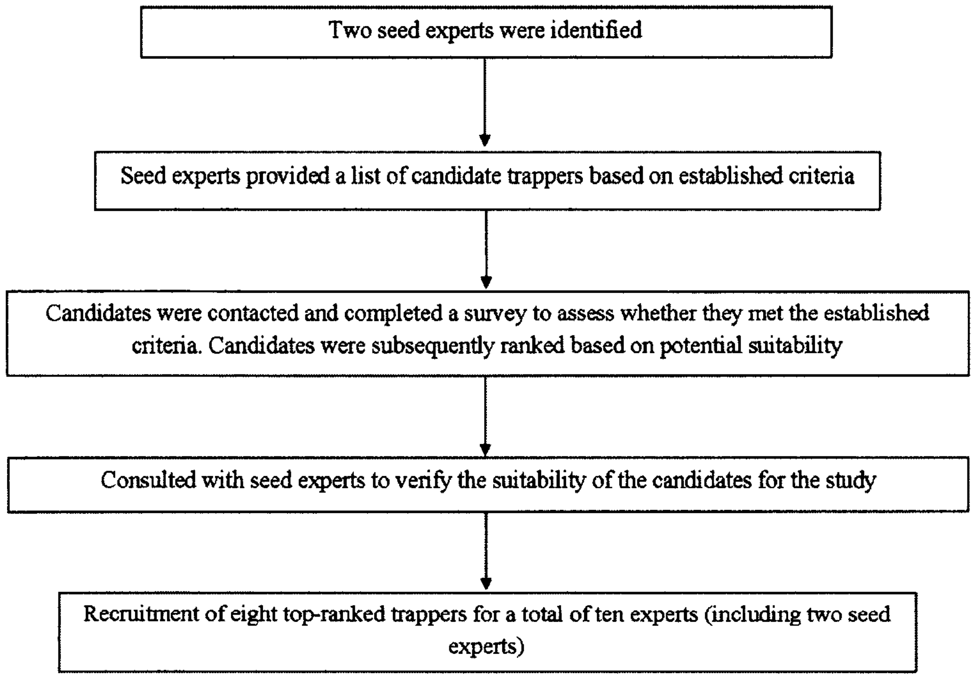


Figure 2.2. The peer-referral method used for identifying trapper experts for the development of expert-based habitat models. Seed experts identified candidates that met specific criteria and were selected based on their suitability for the study.

Elicitation of Expert Knowledge

Prior to, and throughout the elicitation process experts were made aware of the time commitments expected, the type of information to be elicited, and how that information would be used. During the elicitation, we met with individual trapper experts in person or via telephone to conduct surveys. Due to travel and time constraints, all surveys with biologists were conducted via email and portable document format (PDF) forms. Prior to conducting a survey, we submitted the set of proposed questions and topics to the advisory expert for review.

Identification of Focal Species

The first step in the elicitation process required the experts to complete a survey identifying three focal furbearer species for the study (Appendix B). The experts were asked to identify those species that were most sensitive to landscape change resulting from anthropogenic activities. We tallied the number of selections for each species from the biologist experts and the trapper experts separately to observe the agreement within and between groups. The expert responses were then combined and totaled and we identified the three species with the greatest number of selections.

Identification of Habitat Variables

We conducted a thorough literature review and identified 18 candidate habitat and disturbance variables (Appendix B) hypothesised to influence the distribution of the focal species. Experts were asked to provide a score from 0–4 for each variable, representing its relative importance in contributing to habitat for each focal species (Appendix B). Experts were also asked to provide a confidence score on a scale from 1–10, representing the confidence that the expert had in assessing each variable.

We used a Wilcoxon rank-sum test to measure the significance of differences in scores between expert groups (Stata, ver. 12.1, StataCorp, 2011). Few differences occurred, thus the expert scores were combined. We established a model inclusion threshold of '2'; any variable meeting this threshold was considered to be at least moderately important and was included in the respective habitat model. All habitat variables that were included in the models for each species were further classified into subclasses, levels, or categories (Appendix C). The classifications were based on previous literature, or on-the-ground measurements.

We used the analytical hierarchy process (AHP; Saaty 1977) to develop the expert-based habitat models (Appendix B). Analytical hierarchy process is a decision making process in which experts provide pairwise comparisons of the relative importance of two habitat criteria. A form of multi-criteria evaluation, AHP provides structure to the elicitation process so that each variable is evaluated consistently across all participating experts (Johnson et al. 2012). Experts provided pairwise scores, on a nine-point scale, of the relative importance of every possible combination of habitat variables and associated subclasses of those variables (Tables 2.2, 2.3). Before scoring the variables, experts were provided with detailed instruction on the AHP protocols and examples of AHP matrices. We also provided a handout containing photographic examples of different classifications of most habitat variables (Appendix B). This was used to aid the experts in visualizing the features during the elicitation process, and increase consistency across expert responses. Experts also provided confidence scores for each completed matrix.

After the elicitation process, we calculated eigenvector values and consistency ratio scores (Microsoft Excel, ver.14.0, Microsoft Corporation, 2010). The eigenvector values represented the relative importance of each classification of habitat variables (Saaty 1977). Consistency ratios, which tested the probability that the matrices were randomly generated (Saaty 1977), were used to assess the matrices for operative errors. Initially, we kept the biologist and trapper responses separate and conducted a Wilcoxon rank-sum test to examine the differences in eigenvector scores between expert groups. We then combined the expert scores for both groups and calculated the mean eigenvector scores, along with the standard error and 95% confidence intervals. We used the mean eigenvector scores (representing the relative value of each habitat variable) to build the expert-based habitat models.

Table 2.2. Example of an AHP matrix that evaluates preferred topographic elevation by a theoretical species. For example, <500 m compared to itself is of equal importance, represented by a score of '1', 1000 m–1500 m is very strongly more important than <500 m, represented by a score of '7', and >2000 m is moderately less important than <500 m, represented by a score of '1/3'. All shaded columns are the inverse of their respective scores. The outputs of each AHP matrix are eigenvector scores, representing the relative value of each habitat class.

	<500 m	500 m – <1000 m	1000 m – <1500 m	1500 m – <2000 m	≥2000 m
<500 m	1				
500 m–<1000 m	3	1			
1000 m–<1500 m	7	5	1		
1500 m–<2000 m	5	3	1/3	1	
≥2000 m	1/3	1/5	1/7	1/5	1

Table 2.3. Scoring scheme used by experts for the pairwise comparisons of habitat variables.

Positive Values	Negative Values
1 = Equal importance	1 = Equal importance
3 = Moderately more important	1/3 = Moderately less important
5 = Strongly more important	1/5 = Strongly less important
7 = Very strongly more important	1/7 = Very strongly less important
9 = Extremely strongly more important	1/9 = Extremely strongly less important

Mapping Habitat

We used Geographic Information Systems (GIS) to develop a chronology of maps showing habitat change across the ten reference landscapes/traplines at four time intervals: 1990, 2000, 2005, and 2013 (ArcGIS ver. 10.1, ESRI Inc., 2012). Habitat variables were represented by a number of spatial data sources (Table 2.4). Primarily, we used a broad-scale, forest-cover layer, the BC Vegetation Resource Inventory (VRI; DataBC Distribution Service), which contained numerous forest attributes used for the elicitation process (Appendix C). The VRI data were unavailable for 10% of one trapline and 25% of another;

these areas were removed from the analysis. All large water-bodies were also removed from the analysis.

Table 2.4. List of habitat variables and spatial data sources used for the development of expert-based habitat models.

Habitat Variable	Spatial Data Source
Canopy Cover, Coarse Woody Debris, Forest Stand Age, Forest Stand Density, Ground Shrub Cover, Leading Tree Species, Structural Complexity	Vegetation Resource Inventory – DataBC Distribution Service (http://www.data.gov.bc.ca/)
Cutblock Age	Vegetation Resource Inventory and Forest Tenure Cutblock Polygons – DataBC Distribution Service (http://www.data.gov.bc.ca/)
Forest Fire Age	Fire Perimeters – Historical – DataBC Distribution Service (http://www.data.gov.bc.ca/)
Habitat Connectivity	GIS-derived variable
Proportion of Landscape Harvested	GIS-derived variable

We used multiple data sources to represent the history of forest harvesting across the study landscape. We retrieved the cutblock (logging) polygons from the VRI layer (DataBC Distribution Service) and the Forest Tenure Cutblock layer (DataBC Distribution Service). All polygons within the cutblock layer that had a projected age >40 years old (relative to the map date), basal area >10 m^2/ha, and canopy cover >10%, were removed from the cutblock layer and merged with the VRI layer; these polygons were considered reforested. Habitat connectivity was calculated according to the adjacency of mature forest stands with harvested or disturbed patches (i.e., cutblocks). High values for connectivity (based on expert scores) were applied to forest polygons adjacent to one another, while forest polygons adjacent to, or intersected by, disturbances or openings were given lower values. Finally, forest fire age was derived from the Fire Perimeters – Historical layer (DataBC Distribution Service). All fire polygons >40 years old were removed from the layer and considered reforested.

There were no corporate data representing the historical growth and composition of BC's forests. Thus, for the historical landscapes (1990, 2000, and 2005), stand attributes were back-dated to account for change over time. Because the contemporary VRI layer contained cutblock polygons that were harvested after the 1990, 2000, and 2005 time periods, those 'future cutblocks' required designation of forest attributes that best represented the historical forest stand. To do this, we selected for all forest-cover polygons directly adjacent to the 'future cutblock' polygons and used VRI data to determine the most likely leading tree species, and the average canopy cover, basal area, shrub cover, and forest stand age. In order to back-date the canopy cover and basal area, we used VRI data to determine the natural rate of change based on forest stand age. We assumed that the leading tree species for each harvested block was constant over the study period.

All spatial data were rasterized (25x25-m cell) and the mean eigenvector scores for each habitat variable were applied to their respective raster layer (IDRISI Selva ver. 17, Clark Labs, 2011). Raster layers were then combined additively to generate one habitat map for each focal species on each reference landscape at four time intervals. For each historical map we classified the habitat into four classes (i.e., Poor, Moderate, Good, and Very Good). The categorical break points were calculated as the quartile values of the habitat scores for the year-2000 map. This allowed for the consistent comparison of the change in habitat area over time (i.e., the cumulative impacts of landscape change). These maps also illustrated the spatial configuration of habitat across the landscape.

Map Variation and Validation

Expert-based habitat models can be sensitive to variation in the knowledge elicited from the experts (Johnson and Gillingham 2004). Thus, we calculated the upper and lower 95% confidence intervals for the combined eigenvector scores for the biologist and trapper experts and recreated the habitat maps. We recalculated the area of each habitat class and used the difference between the upper and lower 95th percentile maps to represent the variation around the mean predicted area of habitat. Additionally, we recreated habitat maps based on the eigenvector scores of the biologists and trappers separately. We quantified habitat change according to the recreated maps and compared these values to the combined expert maps in order to determine variation between expert groups.

As one form of validation, we asked each trapper to evaluate the distribution and area of ranked habitat for their traplines. Trappers located both good and poor trapping areas on generic maps of their traplines, and then compared those locations to the expert-based habitat maps for each focal species. For each species, trappers were asked to provide a score from 0–10 representing the accuracy of the maps of predicted habitat.

Results

Identification of Focal Species

Experts identified three species that were most suitable for this study, based on their perceived ecological and economic importance, and susceptibility to landscape change. The biologists identified marten, lynx, and fisher while the trappers identified marten, lynx, and beaver (*Castor canadensis*). Trappers also suggested wolverine (*Gulo gulo*) and red squirrel (*Tamiasciurus hudsonicus*), while biologists identified ermine (*Mustela erminea*), mink

(*Neovison vison*), and otter (*Lontra canadensis*) as other potential candidates. When combined, marten, lynx, and fisher were selected as the most suitable focal species.

Identification of Habitat Variables

We provided the experts with a list of 18 candidate habitat variables for each focal species. Eleven variables were voted into the habitat models for fisher and marten, while ten variables were voted into the lynx model (Figure 2.3).

The combined scores for the inclusion of habitat variables for fisher was highest for structural complexity, while cutblock age was highest for lynx, and coarse woody debris was highest for marten. Uncertainty in the selection of habitat variables by biologists was lowest for fisher (SE = 0.283) and highest for lynx (SE = 0.312). For trappers, uncertainty was lowest for marten (SE = 0.279) and highest for fisher habitat variables (SE = 0.333). Confidence scores were highest for biologists and trappers when voting for lynx habitat variables ($\bar{x}$ confidence scores = 7.12 and 8.57, respectively) and lowest when biologists voted for marten ($\bar{x}$ = 6.94) and when trappers voted for habitat variables for fisher ($\bar{x}$ = 8.10).

Overall, there was high consistency in the selection of variables by the two expert groups. A Wilcoxon rank-sum test revealed significant differences in scores between expert groups for Canopy Cover ($z = 1.994$, $P = 0.046$) and Forest Stand Age ($z = 2.743$, $P = 0.006$) in the marten model. There were no significant differences in voting between expert groups for the fisher (All $z < 1.764$; all $P > 0.078$) and lynx habitat variables (All $z < 1.864$; all $P > 0.062$).

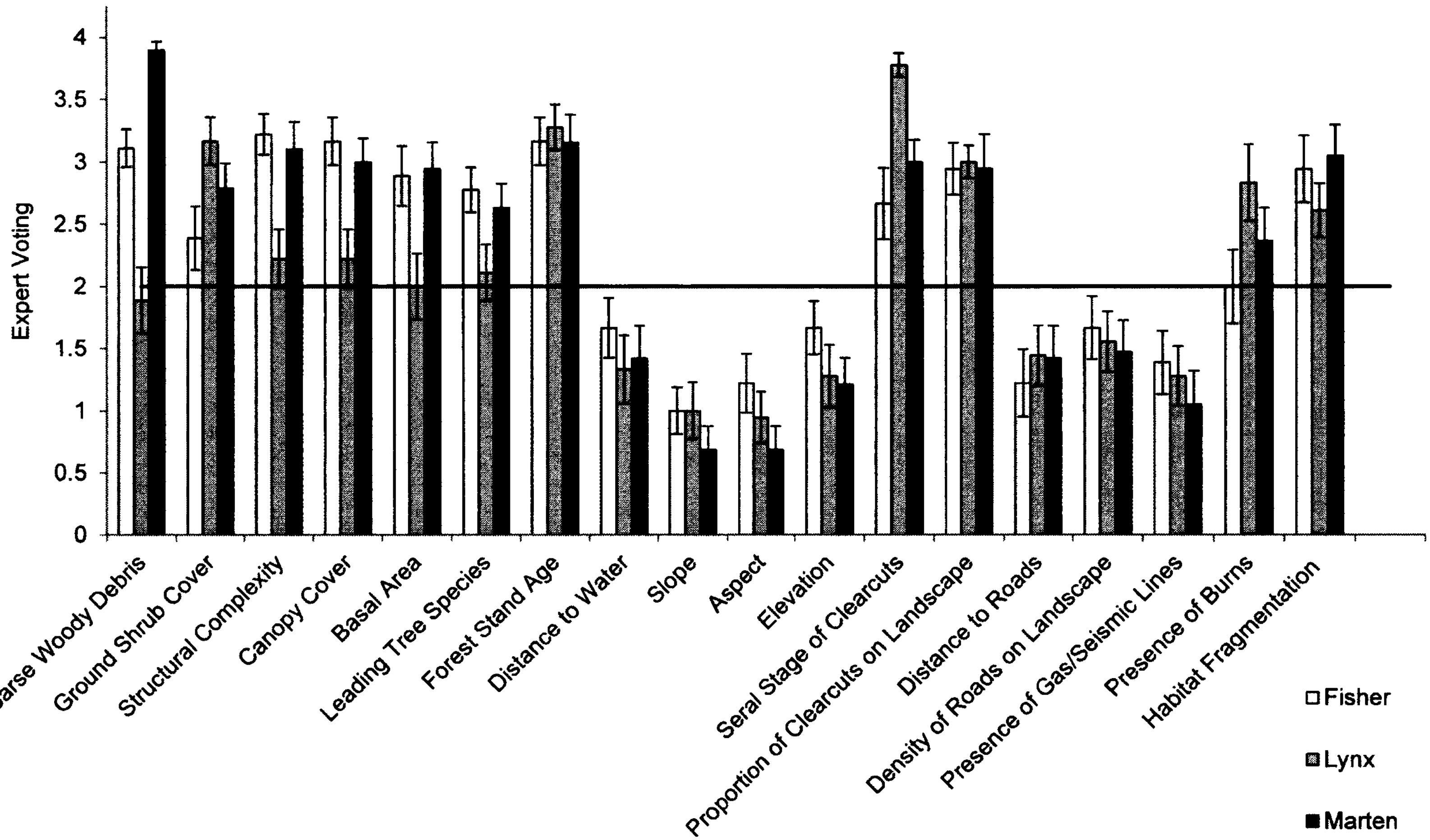


Figure 2.3. Combined scores (mean and standard error) from biologists and trapper experts to include variables for habitat models for fisher, lynx, and marten. The inclusion threshold (horizontal reference line) was set at a score of 2.

Evaluation of Habitat Variables

We used consistency ratios to test for randomness in the weighting of habitat variables by the two expert groups. No ratios surpassed the threshold of 0.1, suggesting that there were few or minor operative errors during the survey process (Saaty 1977). Wilcoxon rank-sum tests revealed that six variables in the fisher model had significantly different eigenvector scores when comparing expert groups. Trappers provided significantly higher scores for Open Canopy Cover, Other Conifers, Young Deciduous, and Mid-Age Deciduous, while biologists provided significantly higher scores for Cottonwood and Old Deciduous (all $z < 2.741$; all $P < 0.041$; Appendix D). In the lynx model, biologists provided significantly higher scores for Lodgepole Pine ($z = 2.001$, $P = 0.045$; Appendix D). The marten model had seven variables with significantly different eigenvector scores when comparing expert groups. Trappers provided significantly higher scores for Moderate Structural Complexity, Minimal Canopy Cover, High Forest Stand Density, Young Deciduous, and Mid-Age Deciduous, while biologists provided significantly higher scores for Moderate Canopy Cover, and Old Deciduous (all $z < 2.551$; all $P < 0.041$; Appendix D).

Quantification of Habitat Change

Habitat models for fisher, lynx, and marten were applied to the ten reference landscapes providing a measure of change in habitat availability and quality over time (Figure 2.4 and Appendix E). In the West, the combined expert-based habitat model revealed a 52% and 79% decrease in 'Good' and 'Very Good' fisher habitat, respectively (Table 2.5). Similar trends in habitat change were observed for lynx and marten habitat. In the East, and minimally deforested study area, the availability of habitat changed very little since 1990 (Table 2.5).

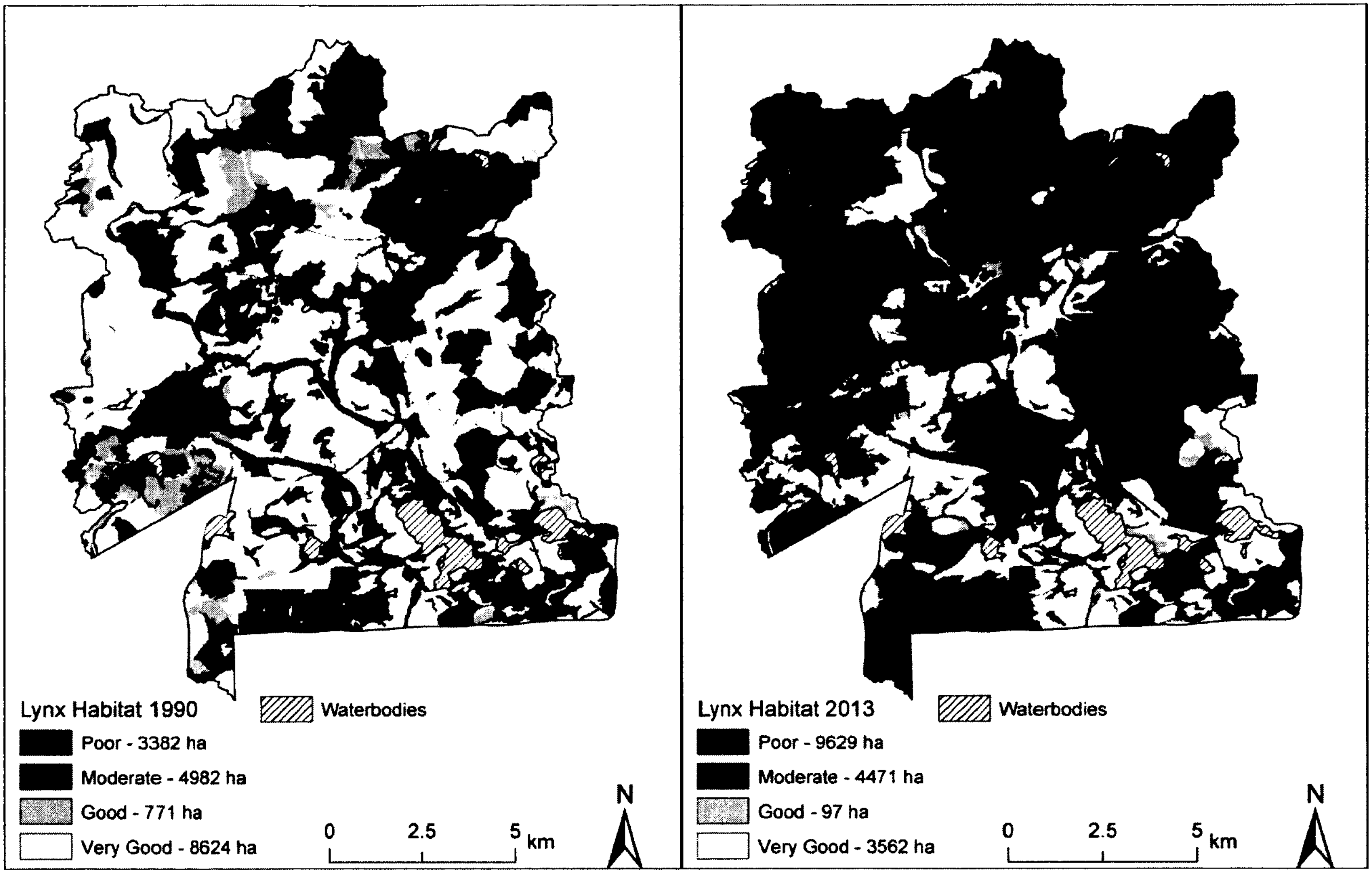


Figure 2.4. Predicted habitat for lynx on one example trapline in the West Study Area, central-interior BC, Canada, during 1990 and 2013.

Table 2.5. Change in availability of habitat for fisher, lynx, and marten from 1990 to 2013 in the West and East Study Area across central-interior BC, Canada. The percentages represent the composition of habitat across the study area in 1990 and 2013. The upper and lower 95% values represent the variation around the mean habitat change when the maps were constructed using the upper and lower 95th percentile eigenvector scores.

	West Study Area					East Study Area				
	1990 (%)	2013 (%)	Net Change (ha)	Lower and Upper 95% (ha)		1990 (%)	2013 (%)	Net Change (ha)	Lower and Upper 95% (ha)	
Fisher Habitat										
Poor	18.3	52.2	77916	72006	83826	26.0	25.8	-540	5124	-6204
Moderate	25.1	26.8	3776	-11635	19187	27.5	28.7	4539	12605	-3527
Good	34.1	16.3	-40961	-57105	-24817	23.3	19.6	-13385	-8057	-18713
Very Good	22.5	4.8	-40734	-49959	-31509	23.2	25.9	9387	17118	1656
Lynx Habitat										
Poor	17.6	50.9	76537	75374	77700	26.8	25.7	-3983	-1500	-6466
Moderate	21.7	35.7	32344	-24167	88855	24.8	24.4	-1604	6163	-9371
Good	28.8	8.0	-47944	-80279	-15609	22.3	18.8	-12472	-5304	-19640
Very Good	31.9	5.4	-60936	-74123	47749	26.1	31.1	18058	30761	5355
Marten Habitat										
Poor	18.1	52.3	78616	69470	87762	26.2	25.9	-983	6327	-8293
Moderate	25.4	24.3	-2500	-10709	5709	27.0	28.5	5305	10552	58
Good	34.5	17.4	-39343	-50077	-28609	23.1	18.3	-17215	-11611	-22819
Very Good	22.0	6.0	-36786	-42471	-31101	23.8	27.4	12896	20557	5235

There was a 16% decrease and 11% increase in 'Good' and 'Very Good' fisher habitat, respectively. Similar trends in habitat change were observed for lynx and marten habitat. 'Very Good' habitat increased by 19% for lynx and by 15% for marten in the East Study Area.

We used the mean eigenvector scores from the biologists and trappers separately to build habitat models for fisher, lynx, and marten in the West and East Study areas (Figure 2.5). In the West, scores from both expert groups suggested declines in fisher, lynx, and marten habitat. The biologist model predicted an 81% and 71% decrease in 'Very Good' fisher and marten habitat, while the trapper model predicted an 80% and 73% decrease. Similarly, the biologist model predicted a 70% decrease in 'Very Good' lynx habitat, while the trapper model predicted an 85% decrease. In the East, there was variation in the predictions of habitat change for fisher. The biologist model predicted a 1 and 11% increase in 'Very Good' fisher and marten habitat, while the trapper model predicted a 7 and 8% decrease. Similarly, the biologist model predicted a 3% decrease in 'Very Good' lynx habitat, while the trapper model predicted a 33% decrease.

Map Validation

The trappers were asked to evaluate the accuracy of the habitat maps for each focal species based on their perception of the species' distribution on their individual traplines (Figure 2.6). In the West and East Study Areas, the marten habitat maps scored the highest with averages of 8.7 (SE = 0.30) and 8.6 (SE = 0.32), respectively. The fisher habitat maps in the West and East Study Areas averaged 7.6 (SE = 0.46) and 8.2 (SE = 0.89), respectively. The lynx maps had the lowest scores in both the West and East Study Areas, with averages of 5.5 (SE = 0.91) and 6.7 (SE = 1.96), respectively.

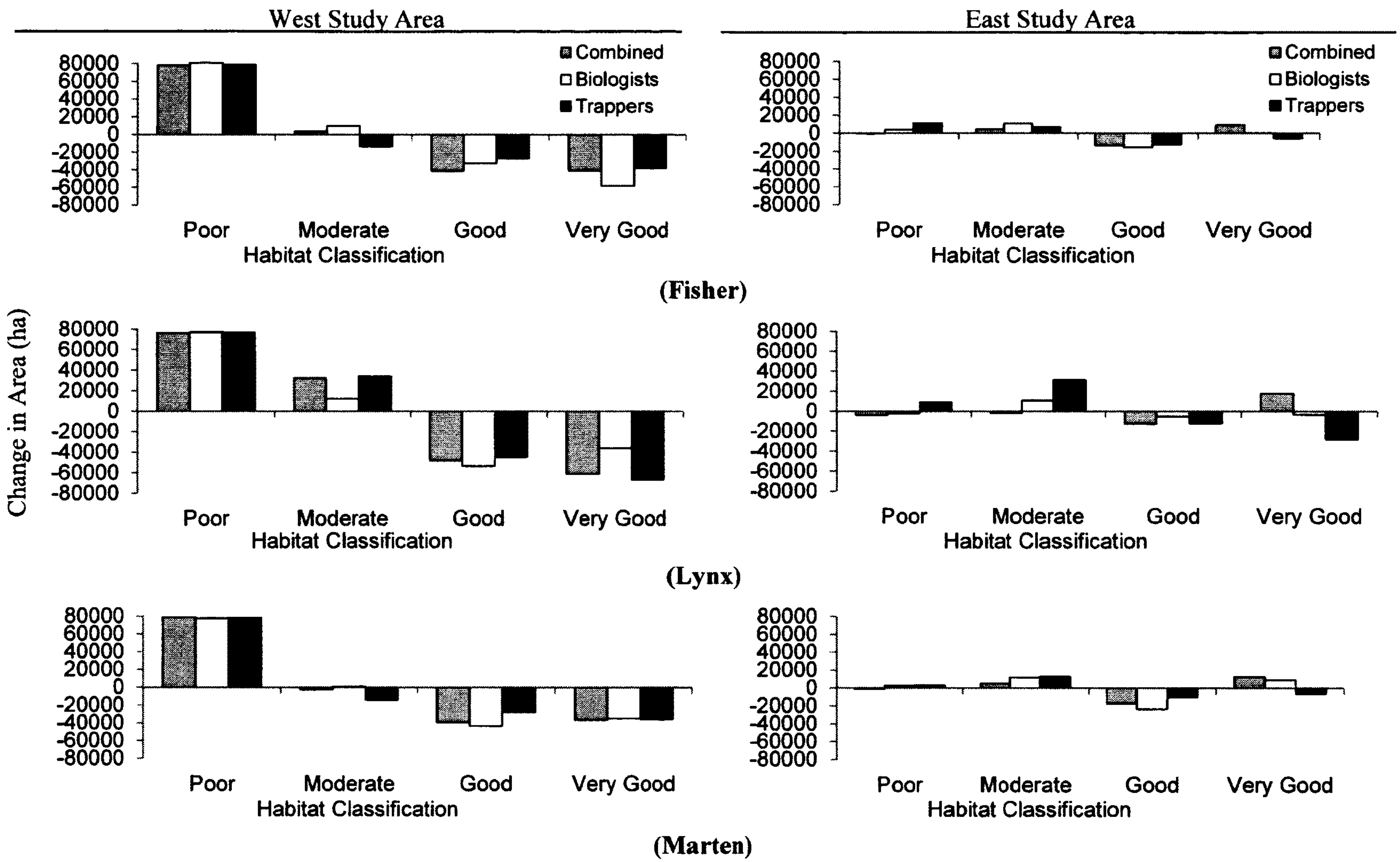


Figure 2.5. Change in the area (ha) of four habitat classifications (1990 to 2013) for expert-based habitat models for fisher, lynx, and marten developed by biologist, trapper, and combined expert models applied to the West and East Study Areas across central-interior BC, Canada.

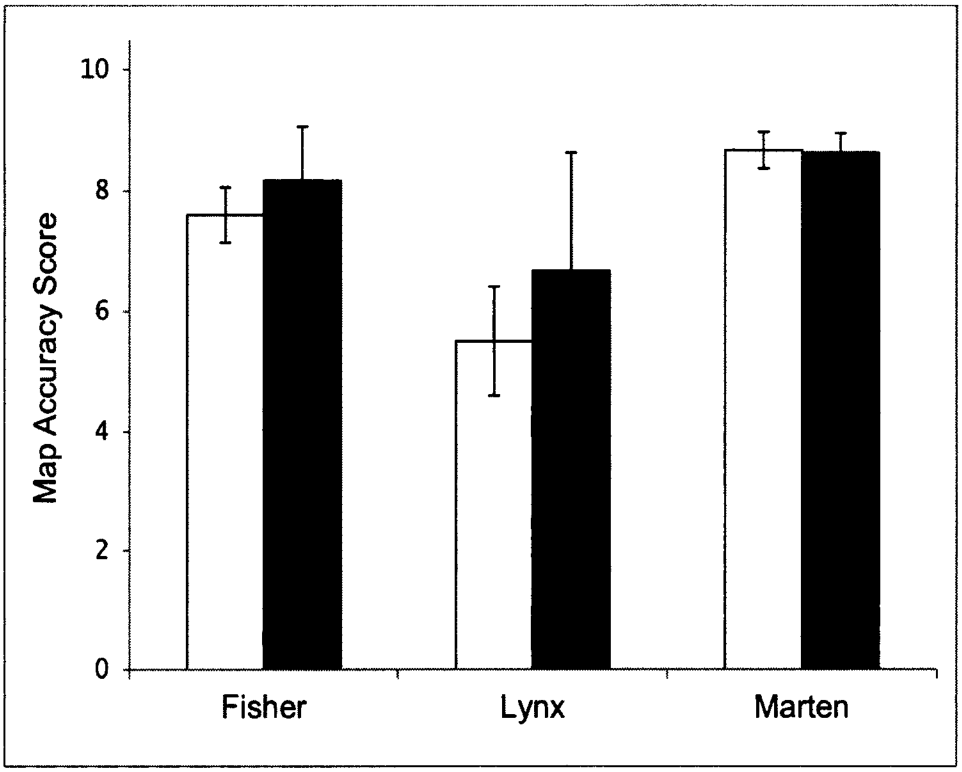


Figure 2.6. Mean accuracy (± SE) scores for the habitat maps for each focal species in the West (unshaded) and East (shaded) Study Areas. Trappers evaluated the distribution and area of ranked habitat for their traplines and provided scores representing perceived accuracy from 0–10.

Discussion

Expert-Based Habitat Modeling

The utility of expert knowledge for predictive modeling has been acknowledged in previous wildlife research (Store and Kangas 2001, Yamada et al. 2003, Doswald et al. 2007, O'Neill et al. 2008, Hurley et al. 2009). With traditional empirical studies, the collection of data is often limited by financial and logistical constraints. For this study, we acquired large amounts of data over a short time span, which could then be applied to habitat models that were applicable across a large study area (602,690 ha). The consistency in the selection of species and AHP scores within and across expert groups, and the strong validation of the final maps suggested that expert-based approaches were appropriate for the species and study areas modeled in this project.

The selection of experts is a critical step in the elicitation and application of expert-based knowledge (O'Neill et al. 2008). Although more robust than *ad hoc* approaches, the peer-referral process can result in selection bias and misrepresentation of the spectrum of knowledge, as peer nomination can lead to the referral of likeminded people (Drescher et al. 2013). To reduce selection bias we identified a diverse range of experts by recruiting seed experts from three sub-categories of biologist experts (government, academic, and consultant).

Throughout the elicitation process, we maintained rigorous, transparent, and repeatable methods; such rigour is necessary to conduct effective expert-based habitat modeling (Johnson et al. 2012). The experts were given full opportunity to provide input throughout the study, from the identification of focal species and habitat variables to the subsequent evaluation of those variables. The relatively high consistency in expert scores and lack of operative errors in the AHP suggested that the research design was appropriate for the suite of experts involved.

The experts agreed that marten and lynx were ideal species for the study, while trappers suggested beaver as the third species and biologists suggested fisher. Overall, fisher had more votes than beaver. Fisher, lynx, and marten are sensitive to habitat change, and thus fit the objectives of this research (Soutiere 1979, Thompson and Colgan 1994, Buskirk et al. 2000, Proulx 2000, Mowat and Slough 2003, Poole 2003, Hoving et al. 2004, Fuller and Harrison 2005, Weir and Almuedo 2010). Although similar in their general ecology, the three focal species use a range of habitats that may be affected differently by broad-scale, forest harvesting. Marten occupy small home-range sizes, averaging 2–3 km^2 for females and 5 km^2 for males, and are heavily dependent on forest structures associated with old-growth stands (Buskirk 1992, Thompson and Colgan 1994, Chapin et al. 1998, Payer and Harrison 2003, Carroll 2007). Although fisher also depend on old-growth forests, they are more likely to use a range of different seral stages of forest (Proulx 2006, Weir and Almuedo 2010). The home ranges of fisher in BC are typically >100 km^2 for males and >25 km^2 for females (Weir and Almuedo 2010). Lynx also have large home ranges, averaging around 220 km^2 depending on habitat features and prey abundance (Hatler and Beal 2003). Lynx are believed to be adaptable to a range of seral stages and may benefit from landscape changes that promote habitat for prey (Mowat and Slough 2003, Poole 2003, Hoving et al. 2004).

Experts were consistent in their choice of habitat variables for each species. Biologists provided their largest confidence scores when selecting habitat variables for lynx; however, as a group, there was high variability between individual biologists possibly due to the propensity of lynx to use a variety of habitat types. These experts were most certain when scoring habitat for fisher. In contrast, trappers displayed their lowest confidence scores and the highest variation when voting for habitat variables for fisher. Low capture rates of fisher on most traplines in the study area (likely corresponding to low fisher densities) may equate to less knowledge of fisher habitat by trappers.

Habitat classifications were relatively consistent within and between expert groups, and occurred without operator error (according to the consistency ratios of the AHP matrices). Trappers reported higher average confidence scores than biologists; however, the variation around the actual eigenvector scores was lower for biologists than trappers. The trappers' specific knowledge of furbearer habitat may be limited to, or skewed by, the habitat types that are present on their respective traplines, possibly resulting in discrepancies among the experts in the group. The agreement among biologists may be a product of exposure to similar research studies and literature, or perhaps they possess a broader, general knowledge of the focal species' habitat. Doswald et al. (2007) and Hurley et al. (2009) found similar variation when comparing the evaluations of habitat variables obtained from two distinct expert groups.

Failure to consider uncertainty when interpreting habitat models and subsequent maps can lead to inaccurate representations of habitat, potentially biasing future management decisions (Johnson and Gillingham 2004, Johnson et al. 2012). A relatively high consistency in the scoring of variables by the two expert groups resulted in no substantive changes to the conclusions of the study. The underlying error in the GIS data was an additional source of uncertainty that may have had a differential effect across the three species. Although we had no means to ground truth or assess the accuracy of the spatial data, the VRI has been verified in previous studies focused on furbearers (Proulx 2006, Proulx et al. 2006).

Variation in expert scores was generally greatest for lynx and least for marten and resulted in some differences in the predictions of habitat change. The relatively wide range of scores in the lynx model may be because this species is a habitat generalist, occurring across landscapes with a diversity of seral stages and habitat types (Mowat and Slough 2003, Poole 2003, Hoving et al. 2004). This inherent variability in habitat use could have led to less certainty by individual experts and greater differences amongst experts when parameterising the lynx model. Additionally, there has been little to no previous research of lynx in the ecological zones found across the central-interior of BC. Trappers assessed the lynx maps as the least accurate of the three focal species.

In the West Study Area, biologists and trappers showed similar predictions of habitat change over time for the three focal species. In the East, the consistency in scores between expert groups was lower. This raises concerns regarding the application of these habitat models across ecosystems. The experts were initially asked to evaluate habitat according to their knowledge of the Sub-Boreal Spruce BEC zone, which comprises the majority of the West Study Area. The models may not have been compatible with the East Study Area, which includes a greater proportion of the Engelmann Spruce-Subalpine Fir zone.

Habitat Change

The expert-based habitat models suggested significant declines in predicted habitat for furbearers in the West Study Area, while the East remained relatively stable. The West Study Area has been subjected to unprecedented levels of timber harvesting during the study period in response to a mountain pine beetle outbreak. In order to salvage merchantable timber, the allowable annual cut in the interior of BC had increased significantly over the past decade, peaking at over 60 million m^3 per year (BC Ministry of Forests, Mines, and Lands 2010). Large-scale clear-cut logging was the principal method of timber removal that also included mature spruce and fir species. Although the rate of timber harvesting is now decreasing, the rapid extraction of timber has resulted in younger and less diverse forest types across much of the interior of BC. Forestry is the driving force for cumulative impacts in the region and the reduction in habitat for the three focal species. A lack of mature and complex forest stands, widespread openings resulting from clear-cut logging, and habitat fragmentation may be limiting the distribution of furbearers.

The East Study Area has been exposed to relatively low levels of timber harvesting. In the mid-1980s, this area experienced an outbreak of spruce budworm (*Choristoneura biennis*), which initiated some salvage logging. Since that outbreak, new logging activity has been limited. This has allowed forest stands to mature and may be the primary reason for the slight increase in optimal habitat for all three focal species. Thus, observed differences in the level of forest harvesting across the East and West Study Areas are consistent with the structure and ultimately the predictions of the expert-based habitat models.

The combination of late-successional and regenerating forests in the East may provide an ideal mix of habitat for fisher (although they may be limited by high snow depths in this area). The abundance of old-growth conifer forests may be ideal for marten. According to the expert-based models, habitat availability does not appear to be a limiting factor for fisher or marten in that area. The distribution of both species may be restricted by other factors such as elevation, overhead cover in recently logged areas, snow accumulation (Weir and Harestad 2003), or the availability of elemental habitat features like denning trees (Weir et al. 2012). Competition with fisher may also limit marten in areas where they overlap (Carroll 2007).

The expert-based habitat model predicted significant decreases in the availability and quality of lynx habitat across the West, but not the East study area. Again, the discrepancy is likely a result of vastly different levels of anthropogenic impacts. Although the habitat model predicted declines in lynx habitat in the West Study Area, the trapping community report relatively high numbers of lynx (M. Bridger unpub. data). This suggests that lynx are not necessarily tied to what experts perceive as quality habitat, but rather are dependent on prey availability or other factors. The presence of widespread regenerating pine forests may currently be benefiting snowshoe hare (*Lepus americanus*) populations, which appear to be peaking (M. Bridger unpub. data). Some experts reported that the lynx habitat model may have been overly influenced by the attributes of old-forest stands, possibly over-predicting habitat quality in areas of late-successional forests. Although lynx do use old forest stands for certain life requisites (Paragi et al. 1997), perhaps not enough emphasis was placed on the importance of younger, regenerating forest stands that may provide abundant prey habitat.

Management Implications

Fisher

In BC, fishers are most prevalent across intact landscapes containing habitat features associated with late-successional forests (Proulx 2006, Weir and Almuedo 2010, Weir and Corbould 2010). These features are particularly important for denning, resting, and providing cover from snow accumulation (Weir and Harestad 2003). Given the large home ranges and low density of fishers in BC (Weir and Corbould 2006), the maintenance of landscape-level habitat connectivity may be critical. Habitat fragmentation is a significant concern given the fishers' propensity to avoid open areas associated with industrial activities (Weir and Harestad 2003, Weir and Almuedo 2010).

Although the models depicted fisher habitat at a landscape level, the experts recognized the importance of elemental habitat features throughout the process of model development. Certain life requisites are associated with elements found in late-successional forests, but fishers are not necessarily old-growth specialists. They are known to use early-seral forests, mixed forest stands, and edge habitat (Weir and Almuedo 2010). The structure of the forest itself may be more important than stand age or type. Their primary prey species, the snowshoe hare, and other small mammalian prey are often associated with young, regenerating forests (Weir and Harestad 2003, Weir and Almuedo 2010). These prey species, and thus, fisher, still require abundant coarse woody debris (CWD), ground cover, and structurally complex forest floors (Weir and Harestad 2003).

In BC, the rearing of young fishers occurs exclusively in tree cavities, primarily deciduous tree species (Lofroth et al. 2010). Thus, during denning, female fishers are dependent on large, decaying trees, primarily deciduous or conifers such as Douglas fir and pine that have heart rot (Weir et al. 2012). Managers must recognize the importance of maintaining or promoting den sites, but these features are not directly represented in large-scale landscape models (McCann et al. 2014), such as those presented in this work.

Lynx

Anthropogenic disturbance may influence lynx habitat in both positive and negative ways. In general, lynx distribution is highly correlated with their primary prey species, snowshoe hare (Apps 2000, Poole 2003, Hoving et al. 2004, Simons-Legaard et al. 2013). Habitat for snowshoe hare is often associated with densely vegetated, regenerating forests that occur following logging or wildfire (Mowat et al. 2000, Poole 2003, Simons-Legaard et al. 2013). Consequently, both snowshoe hare and lynx may benefit from landscape disturbance (Mowat and Slough 2003, Hoving et al. 2004). Habitat changes stemming from forestry activities may not be immediately beneficial, as lynx have been found to avoid recently disturbed habitats (Poole 2003, Hoving et al. 2004). Furthermore, an increase in openings associated with timber harvesting may fragment lynx habitat. Given the large annual range of lynx, habitat fragmentation may be a concern (Buskirk et al. 2000, Mowat and Slough 2003).

Although most foraging habitat is associated with early-successional forests and edge habitat, lynx do require mature forest stands to meet certain life requisites. Mature conifer or mixed forests provide valuable habitat for denning, resting, and cover from extreme climatic conditions (Paragi et al. 1997). It is widely accepted that lynx use mature forest stands, although few studies have reported selection for these habitats (Mowat et al. 2000, Poole 2003, Hoving et al. 2004). Late-successional forests may be of particular importance to lynx during low periods of the hare cycle, as lynx often switch to alternate prey found in these areas, such as red squirrels (Paragi et al. 1997, Mowat et al. 2000).

Marten

The availability of marten habitat must be managed at a landscape level, as they are sensitive to habitat fragmentation (Soutiere 1979, Thompson and Colgan 1994, Hargis et al. 1999, Fuller and Harrison 2005). Home-range sizes of marten living on fragmented landscapes are much larger compared to those inhabiting intact forests (Soutiere 1979, Thompson and Colgan 1994, Fuller and Harrison 2005). Marten avoid openings associated with anthropogenic disturbances, such as cutblocks, likely due to predation risk (Potvin et al. 2000, Carroll 2007, Cheveau et al. 2013). Previous studies have shown that marten do not tolerate landscapes that contain greater than 25–30% unsuitable habitat, including natural openings and cutblocks (Hargis et al. 1999, Potvin et al. 2000, Cheveau et al. 2013).

Marten are widely associated with late-successional, coniferous forest stands (Payer and Harrison 2003, Proulx et al. 2006, Carroll 2007, Webb and Boyce 2009, Cheveau et al. 2013). These forests contain elemental features that provide thermal cover during winter, cover from predators, foraging habitat, and resting and denning areas (Thompson and Colgan 1994, Potvin et al. 2000, Carroll 2007, Cheveau et al. 2013). Unlike lynx, and in some cases fisher, marten avoid regenerating forests (Soutiere 1979, Potvin et al. 2000, Fuller and Harrison 2005); although, they may hunt along edges provided there is adequate overhead cover (Chapin et al. 1998). Researchers have emphasized the importance of maintaining forest stands with basal areas greater than 18–20 m^2/ha and 30–50% canopy cover (Soutiere 1979, Fuller and Harrison 2005, Proulx et al. 2006). The maintenance of CWD in forest stands is also critical (Payer and Harrison 2003). Basal area, crown closure, and CWD were recognized as important by both expert groups and, thus, were parameterised at the scale of the supporting GIS data (Figure 2.3).

Conclusion

Habitat models can be important tools for developing and implementing management plans for wildlife species. Although empirical models have value for predicting and mapping wildlife habitat (Guisan and Thuiller 2005), a need to develop models quickly and effectively may lead researchers to consider expert-based approaches. Where the collection of empirical data is limited by time and financial constraints, expert knowledge provides an efficient and rapid alternative. This may be particularly important for cryptic species that are difficult to study. The performance of expert-based models has received mixed reviews (Store and Kangas 2001, Clevenger et al. 2002, Doswald et al. 2007). The results of this study, however, suggest considerable utility in the use of expert knowledge for mapping habitat and subsequently examining habitat change over time.

There are advantages to involving multiple groups of experts that have unique, but complementary domains of expertise. For this study, trapper experts can assist with the on-ground validation of model results and link habitat change to population abundance in the form of trapping records (Smith et al. 1984, Ruette et al. 2003). Professional experts may provide a more general perspective on the habitat requirements of individual species. For the three focal species presented in this study, model structure was remarkably similar among expert groups.

There are a variety of techniques available for eliciting expert knowledge that can be applied to the development of habitat models. These depend on the study objectives, the skill of the research team, the focal species, and the availability of supporting GIS data. The identification of suitable experts, application of rigorous and repeatable methods, and quantification of uncertainty, however, are key components of any method (Burgman et al. 2011a, Johnson et al. 2012, McBride and Burgman 2012, Drescher et al. 2013). This research demonstrates strict adherence to those principles. The purposeful and incremental assessment of the elicitation process – including consistency ratios, measures of confidence, parameter variance and validation of predictions – provides evidence of rigour and a measure of the reliability of resulting models and predictions of habitat change. Ultimately, however, understanding of the spatiotemporal change in habitat for these three species would be impossible or much delayed if there was a strict requirement for empirical data. These study findings are transparent and defensible and can be used to influence habitat management and strategic decisions relative to past and future cumulative landscape change. The findings also suggest that habitat for fisher, lynx, and marten may decrease substantially where intensive forestry occurs. Forest and wildlife managers must recognize the importance of maintaining furbearer habitat on landscapes subjected to cumulative industrial impacts.

Chapter 3: Assessing cumulative impacts of forest development on the abundance of furbearers using harvest records

Abstract: Understanding the cumulative impacts of landscape change is important when managing and conserving wildlife populations. Across the central-interior of British Columbia, Canada, furbearer populations are being subjected to the cumulative impacts of industrial development. This region has witnessed unprecedented levels of anthropogenic landscape change, primarily in the form of increased forestry. We used trapping records to investigate the relationship between habitat change resulting from cumulative impacts of landscape change and population abundance of Canada lynx (*Lynx canadensis*) and American marten (*Martes americana*). We applied expert-based habitat models to ten reference landscapes (i.e., traplines) in two distinct study areas to serve as measures of habitat change over the study period between 1990 and 2013. We elicited fur harvest records (1990–2013) from trapper experts and then used negative binomial count models to relate capture success to habitat change. We controlled for factors that were hypothesised to influence capture success, including effort and climatic conditions, allowing us to observe the effects of habitat availability and quality on population abundance. Overall, the top-ranked count models identified combinations of habitat availability and quality, trapping effort, and trapline area as factors positively influencing the capture success of lynx and marten. These results suggest that reduction in high-quality habitat may have a direct and negative effect on the abundance of lynx and marten in the study area. Results of this study also illustrate the utility of fur-harvest records for investigating population abundance of furbearer species. A precise measure of trapping effort, however, is necessary to relate environmental covariates, including habitat change, to harvest at the scale of individual traplines.

Introduction

Furbearer species have significant cultural and economic importance for fur-trapping industries across North America (Hamilton et al. 1998, Webb and Boyce 2009). Between the years 2000–2012, the fur trapping industry in British Columbia (BC), Canada, grossed nearly $17 million in revenue (BC Fur Returns unpub. data). Recent increases in industrial activity, however, have led to concerns about the distribution and abundance of furbearer populations. Across the central-interior of BC, forestry has had a notable impact on the landscape, largely in response to a mountain pine beetle (*Dendroctonus ponderosae*) epidemic that has killed 53% of merchantable pine stands (BC Ministry of Forests, Lands, and Mines 2010). Given the current understanding of furbearer biology, the large-scale loss of forests and resulting salvage harvest is certain to have negative impacts on the habitat of furbearer populations; however, the magnitude of these impacts is unknown.

The high rate and large area of forest harvesting occurring across the central-interior of BC may result in cumulative impacts for wildlife species that are dependent on old forests. Cumulative impacts can be interactive, additive, or synergistic, and can alter the environment at a number of temporal and spatial scales (Nitschke 2008, Johnson 2011). Compared to acute, immediate changes to habitat, cumulative impacts can be complex and difficult to understand (Johnson 2011). Cumulative landscape change may have substantial and long-term negative impacts on the habitats and ultimately the distribution and abundance of furbearer populations (Thompson 1994, Proulx 2000, Webb and Boyce 2009).

Canada lynx (*Lynx canadensis*) and American marten (*Martes americana*) use a range of habitats that may be affected differently by the cumulative impacts of landscape change. Lynx have large home ranges and are adaptable to varying seral stages of forested habitats (Mowat and Slough 2003, Poole 2003, Hoving et al. 2004). Lynx populations may ultimately benefit from some landscape disturbances that promote habitat for prey, provided other life-history requirements remain available. In contrast, marten have small home ranges and are considered old-forest specialists, dependent on forest structures, such as coarse woody debris, associated with late successional forests (Buskirk 1992, Thompson and Colgan 1994, Chapin et al. 1998, Payer and Harrison 2003, Carroll 2007). The loss of contiguous habitat to timber harvesting is likely to have negative impacts on marten populations, a concern which has been voiced by trappers (M. Bridger unpub. data; Chapter 2).

There are approximately 2600 registered traplines in BC, and 900 licenses issued annually. Trappers are required to document their capture totals when selling furs to market, which are entered into a provincial database. Additionally, many trappers consider themselves stewards of populations on their traplines, and thus, keep personal records of trapping activity and harvests. Trapping records have been used to monitor abundance and population trends of furbearers (McDonald and Harris 1999, Ruette et al. 2003, Webb and Boyce 2009) and they can be particularly useful when the behavior of furbearer species makes typical monitoring difficult (Ruette et al. 2003). Also, trapping records represent a significant amount of data that can be collected for large geographic areas at a relatively low cost (Ruette et al. 2003).

Although trapping records may not be useful for detecting population changes over small spatial and temporal scales, they have utility for identifying long-term population trends across regional areas (Smith et al. 1984, Raphael 1994, Poole and Mowat 2001, Ruette et al. 2003). Such data require careful interpretation, however, and researchers have cautioned against the use of databases that report harvest totals only. In particular, a failure to report or control for factors that influence harvest dynamics can make interpretation of harvest records difficult (McDonald and Harris 1999, Poole and Mowat 2001). The pitfalls associated with broad-scale harvest data may be avoided by using site-specific harvest records from individual traplines that cover large geographical areas over long timeframes (Erickson 1982, Raphael 1994).

Numerous factors may influence trapping success thus biasing capture records or data representing fur sales. Of greatest importance may be trapping effort that can be influenced by population cycles, quota changes, trap-type restrictions, access, weather, fur prices, and socio-economic conditions (Raphael 1994, McDonald and Harris 1999, Poole and Mowat 2001, Cattadori et al. 2003, Ruette et al. 2003, Webb and Boyce 2009). Failing to account for such factors will limit any inference to the underlying population dynamics of the trapped species (McDonald and Harris 1999).

We developed an expert-based approach to quantify variation in the harvest and ultimately the population abundance of two species of furbearers following rapid change in the quality and availability of habitat across landscapes. Where previous studies have used harvest datasets collected from large geographical areas, we used the personal records of trappers specific to their registered traplines to account for both effort and success. We related trap data for marten and lynx to the availability and quality of habitat, as modeled using expert knowledge. After controlling for trapping effort, this relationship served as an index of the population abundance of the two species. Traplines were located within two distinct study areas subjected to high levels of forestry development (hereafter referred to as the 'West Study Area') and low levels of forestry development (hereafter referred to as the 'East Study Area'; Figure 1.1). We hypothesised that the capture success of lynx and marten would be related to trapping effort and habitat availability and quality.

Methods

Data Collection

We used trapping records (corresponding to registered traplines) and negative binomial count models to investigate factors that influenced capture success of lynx and marten. We collected harvest data specific to the traplines of ten trappers. We met with trappers in person and documented annual catch statistics for each species. Records were in the form of personal journals or fur return records (mandatory for the commercial sale of furs in BC). We collected records dating back to 1990 for lynx and marten; records for fisher (*Pekania pennanti*) were also collected, but the capture rate was too infrequent to be used for these analyses. Few trappers had complete records from 1990–2013.

We established a number of measures of trapping effort for each set of harvest data, depending on the information possessed by the trappers. In one instance, a trapper kept catch per unit effort (CPUE) harvest records for each year of trapping. Three trappers recorded only the number of days spent trapping per season, while three others were able to approximate the number of traps set per season. The three remaining trappers did not record data that could be used to quantify effort. In this case, the trappers used their recollection of trapping activity to assign a value of effort from 0–10 for each year. These trappers identified particular years when effort was highest and assigned a score of 10; scores for the remaining years were assessed relative to those years of highest effort. All other measures of effort were then standardised on a scale from 0–10 to be used as a covariate in the negative binomial count models.

We conducted a brief survey with the trappers to identify other variables that they felt influenced trapping effort and success. We also discussed changes in their trapping methods over time, as well as the spatial distribution of effort across the trapline. Trappers provided map locations of productive trapping areas and noted changes in trapping locations due to habitat alteration.

Model Development

We used the literature and consulted with expert participants to identify a set of predictor variables that we hypothesised would explain capture success of lynx and marten (Table 3.1). Those variables included measures of effort and habitat value, trapline area, fur prices, and climatic conditions. Determining the influence of cumulative landscape change on capture success was of particular interest. Therefore, we tested three habitat-related variables derived from habitat models. Those models were developed through an expert-based approach, where biologists and trappers identified and evaluated habitat variables for lynx and marten. The expert-based habitat models were used to quantify change in habitat availability and quality for lynx and marten on each trapline at four time intervals: 1990, 2000, 2005, and 2013 (Chapter 2). We extrapolated habitat values (Table 3.1) for all missing years between 1990 and 2013 by determining the rate of change between time intervals; this assumed a linear rate of habitat change.

Table 3.1. Variables used for the development of count models for predicting capture success of lynx and marten across central-interior BC, Canada.

Parameter	Abbreviation	Description
Effort	E	Measure of trapping effort on a scale from 0–10
Standardised Effort	SE	Measure of trapping effort relative to trapline area, where 'Effort' was multiplied by 'Trapline Area'
Trapline Area	TA	Trapline area in hectares
Habitat Value	HV	Sum total of the raster habitat values on each respective trapline, according to expert-based habitat maps
Standardised Habitat Value	SH	Habitat relative to trapline area, where 'Habitat Value' was divided by 'Trapline Area'
% Good and Very Good Habitat	GVGH	Percent of the respective trapline area composed of 'Good' or 'Very Good' habitat, according to expert-based habitat maps
Fur Price	FP	The average fur price from the previous year's trapping season
Mean Minimum Temperature	MMT	Average daily minimum air temperature recorded at Prince George Airport weather station (Nov–Jan for marten; Dec–Feb for lynx)
Extreme Minimum Temperature	EMT	Average monthly extreme minimum air temperature recorded at Prince George Airport weather station (Nov–Jan for marten; Dec–Feb for lynx)
Snow Depth Sum	SMS	Cumulative snow depth recorded at Prince George Airport weather station (Nov–Jan for marten; Dec–Feb for lynx)

We acquired historic fur prices through the provincial fur return database, and weather data from the Environment Canada weather station at Prince George, BC (Environment Canada 2014). We acquired weather data for the peak trapping months for lynx (December–February) and marten (November–January). Trappers identified low temperatures and snow cover as important factors influencing capture success, thus we calculated the mean minimum and extreme minimum air temperatures and snow depth for those months.

We used negative binomial regression models (NBRM) to examine factors that influenced capture success (Stata, ver. 12.1, StataCorp, 2011). The harvest data from individual traplines for each year were used as the dependent variable for the count models. We developed sets of models for lynx and marten in the West and East Study Areas separately. Due to a relatively high number of zero capture events of lynx in the East Study Area, I attempted to fit a zero-inflated negative binomial model (ZINB) to the data (Vuong tests; Vuong 1989). However, the ZINB model did not conform well to the data, thus I used a NBRM.

Model Selection

Empirical data explaining variation in capture success were lacking, thus we used categories of explanatory hypotheses to guide the model-selection process: trapping effort; variation in habitat over time; effort and habitat; effort and weather; habitat and weather; and effort, habitat, and weather (Appendix F). In some cases, low sample sizes dictated relatively few model parameters, where we followed a rule of approximately one covariate for every 10 records (Vittinghoff and McCulloch 2007). We used an information-theoretic approach and Akaike's Information Criteria (AIC_c) for small sample sizes to identify the most parsimonious model from each set of explanatory hypotheses (Burnham and Anderson 2002). The best model in the set had the lowest AIC_{ci} and the highest AIC_c weight (w_i); where model separation was uncertain, we selected all models that differed by < 2 Δ_i AIC points.

For the best models in the set, we generated β-coefficients for each parameter, representing the positive or negative direction of the effect; we considered a parameter statistically significant at $\alpha \leq 0.05$. We clustered data on trapline to correct the variance for repeated sampling across years on each trapline (Dormann et al. 2007). We used the variance inflation factor to test the best-fit models for multicollinearity; no covariates surpassed the variance inflation threshold of 10 (Chatterjee and Hadi 2006).

Model Prediction

Information theoretic approaches provide only a relative measure of model parsimony, not an absolute measure of model fit. Thus, we used cross-validation to assess the predictive accuracy of the most parsimonious models. We used a bootstrapping-type method, where each capture record was withheld sequentially from the model fitting process, and the resulting model (N-1) and the withheld record was used to predict an independent harvest count. We then calculated the unstandardised residuals (difference between observed and predicted counts); a mean of zero suggested perfect prediction, a negative value suggested over-prediction, and a positive value suggested under-prediction. We used Wilcoxon rank sum tests to statistically compare the predicted and observed captures.

Catch per Unit Effort

As a second index of lynx and marten population abundance, we assessed the trends in CPUE and trapping effort over time (Microsoft Excel, ver.14.0, Microsoft Corporation, 2010). Catch per unit effort was derived from the annual number of captures by each trapper divided by their effort level. Both trapping effort and CPUE were standardised by trapline area. We calculated best-fit linear trend lines to the resulting scatterplots.

Results

Catch per Unit Effort

Trends in CPUE and trapping effort for lynx and marten varied over time. In the West Study Area, CPUE ($F_{1,73} = 5.56$, $P = 0.021$) and trapping effort ($F_{1,73} = 17.22$, $P < 0.001$) for lynx increased over time (Figure 3.1a), suggesting that trappers were capturing more lynx as they increased their effort levels. We did not analyse the CPUE and trapping effort for lynx in the East Study Area, due to low capture numbers. In the West, CPUE ($F_{1,84} = 6.80$, $P = 0.011$) for marten decreased and trapping effort ($F_{1,84} = 9.14$, $P = 0.003$) increased with time, suggesting that trappers applied more effort over time, but captured fewer marten (Figure 3.1b). In the East, there was no significant relationship between CPUE or trapping effort and time ($F_{1,45} = 1.90$, $P = 0.175$ and $F_{1,45} = 0.25$, $P = 0.616$, respectively; Figure 3.1c).

Count Models

Lynx

The NBRM was the best model for lynx in the West Study. While the ZINB model appeared to be a better fit for lynx captures in the East (Vuong = 2.42, $P = 0.008$), the ZINB model did not conform to the data, thus I used a NBRM. The top-ranked model for lynx in the West Study Area (AIC_c $w_i = 0.520$) included the parameters for 'Effort', 'Trapline Area', 'Good and Very Good Habitat', and 'Extreme Minimum Temperature' (Table 3.2).

(a)

(b)

(c)

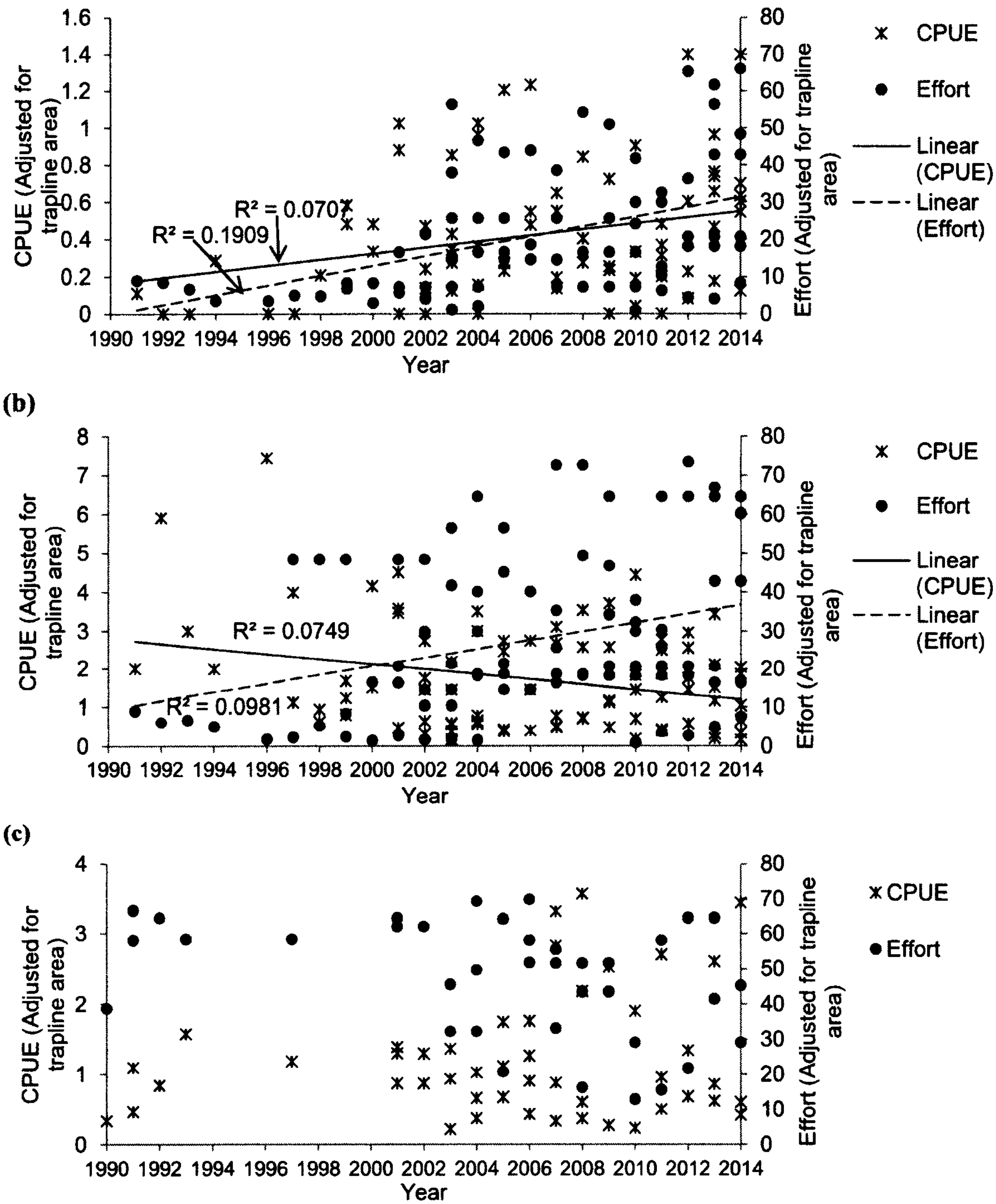


Figure 3.1. Scatterplots and linear regressions displaying catch per unit effort (CPUE) and trapping effort for lynx captures in the West Study Area (a) and marten captures in the West (b) and East Study Area (c) across central-interior BC, Canada. The CPUE represents the number of lynx or marten captured by each trapper in a given year divided by their effort level.

Table 3.2. Summary of model selection statistics for the candidate count models to predict lynx captures in the West Study Area (Capture events; N = 75) across central-interior BC, Canada. The models were developed from six *a priori* categories of explanatory hypotheses. The top models from each category were selected and then ranked against each other.

Model	Category	Rank	AIC_{ci}	AIC_cw_i	$\Delta_i AIC_c$
E + TA + GVGH + EMT	Effort + Habitat + Weather	1	397.97	0.520	0.000
E + TA + GVGH	Effort + Habitat	2	398.14	0.479	0.165
E + TA	Effort	3	412.83	<0.001	14.853
E + EMT	Effort + Weather	4	428.93	<0.001	30.953
GVGH + TA	Habitat	5	468.41	<0.001	70.433
SH + EMT	Habitat + Weather	6	470.39	<0.001	72.413
SH + SDS	Habitat + Weather	7	471.49	<0.001	73.513
SH + SDS + EMT	Habitat + Weather	8	471.78	<0.001	73.805
SH + SDS + MMT	Habitat + Weather	9	472.34	<0.001	74.365

The second-ranked model differed by <2 points, but was a subset of the top model. The top two models accounted for 99.9% of the AIC_cw_i.

There were only 27 capture events for lynx in the East Study Area. The low sample size required the inclusion of few parameters in the models. The top-ranked model (AIC_cw_i = 0.223) included the parameters for 'Effort', 'Trapline Area', and 'Mean Minimum Temperature' (Table 3.3). The top two models accounted for only 58.1% of the AIC_cw_i.

The coefficients generated from the best NBRM suggested that lynx captures in the West Study Area were positively influenced by 'Effort', 'Trapline Area', and 'Good and Very Good Habitat' (Figure 3.2a). 'Extreme Minimum Temperature' did not have a significant effect on capture success. In the East, the coefficients generated from the top-two NBRMs suggested that 'Effort' and 'Trapline Area' had a significantly positive influence on capture success of lynx, while 'Mean Minimum Temperature' and 'Extreme Minimum Temperature' had a significant negative effect (Figure 3.2b; Appendix G).

Table 3.3. Summary of model selection statistics for the candidate count models to predict lynx captures in the East Study Area (Capture events; N = 27) across central-interior BC, Canada. The models were developed from six *a priori* categories of explanatory hypotheses. The top models from each category were selected and then ranked against each other.

Model	Category	Rank	AIC_{ci}	$AIC_c w_i$	Δ_i AIC_c
E + TA + MMT	Effort + Weather	1	117.86	0.305	0.000
E + TA + EMT	Effort + Weather	2	118.06	0.276	0.200
E + TA	Effort	3	122.76	0.094	2.357
E + SH	Effort + Habitat	4	122.98	0.084	2.577
E + TA + SH	Effort + Habitat	5	120.86	0.068	3.000
E + SH + SDS	Effort + Habitat + Weather	6	122.28	0.034	4.420
E + TA + GVGH	Effort + Habitat	7	122.34	0.033	4.480
E + GVGH	Effort + Habitat	8	124.92	0.032	4.517
E + SH + EMT	Effort + Habitat + Weather	9	122.52	0.030	4.660
E + SH + MMT	Effort + Habitat + Weather	10	122.78	0.026	4.920
E + GVGH + EMT	Effort + Habitat + Weather	11	123.54	0.018	5.680
HV	Habitat	12	166.52	<0.001	43.777
HV + SDS	Habitat + Weather	13	165.20	<0.001	44.797
HV + EMT	Habitat + Weather	14	166.14	<0.001	45.737

Marten

The top-ranked negative binomial regression model explaining captures of marten in the West Study Area (AIC_c w_i = 0.471) included parameters for 'Effort', 'Trapline Area', 'Standardised Habitat', and 'Extreme Minimum Temperature' (Table 3.4). The top three models differed by <2 points and accounted for 99.9% of the $AIC_c w_i$.

In the East Study Area, the top model accounted for 51.0% of the $AIC_c w_i$ and included parameters for 'Effort', 'Trapline Area', and 'Good and Very Good Habitat' (Table 3.5). The subsequent three top-ranked models contained the same parameters, but included climatic variables. The top-ranked model was the most parsimonious and differed from the second-ranked model by >2 points.

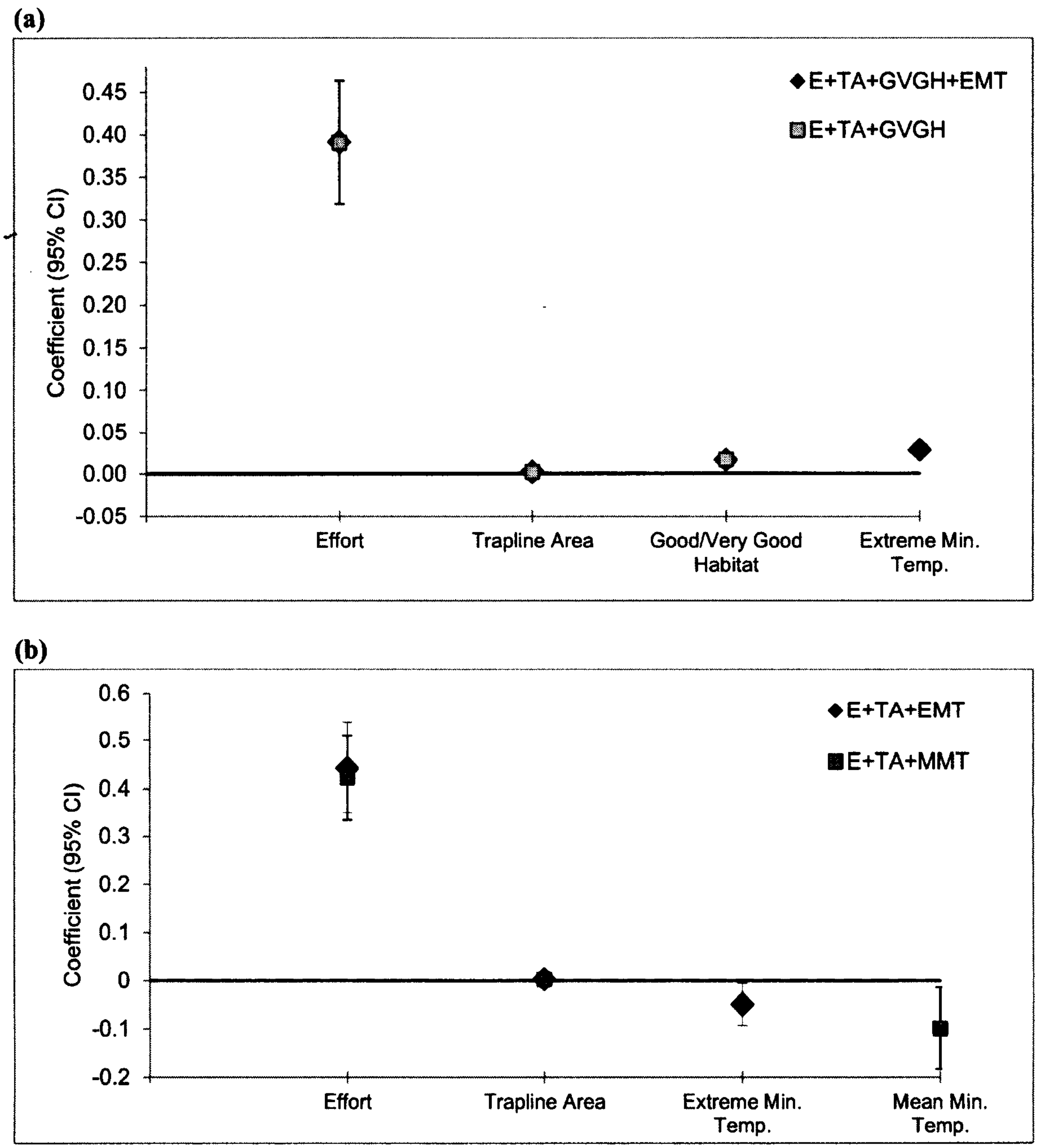


Figure 3.2. Model coefficients and 95% confidence intervals of top-ranked models (where Δ AIC_c was < 2.0) representing influences on capture success of lynx in the West (a) and East (b) Study Areas across central-interior BC, Canada.

Table 3.4. Summary of model selection statistics for the candidate count models to predict marten captures in the West Study Area (Capture events; N = 86) across central-interior BC, Canada. The models were developed from six *a priori* categories of explanatory hypotheses. The top models from each category were selected and then ranked against each other.

Model	Category	Rank	AIC_{ci}	AIC_cw_i	$\Delta_i\ AIC_c$
E + TA + SH + EMT	Effort + Habitat + Weather	1	660.83	0.471	0.000
E + TA + SH + MMT	Effort + Habitat + Weather	2	661.41	0.352	0.582
E + TA + SH	Effort + Habitat	3	662.79	0.177	1.963
E + TA	Effort	4	676.34	<0.001	15.515
E + EMT	Effort + Weather	5	680.78	<0.001	19.955
E + SDS + EMT	Effort + Weather	6	681.83	<0.001	21.003
E + SDS	Effort + Weather	7	682.52	<0.001	21.695
HV	Habitat	8	745.75	<0.001	84.918
HV + EMT	Habitat + Weather	9	746.38	<0.001	85.555
SH + TA	Habitat	10	746.56	<0.001	85.735
HV + TA	Habitat	11	746.76	<0.001	85.935
GVGH + TA	Habitat	12	746.96	<0.001	86.135
HV + MMT	Habitat + Weather	13	746.98	<0.001	86.155
GVGH	Habitat	14	747.01	<0.001	86.178
HV + SDS	Habitat + Weather	15	747.44	<0.001	86.615

The coefficients generated from the best NBRMs suggested that marten captures in the West Study Area were positively influenced by 'Effort', 'Trapline Area', and 'Standardised Habitat', while 'Extreme Minimum Temperature' and 'Mean Minimum Temperature' had a negative effect (Figure 3.3a; Appendix G). The coefficients generated from the best NBRM for marten captures in the East suggested that 'Effort', 'Trapline Area', and 'Good and Very Good Habitat' had a significantly positive influence on the capture success of marten (Figure 3.3b; Appendix G).

Model Fit

We used Wilcoxon rank sum tests to compare the predicted and observed captures from all top models for lynx and marten in the West and East Study Areas. There were significant differences in observed and predicted captures of lynx in both study areas (Appendix H; all H-statistics >24.09, all P <0.039). There were also significant differences

Table 3.5. Summary of model selection statistics for the candidate count models to predict marten captures in the East Study Area (Capture events; N = 47) across central-interior BC, Canada. The models were developed from six *a priori* categories of explanatory hypotheses. The top models from each category were then ranked against each other.

Model	Category	Rank	AIC_{ci}	$AIC_c w_i$	$\Delta_i AIC_c$
E + TA + GVGH	Effort + Habitat	1	429.84	0.510	0.000
E + TA + GVGH + SDS	Effort + Habitat + Weather	2	431.96	0.177	2.117
E + TA + GVGH + EMT	Effort + Habitat + Weather	3	432.22	0.155	2.383
E + TA + GVGH + MMT	Effort + Habitat + Weather	4	432.23	0.154	2.393
GVGH + TA	Effort	5	439.31	0.004	9.475
GVGH + EMT	Effort + Weather	6	466.25	<0.001	36.415
GVGH + SDS	Effort + Weather	7	466.41	<0.001	36.575
SE	Habitat	8	468.23	<0.001	38.391
SE + SDS	Habitat + Weather	9	470.15	<0.001	40.315
SE + FP	Habitat	10	470.17	<0.001	40.335
SE + TA	Habitat	11	470.19	<0.001	40.355
SE + EMT	Habitat	12	470.31	<0.001	40.475

in observed and predicted captures of marten in the West Study Area (Appendix H; all H-statistics >72.23, all P <0.022). There was no significant difference between observed and predicted captures of marten in the East Study Area (Appendix H; H = 38.89, P = 0.385).

Discussion

Our results demonstrate the utility of trapping records for investigating furbearer abundance in relation to cumulative habitat change. Many studies have attempted to use trapping records as a proxy for abundance and for long-term population monitoring (Smith et al. 1984, Raphael 1994, McDonald and Harris 1999, Poole and Mowat 2001, Ruette et al. 2003, Webb and Boyce 2009). Few studies, however, have used trapping records to relate population abundance to habitat change (Webb and Boyce 2009). Such records provide a large amount of data that can be collected relatively quickly and inexpensively (Ruette et al. 2003). This may be particularly important for cryptic and inconspicuous species like

(a)

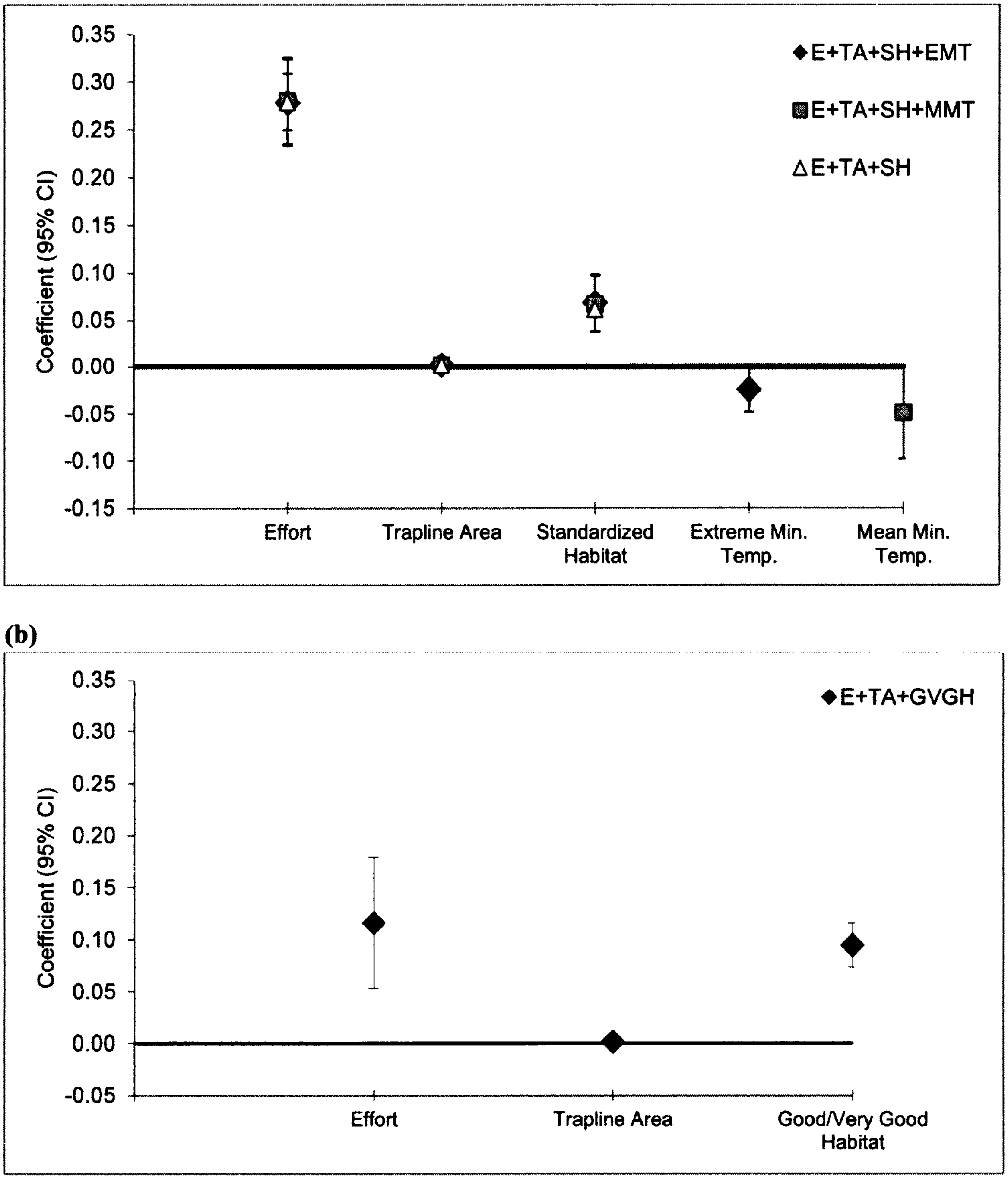


Figure 3.3. Model coefficients and 95% confidence intervals of top-ranked models (where Δ AIC$_c$ was < 2.0) representing influences on capture success of marten in the West (a) and East (b) Study Areas across central-interior BC, Canada

furbearers, where other forms of population monitoring may be difficult (Ruette et al. 2003). Although other studies have used large-scale harvest databases with varying success, we implemented a novel approach that was dependent on the knowledge and personal fur-harvest records of trappers. This allowed us to account for a number of factors that might influence inter-annual variation in harvest success, including habitat change and trapping effort, important considerations that have been difficult to address in other studies (Smith et al. 1984, Raphael 1994, McDonald and Harris 1999, Poole and Mowat 2001).

Erickson (1982) and Raphael (1994) suggested that site-specific harvest records may be useful for identifying relative abundance and population trends, contingent on the quantification of annual trapping effort. An ideal measure of trapping effort would include the number of traps set multiplied by the number of trap days (McDonald and Harris 1999). We attempted to quantify trapping effort through a variety of measures, including the number of traps set per season or per day, or the number of days spent trapping during the season. When quantifiable measures of effort were not available, trappers provided self-evaluations of effort for each year of trapping. These elicited data were a reasonable measure of trapping effort as indicated by the consistent performance of the effort variables in the count models representing annual variation in harvest of each species.

Influences on Capture Success

The most parsimonious count models suggested that changes in lynx and marten harvest were influenced by trapping effort and habitat, and in some cases, weather parameters were also informative. Trapping effort was included in each model, with a positive influence on capture success for both lynx and marten. Size of the trapline also had a positive influence on capture success in all cases. For marten in the West Study Area, low air temperatures increased capture success. Many trappers suggested that marten captures increase with cold temperatures (M. Bridger unpub. data), as marten forage more frequently to meet high energetic demands. This is supported by empirical studies of the winter activity of marten (Buskirk et al. 1988). Similarly, colder temperatures appeared to contribute to increased captures of lynx in the East Study Area.

The top-models for lynx in the West and marten in both study areas included a measure of habitat change: capture success on the traplines were positively related to habitat availability and quality. This supported our hypothesis that capture success, and ultimately population abundance, would vary with cumulative impacts of landscape change. A covariate for habitat availability and quality, however, was not present in the top two models for lynx captures on traplines located in the East Study Area.

Measures of habitat availability and quality were derived from expert-based habitat maps that represented cumulative landscape change for each trapline over time (1990 to 2013; Chapter 2). A previous study by Webb and Boyce (2009) used harvest records and measures of landscape disturbance to model the relationship between inferred habitat change and the abundance of marten. Our results were similar to those found by Webb and Boyce (2009), where the trapping of marten was positively related to forest cover and inversely related to measures of disturbance; however, those authors did not account for trapping effort. Our approach explicitly represented habitat change, rather than measures of disturbance and we tested a relatively full set of factors that might influence trapping success.

The methods employed in this study reduced many of the biases and limitations associated with large data sets of harvest records, typically maintained by management agencies. Working with individual trappers at the scale of the trapline, however, is time consuming, resulting in fewer data. Although the models identified statistically significant predictors of capture success, uncertainty in the model selection and limited predictive power may have been a result of these small sample sizes. Model selection was particularly uncertain for lynx in the East Study Area, where only 27 capture records were obtained. Future studies should include more trapper participants, increasing the sample size of trapping records as well as the spatial scale of the study. Validation of the habitat models with empirical data would also be beneficial (Kliskey et al. 1999).

Our results suggested that the availability of habitat influenced trapping success, likely representing changes in the distribution or abundance of the trapped populations following intensive forestry activity across the West Study Area. The spatial distribution of trapping effort should be considered when attempting to understand the impacts of habitat change. Over the short-term, habitat loss and population decline may not necessarily be represented by low capture success if trappers focus their efforts in large patches of remnant habitat; this may result in a lag in reduced capture rate and an apparent lag in population decline or collapse (Raphael 1994).

We worked closely with the trappers to understand variation in effort across time and spatially across their respective traplines. Most trappers reported that on a yearly basis they trapped the same general locations, unless significant habitat disturbance occurred, in which case they would abandon those locations. Additionally, there was uncertainty as to whether trappers were focusing their efforts in locations that were representative of the highest quality habitat for marten and lynx. Wiebe et al. (2013) reported that trappers generally established marten sets in habitat that was selected for by marten; however, their study found that trapping locations were highly influenced by road or trail access. During our consultations with trappers, we found that many trapping locations aligned with areas identified as high-quality marten habitat on the expert-based habitat maps (see Chapter 2). For lynx, trappers appeared to be applying most of their effort near or within regenerating forest stands; these locations were generally considered moderate lynx habitat, according to the habitat maps.

Aside from effort, there are many other factors that may influence capture success, and ultimately the inferences that can be made to population abundance. Such factors include season length, quota changes, weather, access, trapper skills and motivation, trapping methods, activity on neighbouring traplines, and furbearer population dynamics (McDonald and Harris 1999, Poole and Mowat 2001, Ruette et al. 2003). Thus, one should be cautious when using trapping records as an index of population abundance. We attempted to identify and control for the major confounding factors by interviewing individual trappers. Most trappers reported that their capture success was affected by population abundance, effort, weather, and habitat availability.

Catch per Unit Effort

The count models suggested that capture success of lynx and marten, and ultimately population abundance, varied with habitat availability and quality. This conclusion is further demonstrated when evaluating CPUE and trapping effort for marten in the West Study Area. Since 1990, trappers increased their effort to capture marten in the West, yet CPUE decreased. Over this same time period, the expert-based habitat models predicted substantial declines in the availability and quality of marten habitat. Decreases in CPUE may suggest overharvest, but in this case, provides further evidence that marten populations may be declining in response to habitat loss. This relationship was not found for marten captures in the East Study Area, where habitat had remained relatively stable, even increasing on certain traplines (see Chapter 2). For lynx captures in the West, however, CPUE increased over time, as did trapping effort. This result suggests that lynx populations in the West were not declining, or that increased trapping effort or efficiency masked any potential declines that may have occurred.

Habitat Change and Population Dynamics of Furbearers

Although many researchers would agree that lynx populations depend heavily on the availability of prey (Apps 2000, Poole 2003, Hoving et al. 2004, Simons-Legaard et al. 2013), the link between lynx populations and the availability and quality of habitat is not well quantified. Habitat for their primary prey species, snowshoe hare (*Lepus americanus*), is often associated with regenerating forests that occur following logging or wildfire (Mowat et al. 2000, Poole 2003, Simons-Legaard et al. 2013). Consequently, both snowshoe hare and lynx populations may benefit from landscape disturbance (Mowat and Slough 2003, Hoving et al. 2004). Less is known, however, about the dependence of lynx populations on habitat associated with mature forest stands. Mature conifer or mixed forests provide valuable habitat for denning, resting, and cover from climatic conditions (Paragi et al. 1997). The loss of such forests due to timber harvesting could have detrimental impacts to lynx at a population level.

Lynx captures appeared to be high in the West Study Area despite a considerable reduction in old forests and apparent loss of habitat. This suggests that lynx populations are not necessarily dependent on habitat that is associated with old forests; rather they are regulated by other factors, like the abundance of snowshoe hare. Accounts from trappers suggest that both snowshoe hare and lynx populations are currently high in many portions of the West Study Area. Conversely, lynx captures have been historically low in the East despite a relatively slow rate of forest harvesting; further evidence that lynx populations may not be limited by what experts perceive as quality habitat (see Chapter 2).

Many studies have investigated the impacts of industrial development on marten habitat (Thompson 1994, Chapin et al. 1998, Hargis et al. 1999, Potvin et al. 2000, Payer and Harrison 2003, Fuller and Harrison 2005, Steventon and Daust 2009, Cheveau et al. 2013); however, few have linked habitat change to population abundance. Marten are widely associated with old-growth coniferous stands (Payer and Harrison 2003, Proulx et al. 2006, Carroll 2007, Webb and Boyce 2009, Cheveau et al. 2013). These forests contain structural elements and canopy conditions that ameliorate extreme weather conditions and provide cover from predators, foraging habitat, and resting and denning sites (Thompson and Colgan 1994, Potvin et al. 2000, Carroll 2007, Cheveau et al. 2013). Extensive losses of these late-successional forests due to timber harvesting may have direct impacts on marten populations (Steventon and Daust 2009, Webb and Boyce 2009). For example, Thompson (1994) found that marten had lower mean ages, lower reproductive success, and higher natural and trapping mortality across areas with a high level of forest harvesting. Both the habitat and count models developed in this study provide further evidence that the loss of habitat may result in declines in the abundance of marten populations.

Trappers in the recently and extensively logged West Study Area reported that they were having greater difficulty capturing marten; when interviewed, they suggested that habitat loss was the driving force for low capture rates. The empirical results of this study support those statements. Marten captures, and likely the density of marten populations, varied with the availability of habitat. The trappers in the East Study Area, where timber harvesting has been limited, did not report reductions in capture success. Since 1990, marten captures were stable or increasing (Figure 3.1c).

Conclusion

The results of this study suggest that the capture records maintained by trappers have considerable utility for empirically documenting variation in furbearer abundance relative to cumulative habitat change. Focusing on both capture records and trapping effort at the scale of the trapline avoids many of the pitfalls associated with the use of large-scale harvest databases typically maintained by management agencies (Smith et al. 1984, McDonald and Harris 1999, Poole and Mowat 2001). When trappers are engaged in the research or management process, records can be acquired at a low cost and over a relatively short time span. These data can be particularly important when studying cryptic species like furbearers (Ruette et al. 2003). Harvest records may be poor indicators of short-term population trends (Erickson 1982, Poole and Mowat 2001); however, such records may be ideal for monitoring long-term trends provided researchers apply rigorous data management and control for influential factors, such as trapping effort.

Count models suggested that after controlling for effort, habitat change did influence capture success. This is some of the first empirical evidence indicating that rapid and large-scale forest harvesting can result in a decline in the abundance of marten populations. This is supported both by theory and the expert knowledge of trappers. Where the rapid extraction of timber results in large cutblocks, and the loss of forest complexity and habitat corridors, marten populations are likely at risk. Wildlife and forest managers must consider the cumulative impacts of forest harvesting and perhaps alternative silviculture practices when attempting to maintain large and widely distributed populations of marten (Payer and Harrison 2003).

The influence of forest harvesting on the habitat and population dynamics of lynx is unclear. Although the empirical evidence indicates that lynx abundance varies with habitat availability, expert knowledge of the trappers suggests that lynx populations are primarily influenced by prey populations. Availability of old-forest habitat may not necessarily promote lynx populations if prey species are not supported. Forest managers must consider promoting or enhancing habitat that benefits prey populations, often in the form of early seral forests, while maintaining adequate availability of old-forest habitat. Management of lynx populations would benefit from further research investigating the relationships between lynx, forest structure, and prey abundance.

Chapter 4: General Summary and Management Considerations

Summary

I documented the cumulative impacts of landscape change on habitat availability and quality for three focal species (see Chapter 2). I developed expert-based habitat models to quantify habitat change in the central-interior of BC for fisher (*Pekania pennanti*), Canada lynx (*Lynx canadensis*), and American marten (*Martes americana*) since 1990. Throughout this process, I examined the utility of expert-based habitat modeling, including the quantification of uncertainty.

Across the West Study Area (see Figure 1.1), where recent forest harvesting was extensive, the availability and quality of habitat for all three species decreased dramatically. This result contrasted with the East Study Area where there was relatively little forest harvesting and habitat availability and quality remained stable over time. These results suggest that intensive forestry negatively effects the habitat of these three furbearer species in an immediate and cumulative manner. As a secondary outcome, this study illustrates the utility of expert knowledge for investigating the response of furbearers to cumulative landscape change.

I hypothesised that the extensive loss of habitat would have population implications, thus, I used trapping records to investigate the relationship between habitat change resulting from cumulative impacts and population abundance of lynx and marten (see Chapter 3). I used count models to relate capture success to habitat change, while controlling for other influential factors, including trapping effort. In both study areas, habitat availability and quality, along with trapping effort and trapline area, were found to positively influence capture success of lynx and marten. These results suggest that habitat change may directly affect the abundance of lynx and marten in the study areas. These results also illustrate the utility of trapping records for investigating population dynamics of furbearers; however, a measure of trapping effort is required to relate environmental covariates, including habitat change, to fur harvest at the scale of individual traplines.

Modeling and Predicting Habitat Change

Expert-based habitat modeling required rigorous and defensible methods. The initial selection of experts was a critical step. I developed explicit criteria for identifying experts and then applied a peer-referral technique to select biologist and trapper experts for the study. By identifying seed experts from three unique disciplines of biologists, I was able to recruit ten biologists from different backgrounds and with broad knowledge of furbearers. Seed experts from the local trapping community were also used to aid in the identification of ten suitable trapper experts that met the requirements for this study. This provided me with two distinct groups of experts that offered unique perspectives during the development of the habitat models. This approach also allowed me to test expert agreement and uncertainty within and between expert groups during the model development stages. The total number of experts was logistically manageable, allowing for personal instruction in the elicitation method, as well as direct and timely feedback on study progress and findings, while providing a wide breadth of knowledge of furbearer-habitat relationships. I assumed that the relatively large sample of experts prevented bias and influential error from any one individual (McBride and Burgman 2012).

My study design allowed the experts to participate and guide all stages of the development of the habitat models. Initially, they voted for three focal species that were considered to be economically important to the fur trapping industry and were hypothesised to be sensitive to landscape change associated with natural or anthropogenic disturbance. Fisher, lynx, and marten were selected as the focal species. Although similar in their general biology, these species use different habitats, and thus may be affected differently by cumulative landscape change.

The experts also selected the variables to be included in the habitat models. Overall, there was high consistency between experts both within and between groups when identifying variables hypothesised to influence the distribution of the three focal species; 11 variables were identified for the fisher and marten models, while ten variables were identified for the lynx model. Uncertainty in the selection of habitat variables by biologists was highest for lynx and lowest for fisher. For trappers, uncertainty was highest for fisher and lowest for marten. Using the analytical hierarchy process (AHP), experts then evaluated the relative importance of each subcategory of variables for predicting the distribution of habitat. Elicitation of scores for each variable occurred with minimal operative errors and relatively high consistency within and between experts. When compared to biologist experts, trappers reported a higher confidence in the ranking of their scores; however, there was higher variation in the eigenvector scores generated using the variable rankings provided by the trappers (product of the AHP matrices representing the relative value of the habitat variables).

I used geographic information systems (GIS) to apply the expert-based habitat models to ten reference landscapes (i.e., registered traplines). I developed a chronology of maps showing habitat change across each reference landscapes at four time intervals (i.e., 1990, 2000, 2005, and 2013). According to the models, there were significant declines in habitat for fisher, lynx, and marten in the West Study Area, where high levels of forestry had occurred over the study period. The models predicted relatively little change in habitat for all three species in the East Study Area, where landscape changes have been minimal since 1990.

I evaluated the uncertainty in expert-based models and the resulting habitat maps. I recreated the maps using the upper and lower 95th percentile eigenvector scores resulting from the AHP elicitation. I also created habitat maps based on the biologist and trapper scores separately. This assessment suggested that discrepancies between experts can influence the prediction of habitat area; however, a relatively high consistency of habitat scores between expert groups resulted in no significant changes to the conclusions of this study. As a form of model validation, the trappers evaluated the distribution and area of ranked habitat on their individual traplines. They reported highest accuracy scores for maps of marten habitat and the lowest for lynx. The low score for the lynx maps may have resulted from variation in the prediction of lynx habitat, due to their propensity to use varying seral stages and habitat types. Additionally, the lynx habitat model may have been overly influenced by the attributes of old-forest stands, resulting in an over-prediction of habitat quality in areas of late-successional forests.

Population Modeling

I used trapping records maintained by each of the ten participating trappers to examine the relationship between lynx and marten population dynamics and habitat change. When using capture success as a proxy for population abundance one must control for trapping effort. Along with effort, I identified other factors that might explain capture success, including habitat availability and quality, trapline area, and climatic conditions.

Determining the influence of cumulative landscape change on trapping success was of particular interest. Thus, I tested three variables representing change in habitat availability and quality over time, derived from the expert-based habitat models (see Chapter 2).

I used NBRMs to relate harvest data from individual traplines to factors hypothesised to influence capture success. I developed sets of *a priori* candidate models and used AIC to identify the most parsimonious model from each set of explanatory hypotheses. The most parsimonious models explaining lynx captures in the West Study Area and marten captures in the East and West included a measure of trapping effort, habitat availability and quality, and trapline area; in all cases, these three predictor variables had a significantly positive influence on capture success. Weather variables were also included in the most parsimonious models for lynx captures in the East and West, and marten captures in the West, where extreme or mean minimum temperatures had a significantly negative influence on marten captures in the West Study Area and lynx captures in the East. I assessed the predictive ability of the top count models by testing for differences between observed and predicted harvest data and found that the models had relatively low predictive power. An increase in the number of participating trappers and resulting number of trapping records might improve the predictive ability of the count models.

Management Concerns and Recommendations

The results of this study provide insights into the influence of cumulative impacts of landscape change on the abundance and distribution of furbearers in central-interior BC. To help guide management recommendations that minimize future cumulative impacts on habitat and populations, I conducted surveys with the ten biologist experts and nine of the trapper experts to discuss management concerns and recommendations. Semi-structured interviews were conducted via telephone with the trappers and semi-structured surveys were sent via email to the biologists. The interviews and surveys were structured to guide discussions of key concerns and recommendations toward habitat and population management for the focal species, as well as for the broader group of furbearers in the province.

Fisher

The biologists and trapper experts identified several key themes important to the management of fisher habitat (Table 4.1). Most biologists and trappers identified old deciduous trees (i.e., cottonwood and poplar) as limiting habitat features for fisher, as the rearing of young takes place primarily in such trees (Lofroth et al. 2010). Although mature deciduous trees are not generally targeted for timber harvest, the experts reported that they are often removed incidentally, or lost due to wind-fall in exposed logged areas.

At a landscape scale, the experts stressed the importance of habitat connectivity in areas affected by extensive timber harvesting. The trappers were particularly concerned with the large size of the cutblocks. These experts may have implicitly recognized the large home range sizes and naturally low population densities of fisher (Weir and Almuedo 2010). The experts reported that extensive salvage logging of forest stands killed by mountain pine beetle (MPB) has resulted in a high density of cutblocks, pine-dominated forests that lack structure, and a lack of contiguous mature forest. The biologists and trappers recommended that forest managers maintain linkage zones and corridors across the landscape, limit the size of cutblocks, and reduce the rate of timber harvest.

Table 4.1. Recommendations by biologist and trapper experts for maintaining habitat and numbers of fisher in the central-interior of BC, Canada. Recommendations were obtained through semi-structured interviews and surveys.

Habitat Concerns	Habitat Recommendations
Loss of denning trees (old deciduous) as a result of forestry practices.	Maintain and promote large, deciduous trees for denning sites; experiment with man-made structures as possible denning locations (i.e., denning boxes).
High density of disturbances and large cutblock sizes across the landscape resulting in the loss of mature forests, reduced habitat connectivity, and increased patch isolation.	Focus habitat management on maintaining corridors and linkages; use logging prescriptions that reduce habitat fragmentation across landscapes.
High rate of timber harvest associated with MPB salvage logging and the promotion of future pine-dominated forests lacking structure.	Promote landscape heterogeneity, including prey habitat; reduce the rate of timber harvesting.
Lack of CWD retention in cutblocks.	Retain CWD and dead standing trees to promote future habitat as cutblocks regenerate.
Broadcast herbicide use as a silviculture practice resulting in loss of cover and prey habitat.	Reduce or eliminate the use of aerial herbicides as a silviculture practice.
Population Concerns	**Population Recommendations**
Populations likely in decline resulting from MPB salvage logging.	See habitat recommendations for promoting fisher habitat.
Lack of population connectivity, particularly with low densities and large home ranges; population isolation could result in complete losses of populations.	See habitat recommendations for promoting habitat/population connectivity.
Trapping may be an additive pressure on sensitive populations; uncertainty surrounding the sustainability of fisher harvest.	Trapping management or restrictions may be required in areas with small or declining populations; management of captures on individual traplines; minimize trapper by-catch in marten and lynx traps (i.e., restriction plates on marten traps).
Lack of population monitoring to observe trends.	Better inventory of population numbers and trends; increase in mark-recapture studies or analysis of trapping records.
Climate change could have a positive effect on populations if a reduction in snow cover occurs.	Further research on impacts of climate change on fisher populations.

Relative to elevated levels of forest harvesting across the central-interior of BC, experts were also concerned with a failure to retain sufficient amounts of coarse woody debris (CWD) in recent cutblocks. The experts suggested that greater amounts of CWD should be retained and that this strategy would promote future habitat as the cutblocks regenerate. Several trappers were also concerned with broadcast spraying of herbicides as a silviculture practice in regenerating cutblocks. They suggested that this practice decreases the diversity and structure of future habitat and reduces the quality of habitat for the prey of fisher. Finally, several trappers recognized a lack of coordination of management plans between multiple industrial sectors, as well as between industry and wildlife managers.

Many of the experts suggested that fisher populations are declining in the central-interior of BC, particularly where populations overlap with MPB salvage logging. They reported that the decline was a function of a loss of optimal habitat and a lack of population connectivity across the landscape. Some experts felt that population isolation due to fragmented landscapes could result in complete losses of fisher populations.

Most experts were uncertain when describing the potential impacts of trapping on fisher populations, as there is a lack of monitoring. Most biologists suggested that trapping may be an additive source of mortality for sensitive populations; however, the trappers were generally unconcerned about the impacts of trapping, likely due to low capture rates. Few trappers targeted fisher with most captures being incidental in marten or lynx traps. The biologists recommended better use of trapping records to monitor harvest and population trends. Also, they recommended that trapping restrictions be implemented in areas where populations are thought to be sensitive to overharvest or other anthropogenic impacts.

Lynx

The biologists and trappers identified both positive and negative influences of landscape change on lynx habitat (Table 4.2). Most experts agreed that early seral forests resulting from logging or forest fires could potentially benefit lynx through the promotion of prey habitat; however, trappers were concerned about the length of time required before these habitats become optimal. Most experts recommended implementing forestry practices that promote heterogeneous landscapes, and provide early seral prey habitat.

Both expert groups were unsure of the importance of old-forest stands and attributes for the productivity of lynx populations; several biologists stated a need for further research on lynx and their habitat requirements. Currently, there have been no relevant studies of lynx habitat requirements in the central-interior of BC. Many biologists and trappers suggested that there is a lack of mature forest attributes which may provide habitat for cover, resting, and denning, and such areas must be preserved as refuge habitat. Many trappers were concerned with the aerial broadcast spraying of herbicides, suggesting that this practice significantly impacts prey habitat in regenerating forests; they recommended the elimination of herbicides as a silviculture practice.

Most experts agreed that in the central-interior of BC lynx and hare populations cycle closely. Thus, as regenerating forests continue to provide ample habitat for hare, there may be little reason to consider the cumulative impacts of industrial development relative to the broad-scale habitat needs of lynx. Multiple trappers suggested that the amplitude and period of the hare population cycle, and subsequent lynx cycle, has stabilised as a result of increased hare habitat. Several biologists stated, however, that there is a lack of knowledge of lynx population dynamics in the northern portion of their range.

Table 4.2. Recommendations by biologist and trapper experts for maintaining habitat and numbers of lynx in the central-interior of BC, Canada. Recommendations were obtained through semi-structured interviews and surveys.

Habitat Concerns	Habitat Recommendations
Large-scale habitat alterations, including large cutblocks, promoting homogenous landscapes.	Implement forestry practices that promote heterogeneous landscapes and natural forest dynamics (i.e., young forests for prey habitat, mixed forests for bedding habitat, and mature forests for denning and cover habitat).
Distribution of lynx is heavily reliant on the availability of prey habitat; regenerating cutblocks have slow recovery times before becoming suitable prey habitat.	Implement forestry and silviculture practices (i.e., reforestation, broadcast burning, and late thinning) that rapidly promote early seral habitat for snowshoe hare populations.
Uncertainty surrounding the amount of elemental attributes required to sustain lynx populations; loss of mature forests and a lack of old-forest attributes on landscape.	Increased research on interactions of lynx with forestry practices; maintain large refuge areas of habitat; preserve mature forests.
Broadcast use of aerial herbicides reducing prey habitat and cover.	Reduce or eliminate the use of aerial herbicides on regenerating cutblocks.
Population Concerns	**Population Recommendations**
Lynx populations may not be at risk where snowshoe hare populations are abundant; populations may increases in areas that have been subjected to logging or wildfires, however, it may take 20-30 years post-disturbance.	See habitat recommendations for promoting prey habitat.
There is uncertainty surrounding the impacts of trapping; fur prices may lead to high trapping pressure, however northern populations may not be susceptible to over-trapping, due to wide distribution and nomadic behavior.	Harvest management may not be necessary in northern portions of their range; restrict harvest (trapping and access) in southern portion of range (southern BC); harvest should be reduced during low periods in the population cycle to increase recovery speed.
Currently, government has a passive approach to harvest management and it is unknown whether that is acceptable; lack of population monitoring and trapping data usage.	Implement better use of harvest data for population abundance and population trends.
Lack of knowledge of population dynamics in northern part of range.	Increased research on population dynamics of lynx and the differences between populations inhabiting boreal and mountain ecosystems.

They recommended better use of trapping records to monitor populations, and an overall increase in baseline population monitoring and research.

Many experts suggested uncertainty surrounding the impacts of trapping on lynx populations. Some biologists reported that trapping may be of concern to sensitive lynx populations in southern BC, but not necessarily in their northern range. They felt that lynx populations could benefit from reduced trapping pressure during low population cycles or restricted trapping of sensitive populations. In contrast, most trappers stated that lynx are insensitive to over-trapping due to their large home ranges and nomadic behavior. Some biologists suggested that there is currently a 'hands off' management approach to regulating lynx trapping in the northern half of the province; it is unclear whether this approach is acceptable. Most trappers recognized the importance of population management by trappers on individual traplines, or across multiple traplines.

Marten

The experts identified several concerns and recommendations for the management of marten habitat relative to cumulative landscape change (Table 4.3). At a landscape scale, the experts were concerned about extensive reductions in contiguous mature and old-growth conifer forests due to forestry, resulting in fragmented habitat and direct losses of critical habitat features. This was of particular concern for areas subjected to MPB salvage logging, where habitat may have been diminished to an extent that no longer supports viable marten populations. Trappers reported the negative impacts associated with large cutblocks resulting from salvage logging. They suggested a reduction in the size of cutblocks and the rate of forest harvest. Most experts recognized the importance of preserving contiguous tracts of old and mature forest that provides habitat connectivity.

Table 4.3. Recommendations by biologist and trapper experts for maintaining habitat and numbers of marten in the central-interior of BC, Canada. Recommendations were obtained through semi-structured interviews and surveys.

Habitat Concerns	**Habitat Recommendations**
Loss of habitat connectivity due to forestry impacts; loss of large, contiguous patches of old-growth forest.	Maintain old- and mid-age conifer forests, and habitat connectivity and corridors.
Loss of important habitat structures, including CWD; lack of CWD retention in cutblocks.	Retain CWD and large-diameter standing trees within and around cutblocks to promote future habitat.
Replanting of lodgepole pine resulting in homogenous forests that lack complexity.	Stand-level forest practices to maintain or enhance structure; promote old-forest habitat attributes in younger stands to reduce recovery time.
Large cutblock sizes associated with MPB salvage logging; timber being harvested at an unsustainable rate.	Smaller cutblock sizes; reduce the rate of timber harvest.
Aerial herbicide use reduces structure, diversity, and prey habitat in regenerating cutblocks.	Eliminate or reduce the use of aerial herbicides.
Lack of research on population-level impacts of habitat change.	Further research on impacts of large-scale habitat loss, and ability of marten to inhabit younger forests.
Population Concerns	**Population Recommendations**
Likely a decline in marten populations in central-interior BC due to extensive forest harvesting.	See habitat recommendations for promoting marten habitat.
Risk of population fragmentation across disturbed landscapes.	See habitat recommendations for maintaining habitat/population connectivity.
Populations may be at relatively low risk province-wide given high abundance and wide distribution of marten, however, local populations may be at risk; lack of population monitoring and research investigating the impacts of trapping.	Increase research and population monitoring (i.e., mark-recapture estimates, or trapper samples); implement better use of trapping records for monitoring population trends.
Risk of over-trapping sensitive populations, particularly on small traplines; fur prices may drive trapping pressure.	Management of harvest on individual traplines is important; trappers should employ a cautious approach.
Trapping may be an additive pressure on sensitive populations	Establish refugia, free from trapping pressure.

Both expert groups reported a heavy dependency of marten on old-forest habitat features for denning, resting, cover, and foraging. They suggested that these features may be limiting on industrially impacted landscapes. Many experts stressed the importance of preserving old forest stands that provide important elemental habitat features, such as CWD and structural complexity. Some biologists stated that the small home ranges of marten should allow for the successful implementation of stand-level management. They suggested that certain forestry practices can retain or promote the necessary elemental features and structure required by marten, reducing the recovery time of post-disturbance forests; a suggestion that is supported by previous research (Payer and Harrison 2003, Poole et al. 2004).

Most biologists and trappers acknowledged that large tracts of marten habitat had been lost; therefore, there should be an emphasis on establishing practices that promote future habitat. This included the retention of CWD and dead standing trees in cutblocks. Several trappers suggested that slash piles within cutblocks should be left intact to provide sub-nivean access and prey habitat. Many trappers also suggested that aerial herbicides reduced the structural diversity, cover, and prey habitat in regenerating forest stands. Some experts cautioned against replanting cutblocks with primarily lodgepole pine, as this promotes future forests with simplified forest structure unsuitable for marten. Many biologists recognized a need for research on the ability of marten to use younger forests, as well as further research on the impacts of large-scale habitat change. Several trappers recommended increased coordination of management plans between industrial sectors to reduce cumulative impacts, and stated that there should be more consultation by industry with furbearer experts.

Both expert groups were in agreement that there is likely a decline in marten populations in the central-interior of BC where MPB salvage logging has occurred. Several biologists, however, suggested that marten populations at a broad scale are at relatively low risk, due to their overall abundance, wide distribution, availability of residual habitat, and small home-range sizes. Most experts agreed that habitat loss was the primary concern, but several suggested that populations would recover over time as forests regenerated.

Many biologists felt that local populations may be at risk of over-trapping, although there is currently a lack of population monitoring, thus the impacts of trapping are relatively unknown. They recommended establishing refugia, free from trapping pressure. The biologists also supported increased research and population monitoring. Some trappers felt that there is a risk of over-trapping on individual traplines, particularly if harvest by trappers is mismanaged or high fur prices promotes increased trapping pressure. Conversely, several trappers suggested that marten are at low risk of over-trapping. Most trappers, however, agreed that managing marten harvest on individual traplines was important.

Furbearers in General

The experts also commented on management concerns and recommendations for the broader group of furbearers in BC (Table 4.4). Both expert groups recognized a lack of mandates for industry to manage, maintain, and promote furbearer habitat. Most trappers were particularly concerned with the rate of timber harvesting, the size of the cutblocks, and the overall loss of optimal habitat and travel corridors. They also suggested that the current minimum requirements for industry to preserve or promote habitat are inadequate.

Table 4.4. Recommendations by biologist and trapper experts for maintaining habitat and numbers of the broader group of furbearers in the central-interior of BC, Canada. Recommendations were obtained through semi-structured interviews and surveys.

Habitat Concerns	Habitat Recommendations
Few mandates for industry to manage, maintain, or promote furbearer habitat; current requirements may be insufficient.	Habitat management is important; priority should be placed on preserving old-growth forests.
Cumulative impacts from multiple, competing resource sectors.	Mitigate cumulative impacts; increase coordination amongst industry and consultation with furbearer experts.
Habitat loss resulting from rapid timber harvesting; large cutblocks and lack of corridors.	Forest managers must maintain refuge habitats and landscape-level connectivity.
Reforestation can be a slow, lengthy process.	Habitat must be given sufficient time to regenerate before further alterations occur.
Simplified forest structures resulting from intensive forest harvesting and silviculture practices.	Modify harvest and silviculture practices to retain natural patterns across the landscape.
Lack of knowledge of habitat requirements for furbearers.	Increased research pertaining to habitat requirements of furbearers and impacts of habitat change.
Population Concerns	**Population Recommendations**
Populations may be affected at different spatiotemporal scales; population impacts may be greater at regional scales.	Habitat management should be a priority for maintaining furbearer populations.
Lack of population monitoring and research; trapping data is currently underutilized.	Increase scrutiny and use of trapping data; increase mandatory trapping reporting or inspections to collect population data, particularly for species at risk.
Increased trapper access; trapping pressure may increase with fur prices.	Restrict trapping access and pressure on sensitive populations.
Trapping may not be a concern for the persistence of furbearer species at the broad-scale, but may have implications on local populations.	Increased public and trapper education on population management, particularly on individual traplines.

Furthermore, they reported that a lack of coordination within and between industrial sectors relative to resource extraction is likely to result in cumulative impacts that reduce the extent and quality of furbearer habitat. Several biologists acknowledged that the loss of habitat associated with industry is often rationalized by eventual reforestation; however, this process may occur slowly over a long period of time. Additionally, many of the experts suggested that timber harvesting and subsequent silviculture practices are promoting the regeneration of simplified forest stands resulting in unproductive furbearer habitat. Most trappers reported that the use of aerial herbicides, as a silviculture practice, is detrimental to furbearer habitat.

The forest industry should implement harvesting and silviculture practices that mimic natural landscape changes, while preserving critical habitats. Both expert groups emphasized the importance of protecting old-growth forests and maintaining refuge areas. Several biologists proposed a multi-species approach to habitat management, rather than managing for individual species. This may reduce the complexity of developing and implementing multiple management plans while reducing problems associated with competing habitat requirements of single species.

Forestry and other industrial activities have impacts that vary across different spatiotemporal scales. At a province-wide scale, many biologists suggested that most furbearer species are not of conservation concern. At a regional scale, however, the experts agreed that local populations may be at risk of declines. The majority of experts agreed that the most productive method of supporting furbearer populations is through habitat management.

Although there was uncertainty amongst experts on the impacts of trapping on furbearer populations, most agreed that trapping at a broad scale has minimal impacts. Many experts, however, stated that the combination of habitat loss and trapping at a regional scale could be detrimental to local populations. Several biologists suggested restricting trapping opportunities for sensitive furbearer populations. There was a plea from most experts for an increase in research and population monitoring of furbearers in BC; further development of the use of trapping records and trapper-kills would be beneficial.

Research Conclusions

The results of this study suggest that the cumulative effects of forest harvesting can have considerable impacts on the abundance and distribution of furbearer species. There was strong empirical evidence that the recent and rapid loss of old forest across the West Study Area resulted in declines in furbearer habitat, and subsequently declines in population abundance, particularly for marten. Reports from trappers of high lynx numbers (also evident in the trapping records), however, suggested that lynx populations are stable or increasing despite a loss of mature-forest habitat. This finding suggested that lynx may be food-limited, rather than habitat-limited. In the East Study Area, where forest harvesting has been minimal, the results suggested that stable or increasing habitat availability and quality is promoting abundant furbearer populations. This finding was supported by high capture success for marten over time. Conversely, the trappers reported low numbers of lynx in the East Study Area despite limited forest harvesting and plentiful old-forest habitat. Again, this suggested that lynx were not necessarily dependent on old-forest habitat, but were influenced by other factors, including the availability of prey and prey habitat (early successional forests). The influence of forest harvesting on the habitat and population abundance of lynx remains unclear and warrants further research.

This study contributes to a growing body of ecological literature that validates the use and advantages of expert-based studies (Burgman et al. 2011a, McBride and Burgman 2012, Drescher et al. 2013). In this case, experts allowed the rapid and inexpensive development of models for predicting cumulative change in the availability of habitat for three furbearer species. Additionally, after controlling for trapping effort, capture records maintained by trappers had considerable utility for documenting the numerical response of furbearer populations to habitat change.

As demonstrated by others, expert-based habitat modeling can serve as an efficient and rapid method of documenting species distribution, particularly for cryptic species that are difficult to study (Store and Kangas 2001, Yamada et al. 2003, O'Neill et al. 2008). Involving multiple groups of experts can provide unique, but complementary domains of expertise that minimizes bias and provides a fuller description of species-habitat relationships. The habitat models developed in this study had remarkably high consistency, resulting in model structure that was very similar among expert groups. The consistent results were likely the product of the development of a rigorous study design that included the identification of suitable experts, the application of an easily understood elicitation process, and the full and instructed involvement of the experts throughout the study.

The use of trapping records at the scale of the trapline appeared to be a reasonable method for documenting population dynamics, avoiding many of the pitfalls associated with large-scale harvest databases often generated by management agencies. Quantifying trapping effort was an important step to determining the influence of environmental covariates on capture success, and ultimately population abundance. Although harvest records may be poor indicators of short-term population dynamics, the use of such records may be ideal for monitoring long-term population trends of furbearers. For this study, I correlated harvest records with a time series of habitat change that occurred since 1990.

The application of rigorous and repeatable methods was essential for meeting the study objectives that were primarily focused on the quantification of habitat change and resulting population responses of fisher, lynx, and marten. Application of the study design was meant to generate confidence in the results, but also stimulate discussion and perhaps improve management of furbearers distributed across rapidly changing landscapes. Ultimately, these study findings are transparent and defensible and can be used by wildlife and forest managers to guide habitat and population management and strategic decisions relative to cumulative landscape change.

References

Apps, C.D. 2000. Space-Use, Diet, Demographics, and Topographic Associations of Lynx in the Southern Canadian Rocky Mountains: A Study. Pages 351–372 *in* L.F. Ruggiero, K.B. Aubry, S.W. Buskirk, G.M. Koehler, C.J. Krebs, K.S. McKelvey, J.R. Squires, editors. Ecology and conservation of lynx in the United States. University Press of Colorado, Denver, CO.

B.C. Ministry of Forests, Mines and Lands. 2010. The state of British Columbia's forests, 3rd ed. Forest Practices and Investment Branch, Victoria, BC. (www.for.gov.bc.ca/hfp/sof/index.htm# 2010_report; accessed January 2013).

Burgman, M.A., A. Carr, L. Godden, R. Gregory, M. McBride, L. Flander, and L. Maguire. 2011a. Redefining expertise and improving ecological judgment. Conservation Letters 4:81–87.

Burgman, M.A., M. McBride, R. Ashton, A. Speirs-Bridge, L. Flander, B. Wintle, F. Fidler, L. Rumpff, and C. Twardy. 2011b. Expert status and performance. Public Library of Science ONE 6: e22998. doi: 10.1371/journal.pone.0022998

Burnham, K.P., and D.R. Anderson. 2002. Model selection and multimodel inference: a practical information-theoretic approach. 2nd ed. Springer-Verlag, New York, NY.

Buskirk, S.W. 1992. Conserving circumpolar forests for martens and fishers. Conservation Biology 6:318–320.

Buskirk, S.W., H.J. Harlow, and S.C. Forrest. 1988. Temperature regulation in American marten (*Martes americana*) in winter. National Geographic Research 4:208–218.

Buskirk, S.W., L.F. Ruggiero, and C.J. Krebs. 2000. Habitat Fragmentation and Interspecific Competition: Implications for Lynx Conservation. Pages 83–100 *in* L.F. Ruggiero, K.B. Aubry, S.W. Buskirk, G.M. Koehler, C.J. Krebs, K.S. McKelvey, J.R. Squires, editors. Ecology and conservation of lynx in the United States. University Press of Colorado, Denver, CO.

Carroll, C. 2007. Interacting effects of climate change, landscape conversion, and harvest on carnivore populations at the range margin: marten and lynx in the northern Appalachians. Conservation Biology 21:1092–1104.

Cattadori, I.M., D.T. Haydon, S.J. Thirgood, and P.J. Hudson. 2003. Are indirect measures of abundance a useful index of population density? The case of red grouse harvesting. Oikos 100:439–446.

Chapin, T.G., D.J. Harrison, and D.D. Katnik. 1998. Influence of landscape pattern on habitat use by American marten in an industrial forest. Conservation Biology 12:1327–1337.

Chatterjee, S., and A.S. Hadi. 2006. Regression Analysis by Example, 5th ed. John Wiley and Sons, Hoboken, NJ.

Cheveau, M., L. Imbeau, P. Drapeau, and L. Belanger. 2013. Marten space use and habitat selection in managed coniferous boreal forests of eastern Canada. Journal of Wildlife Management 77:749–760.

Clark Labs. 2011. IDRISI Selva 17.02. Clark Labs, Clark University, Worcester, MA.

Clark, D.F., D.D. Kneeshaw, P.J. Burton, and J.A. Antos. 1998. Coarse woody debris in sub-boreal spruce forests of west-central British Columbia. Canadian Journal of Forest Research 28:284–290.

Clevenger, A.P., J. Wierzchowski, B. Chruszcz, and K. Gunson. 2002. GIS-generated, expert-based models for identifying wildlife habitat linkages and planning mitigation passages. Conservation Biology 16:503–514.

Dormann, C.F, J.M. McPherson, M.B. Araujo, R. Bivand, J. Bolliger, G. Carl, R.G. Davies, A. Hirzel, W. Jetz, W.D. Kissling, I. Kuhn, R. Ohlemuller, P.R. Peres-Neto, B. Reineking, B. Schroder, F.M. Schurr, and R. Wilson. 2007. Methods to account for spatial autocorrelation in the analysis of species distributional data: a review. Ecography 30:609–628.

Doswald, N., F. Zimmerman, and U. Breitenmoser. 2007. Testing expert groups for a habitat suitability model for lynx *Lynx lynx* in the Swiss Alps. Wildlife Biology 13:430–446.

Drescher, M., A.H. Perera, C.J. Johnson, L.J. Buse, C.A. Drew, and M.A. Burgman. 2013. Toward rigorous use of expert knowledge in ecological research. Ecosphere 4: 83. http://dx.doi.org/10.1890/ES12-00415.1

Environment Canada. 2014. Historical Climate Data. (http://climate.weather.gc.ca/; accessed July 2014).

Environmental Systems Research Institute (ESRI). 2012. ArcGIS 10.1. Environmental Systems Research Institute Inc., Redlands, CA.

Erickson, D.W. 1982. Estimating and using furbearer harvest information. Pages 54–65 *in* G.C. Sanderson, editor. Midwest furbearer management. Proceedings of a symposium held at the 43rd Midwest Fish and Wildlife Conference, Wichita, KS.

Fuller, A.K., and D.J. Harrison. 2005. Influence of partial timber harvesting on American martens in north-central Maine. Journal of Wildlife Management 69:710–722.

Guisan, A., and W. Thuiller. 2005. Predicting species distribution: offering more than simple habitat models. Ecology Letters 8:993–1009.

Guisan, A., and N.K. Zimmerman. 2000. Predictive habitat distribution models in ecology. Ecological Modelling 135:147–186.

Hamilton, D.A., B. Roberts, G. Linscombe, N.R. Jotham, H. Noseworthy, and J.L. Stone. 1998. The European Union's wild fur regulation: a battle of politics, cultures, animal rights, international trade and North America's wildlife policy. Transactions of the North American Wildlife and Natural Resources Conference 63:572–588.

Hargis, C.D., J.A. Bissonette, and D.L. Turner. 1999. The influence of forest fragmentation and landscape pattern on American martens. Journal of Applied Ecology 36:157–172.

Hatler, D.F., and A.M.M. Beal. 2003. Furbearer management guidelines: Lynx *Lynx canadensis*. Province of BC and Habitat Conservation Trust Foundation. (http://www.env.gov.bc.ca/fw/wildlife/trapping/docs/lynx.pdf; accessed January 2013).

Hoving, C.L., D.J. Harrison, W.B. Krohn, W.J. Jakubas, and M.A. McCollough. 2004. Canada lynx *Lynx canadensis* habitat and forest succession in northern Maine, USA. Wildlife Biology 10:285–294.

Hurley, M.V., E.K. Rapaport, and C.J. Johnson. 2009. Utility of expert-based knowledge for predicting wildlife-vehicle collisions. Journal of Wildlife Management 73:278–286.

Johnson, C.J. 2011. Regulating and Planning for Cumulative Effects: The Canadian Experience. Pages 29–46 *in* P.R. Krausman and L.K. Harris, editors. Cumulative effects in wildlife management: impact mitigation. CRC Press, Boca Raton, FL.

Johnson, C.J., and M.P. Gillingham. 2004. Mapping uncertainty: sensitivity of wildlife habitat ratings to expert opinion. Journal of Applied Ecology 41:1032–1041.

Johnson, C.J., M. Hurley, E. Rapaport, and M. Pullinger. 2012. Using Expert Knowledge Effectively: Lessons from Species Distribution Models for Wildlife Conservation Management. Pages 153–171 *in* A.H. Perera, C.A. Drew, and C.J. Johnson, editors. Expert knowledge and its application in landscape ecology. Springer, New York, NY.

Kliskey, A.D., E.C. Lofroth, W.A. Thompson, S. Brown, and H. Schreier. 1999. Simulating and evaluating alternative resource-use strategies using GIS-based habitat suitability indices. Landscape and Urban Planning 45:163–175.

Lofroth, E.C., C.M. Raley, J.M. Higley, R.L. Truex, J.S. Yaeger, J.C. Lewis, P.J. Happe, L.L. Finley, R.H. Naney, L.J. Hale, A.L. Krause, S.A. Livingston, A.M. Myers, and R.N. Brown. 2010. Conservation of fishers (*Martes pennanti*) in south-central British Columbia, western Washington, western Oregon, and California – Volume I: Conservation Assessment. USDI Bureau of Land Management, Denver, CO.

Martin, T.G., M.A. Burgman, F. Fidler, P.M. Kuhnert, S. Low-Choy, M. McBride, and K. Megersen. 2011. Eliciting expert knowledge in conservation science. Conservation Biology 26:29–38.

McBride, M.F., and M.A. Burgman. 2012. What Is Expert Knowledge, How Is Such Knowledge Gathered, And How Do We Use It To Address Questions In Landscape Ecology? Pages 11–32 *in* A.H. Perera, C.A. Drew, and C.J. Johnson, editors. Expert knowledge and its application in landscape ecology. Springer, New York, NY.

McCann, N.P., P.A. Zollner, and J.H Gilbert. 2014. Bias in the use of broadscale vegetation data in the analysis of habitat selection. Journal of Mammalogy 95:369–381.

McDonald, R.A., and S. Harris. 1999. The use of trapping records to monitor populations of stoats *Mustela ermine* and weasels *M. nivalis*: The importance of trapping effort. Journal of Applied Ecology 36:679–688.

Meidinger, D.V., and J. Pojar. 1991. Ecosystems of British Columbia. Ministry of Forests, Research Branch, Victoria, BC.

Microsoft Corporation. 2010. Microsoft Excel 14.0. Microsoft Corporation, Redmond, WA.

Mowat, G., K.G. Poole, and M. O'Donoghue. 2000. Ecology of Lynx in Northern Canada and Alaska. Pages 265–306 *in* L.F. Ruggiero, K.B. Aubry, S.W. Buskirk, G.M. Koehler, C.J. Krebs, K.S. McKelvey, J.R. Squires, editors. Ecology and conservation of lynx in the United States. University Press of Colorado, Denver, CO.

Mowat, G., and B. Slough. 2003. Habitat preference of Canada lynx through a cycle in snowshoe hare abundance. Canadian Journal of Zoology 81:1736–1745.

Nitschke, C.R. 2008. The cumulative effects of resource development on biodiversity and ecological integrity in Peace-Moberly region of northeast British Columbia, Canada. Biodiversity and Conservation 17:1715–1740.

O'Neill, S.J., T.J. Osborn, M. Hulme, I. Lorenzoni, and A.R. Watkinson. 2008. Using expert knowledge to assess uncertainties in future polar bear populations under climate change. Journal of Applied Ecology 45:1649–1659.

Paragi, T.F., W.N. Johnson, D.D. Katnik, and A.J. Magoun. 1997. Selection of post-fires seres by lynx and snowshoe hares in the Alaskan taiga. Northwestern Naturalist 78:77–86.

Payer, D.C., and D.J. Harrison. 2003. Influence of forest structure on habitat use by American marten in an industrial forest. Forest Ecology and Management 179:145–156.

Poole, K.G. 2003. A review of Canada lynx, *Lynx canadensis*, in Canada. The Canadian Field-Naturalist 117:360–376.

Poole, K.G., and G. Mowat. 2001. Alberta furbearer harvest data analysis. Alberta Sustainable Resource Development, Fish and Wildlife Division, Alberta Species at Risk Report No. 31, Edmonton, AB.

Poole, K.G., A.D. Porter, A. de Vries, C. Maundrell, S.D. Grindal, and C.C. St. Clair. 2004. Suitability of a young deciduous-dominated forest for American marten and the effects of forest removal. Canadian Journal of Zoology 82:423–435.

Potvin, F., L. Belanger, and K. Lowell. 2000. Marten habitat selection in a clearcut boreal landscape. Conservation Biology 14:844–857.

Proulx, G. 2000. The Impact of Human Activities on North America Mustelids. Pages 53–75 *in* H.I. Griffiths, editor. Mustelids in a modern world: management and conservation aspects of small carnivore: human interactions. Backhuys Publishers, Leiden, The Netherlands.

Proulx, G. 2006. Using forest inventory data to predict winter habitat use by fisher *Martes pennanti* in British Columbia, Canada. Acta Theriologica 51:275–282.

Proulx, G. 2009. Conserving American marten *Martes americana* winter habitat in sub-boreal spruce forests affected by mountain pine beetle *Dendroctonus ponderosae* infestations and logging in British Columbia, Canada. Small Carnivore Conservation 41:51–57.

Proulx, G. 2011. Verification of a forest rating system to predict fisher, *Martes pennanti*, winter distribution in sub-boreal forests of British Columbia, Canada. The Canadian Field-Naturalist 125:7–11.

Proulx, G., R. Kariz, and J. Farkvam. 2006. Using Forest Inventory Data to Predict the Distribution of Potential Winter Habitats for American Martens. Pages 77–88 *in* M. Santos-Reis, J.D.S. Birks, E.C. O'Doherty, and G. Proulx, editors. *Martes* in carnivore communities. Alpha Wildlife Publications, Sherwood Park, AB.

Raphael, M.G. 1994. Techniques for Monitoring Populations of Fishers and American Martens. Pages 224–240 *in* S.W. Buskirk, A.S. Harestad, M.G. Raphael, and R.A. Powell, editors. Martens, sables, and fishers: biology and conservation. Cornell University Press, Ithaca NY.

Ruette, S., P. Stahl, and M. Albaret. 2003. Factors affecting trapping success of red fox *Vulpes vulpes*, stone marten *Martes foina* and pine marten *M. martes* in France. Wildlife Biology 9:11–19.

Saaty, T.L. 1977. A scaling method for priorities in hierarchical structures. Journal of Mathematical Psychology 15:234–281.

Schneider, R.R., J.B. Stelfox, S. Boutin, and S. Wasel. 2003. Managing cumulative impacts of land uses in the Western Canadian Sedimentary Basin: A modelling approach. Conservation Ecology 7:8.

Simons-Legaard, E.M., D.J. Harrison, W.B. Krohn, and J.H. Vashon. 2013. Canada lynx occurrence and forest management in the Acadian forest. Journal of Wildlife Management 77:567–578.

Smith, L.M., and I.L. Brisbin Jr., and G.C. White. 1984. An evaluation of total trapline captures as estimates of furbearer abundance. Journal of Wildlife Management 48:1452–1455.

Soutiere, E.C. 1979. Effects of timber harvesting on Marten in Maine. Journal of Wildlife Management 43:850–860.

StataCorp. 2011. Intercooled Stata 12.1 for Windows. StataCorp LP, College Station, TX.

Steventon, D.J., and D.K. Daust. 2009. Management strategies for a large-scale mountain pine beetle outbreak: modelling impacts on American martens. Forest Ecology and Management 257:1976–1985.

Store, R., and J. Kangas. 2001. Integrating spatial multi-criteria evaluation and expert knowledge for GIS-based habitat suitability modelling. Landscape and Urban Planning 55:79–93.

Thompson, I. D. 1994. Marten populations in uncut and logged boreal forests in Ontario. Journal of Wildlife Management 58:272–280.

Thompson, I.D., and P.W. Colgan. 1994. Marten activity in uncut and logged boreal forests in Ontario. Journal of Wildlife Management 58:280–288.

Vittinghoff, E., and C.E. McCulloch. 2007. Relaxing the rule of ten events per variable in logistic and cox regression. American Journal of Epidemiology 165:710–718.

Vuong, Q.H. 1989. Likelihood ratio tests for model selection and non-nested hypotheses. Econometrica 57:307–333.

Webb, S.M., and M.S. Boyce. 2009. Marten fur harvests and landscape change in west-central Alberta. Journal of Wildlife Management 73:894–903.

Webb, S.M., D.J. Davidson, and M.S. Boyce. 2008. Trapper attitudes and industrial development on registered traplines in west-central Alberta. Human Dimensions of Wildlife: An International Journal 13:115–126.

Weir, R.D., and P.L. Almuedo. 2010. British Columbia's interior fisher wildlife habitat decision aid. BC Journal of Ecosystems and Management 10:1–8.

Weir, R.D., and F.B. Corbould. 2006. Density of fishers in the sub-boreal spruce biogeoclimatic zone of British Columbia. Northwestern Naturalist 87:118–127.

Weir, R.D., and F.B. Corbould. 2010. Factors affecting landscape occupancy by fishers in north-central British Columbia. Journal of Wildlife Management 74:405–410.

Weir, R.D., and A.S. Harestad. 2003. Scale-dependent habitat selectivity by fishers in south-central British Columbia. Journal of Wildlife Management 67:73–82.

Weir, R.D., M. Phinney, and E.C. Lofroth. 2012. Big, sick, and rotting: why tree size, damage, and decay are important to fisher reproductive habitat. Forest Ecology and Management 265:230–240.

Wiebe, P.A., J.M. Fryxell, I.D. Thompson, L. Borger, and J.A. Baker. 2013. Do trappers understand marten habitat? Journal of Wildlife Management 77:379–391.

Yamada, K., J. Elith, M. McCarthy, and A. Zerger. 2003. Eliciting and integrating expert knowledge for wildlife habitat modelling. Ecological Modelling 165:251–264.

Appendix A. Survey conducted by candidate trappers to assess their suitability as experts for the subsequent development of expert-based habitat models.

Assessment of Trapping Activity

The following questionnaire has been developed in order to gain an understanding of your trapping experience and trapline activity. Please answer the following questions by typing directly into the spaces provided, or by selecting the appropriate responses.

1) How many years have you been trapping furbearers in Canada?

2) How many years have you been trapping on your current trapline?

3) Where is your current trapline located?

4) What is the registration number for your current trapline?

5) Do you keep personal records of your trapping activity?

Yes ○

No ○

6) If you answered 'Yes' to Question 3, please explain the types and extent of records that you keep (i.e. effort level, number of captures, location of captures, etc.).

7) Which species do you target on your trapline in most years?

☐ Beaver ☐ Bobcat ☐ Coyote ☐ Fisher ☐ Lynx

☐ Marten ☐ Muskrat ☐ Otter ☐ Wolf ☐ Wolverine

☐ Other

8) What types of landscape change is currently occurring on your trapline, or has occurred in the past?

- ☐ Forestry/Timber Harvesting
- ☐ Forest Fires
- ☐ Mining
- ☐ Oil and Gas
- ☐ Pine Beetle Kill
- ☐ Powerlines
- ☐ Roads
- ☐ Other

9) Describe any levels of landscape change that are currently occurring on your trapline, or have occurred in the past

Appendix B. Examples of surveys conducted by biologist and trapper experts for the purpose of identifying the focal species and habitat variables, and evaluating habitat variables for the development of expert-based habitat models.

Recommendation of Three Focal Species

The following survey has been developed to allow participating experts the opportunity to recommend three furbearers to serve as the focal species for the duration of the study. Keep in mind, the goal of this study is to understand the effects of landscape change on furbearer habitat and population trends. The study area is central-interior British Columbia. Please answer the following questions by typing directly into the spaces provided, or by selecting the appropriate responses.

1) Identify 3 of the following species that you feel would be most important to focus research towards during this study. Three species will be the focus of habitat modeling to investigate the effects of landscape change on habitat quality and availability. They will also be used to relate landscape change to population abundance. The study area is central-interior BC. Ideal focal species for this study will have ecological and economic importance, and will also be sensitive to, or affected by, various forms of landscape change:

☐ Beaver ☐ Bobcat ☐ Coyote ☐ Fisher ☐ Lynx

☐ Marten ☐ Mink ☐ Muskrat ☐ Otter ☐ Wolf

☐ Wolverine

☐ Other ________

2) a. Please provide a brief rationale as to why you selected species 1?

b. Why did you select species 2?

c. Why did you select species 3?

3) Do you have any other suggestions or concerns regarding the selection of three species to serve as the focal species during this study?

Candidate Habitat and Disturbance Variables for Lynx (*Lynx canadensis*) Winter Habitat Model in Central-Interior British Columbia

The following survey has been developed to aid in the identification of general habitat variables thought to influence distribution of lynx across winter range. Please score the following variables in terms of their importance for identifying lynx habitat. In other words, which of the following variables should be included in a lynx winter habitat model in central-interior BC? Keep in mind we are simply identifying the general categories of variables that will be included in the models. During a subsequent survey, I will then ask you to rank the specific habitat variables in terms of importance. Please answer the following questions by typing directly into the spaces provided, or by selecting the appropriate responses. When completed, save the file and submit via e-mail to mbridger4@gmail.com

If you have any questions, please contact me at 250-961-5869, or by e-mail at mbridger4@gmail.com

Please rank the following habitat variables in terms of their importance for identifying lynx habitat, where 4 is very important; 3 is important; 2 is moderate; 1 is low importance; and 0 is unimportant. A habitat variable could be important whether it has a positive or negative influence on lynx distribution. A habitat variable would be unimportant if it had no influence on lynx distribution.

	0	1	2	3	4
Coarse Woody Debris	○	○	○	○	○
Ground Shrub Cover	○	○	○	○	○
Structural Complexity (Overstory)	○	○	○	○	○
Canopy Cover (Crown Closure)	○	○	○	○	○
Density of Mature Trees (Basal Area)	○	○	○	○	○
Dominant (Leading) Tree Species	○	○	○	○	○
Forest Stand Age	○	○	○	○	○
Distance to Water Bodies	○	○	○	○	○
Slope (Steepness)	○	○	○	○	○
Aspect (N,S,E, or W)	○	○	○	○	○
Elevation	○	○	○	○	○
Seral Stage (Age) of Clear-Cuts	○	○	○	○	○
Proportion of Clear-Cuts across Winter Range	○	○	○	○	○
Distance to Roads	○	○	○	○	○
Density of Roads across Range	○	○	○	○	○
Presence of Seismic/Gas Lines	○	○	○	○	○
Presence of Burnt Forest	○	○	○	○	○
Habitat Fragmentation	○	○	○	○	○

Confidence Scores for Habitat Variables: Please score your confidence in the answers you provided above for all habitat variables, where 10 is extremely confident. In other words, how certain are you in the answers you provided for each habitat and disturbance variable when considering their importance for influencing the distribution of lynx across their winter range.

	1	2	3	4	5	6	7	8	9	10
Coarse Woody Debris	○	○	○	○	○	○	○	○	○	○
Ground Shrub Cover	○	○	○	○	○	○	○	○	○	○
Structural Complexity (Overstory)	○	○	○	○	○	○	○	○	○	○
Canopy Cover (Crown Closure)	○	○	○	○	○	○	○	○	○	○
Density of Mature Trees (Basal Area)	○	○	○	○	○	○	○	○	○	○
Dominant (Leading) Tree Species	○	○	○	○	○	○	○	○	○	○
Forest Stand Age	○	○	○	○	○	○	○	○	○	○
Distance to Water Bodies	○	○	○	○	○	○	○	○	○	○
Slope (Steepness)	○	○	○	○	○	○	○	○	○	○
Aspect (N,S,E, or W)	○	○	○	○	○	○	○	○	○	○
Elevation	○	○	○	○	○	○	○	○	○	○
Seral Stage (Age) of Clear-Cuts	○	○	○	○	○	○	○	○	○	○
Proportion of Clear-Cuts across Winter Range	○	○	○	○	○	○	○	○	○	○
Distance to Roads	○	○	○	○	○	○	○	○	○	○
Density of Roads across Range	○	○	○	○	○	○	○	○	○	○
Presence of Seismic/Gas Lines	○	○	○	○	○	○	○	○	○	○
Presence of Burnt Forest	○	○	○	○	○	○	○	○	○	○
Habitat Fragmentation	○	○	○	○	○	○	○	○	○	○

Please suggest any additional information or additional habitat variables that you feel are important to consider when determining the distribution of lynx across their winter range in central-interior BC.

Marten Habitat Assessment

The following is an assessment of the importance of specific habitat variables for the distribution of marten (*Martes americana*) across winter landscapes in the central-interior of British Columbia. The Analytical Hierarchy Process (AHP) is being used to obtain scores in the form of pairwise comparisons for every combination of habitat variables. The scoring scheme for the AHP is provided below. *Important* You will be providing scores for the variables in the column on the left side of the AHP matrices compared to the variables in the row at the top of the matrices. Please keep in mind that all scores are comparative (e.g., A very important variable may be given a high score of '7' or '9' when compared to a low-importance variable, but may receive a lower score of '1' compared to a variable that is equally as important). An example of an AHP matrix is provided below.

You are also asked to provide confidence scores for each of the matrices that you completed. In other words, on a scale from 1- 10, how confident are you in the comparative scores you provided? ('1' being very low confidence and '10' being very high)

Participants are asked to type their scores directly into the AHP comparison matrices provided.

The scoring scheme for the AHP pairwise comparisons of habitat variables

1 = Equal importance	**1** = Equal importance
3 = Moderately more important	**-3** = Moderately less important
5 = Strongly more important	**-5** = Strongly less important
7 = Very strongly more important	**-7** = Very strongly less important
9 = Extremely strongly more important	**-9** = Extremely strongly less important
2,4,6,8, = Intermediate values	**-2, -4, -6, -8** = Intermediate values

Example: This matrix is comparing the importance of tree species for a given wildlife species. For this example, we start by comparing the variables in the left column to the first variable in the top row (Pine). By default, Pine compared to itself is of equal importance, represented by a score of '1'. Next, Spruce is moderately more important than Pine, represented by a score of '3'. Fir is very strongly more important than Pine, represented by a score of '7'. Hemlock is strongly more important than Pine, represented by a score of '5'. Finally, Deciduous is moderately less important than Pine, represented by a score of '-3'. All shaded cells are the opposite of their respective scores, and do not need to be filled out.

	Pine	Spruce	Fir	Hemlock	Deciduous
Pine	1				
Spruce	3	1			
Fir	7	5	1		
Hemlock	5	3	-3	1	
Deciduous	-3	-5	-7	-5	1

AHP Comparison Matrices for Marten Habitat Variables

Please fill in the blank cells of the following AHP matrices. Give comparative scores (using the AHP scoring scheme) for the following habitat variables in terms of importance for marten winter habitat. Please refer to Habitat Variable Handout PDF for examples. ** Score the variables in the column on the left relative to the variables on the top row **

Coarse Woody Debris Load: Patch/Stand Spatial Scale

	Low	Medium	High
Low	1		
Moderate		1	
High			1

Confidence Score: 10

Ground Shrub Cover (Understory Density): Patch/Stand Spatial Scale

	Low (<30% cover)	Moderate (30-60% cover)	High (>60% cover)
Low (<30% cover)	1		
Moderate (30-60% cover)		1	
High (>60% cover)			1

Confidence Score: 10

Structural Complexity (Overstory): Patch/Stand Spatial Scale

	Low	Moderate	High
Low	1		
Moderate		1	
High			1

Confidence Score: 10

Canopy Cover (Crown Closure): Patch/Stand Spatial Scale

	Open (<10%)	Minimal (10 – 40%)	Moderate (40 – 70%)	High (>70%)
Open (<10%)	1			
Minimal (10 – 40%)		1		
Moderate (40 – 70%)			1	
High (>70%)				1

Confidence Score: 10

Forest Stand Density of Mature Trees (Basal Area): Patch/Stand Spatial Scale

	Low	Moderate	High
Low (<$20m^2$/ha)	1		
Moderate (20 – $40m^2$/ha)		1	
High (>$40m^2$/ha)			1

Confidence Score: 10

Leading Tree Species (Forest Stand-Type): Patch/Stand Spatial Scale

	Spruce (Wh. En. Hy)	Lodgepole Pine	Black Spruce	Other Conifer (Sub-Alpine/ Balsam/ Douglas)	Deciduous	Mixed (Conifer + Deciduous)
Spruce (White/Engl./Hybrid)	1					
Lodgepole Pine		1				
Black Spruce			1			
Other Conifer (Sub-Alpine/ Balsam/ Douglas)				1		
Deciduous					1	
Mixed (Coniferous. + Deciduous)						1

Confidence Score: 10

Coniferous Stand Age: Patch/Stand Spatial Scale

	Young (<20 years)	Mid-Age (20-50 years)	Mature (50-80 years)	Old (>80 years)
Young (<20 years)	1			
Mid-Age (20-50 years)		1		
Mature (50-80 years)			1	
Old (>80 years)				1

Confidence Score: 10

Deciduous Stand Age: Patch/Stand Spatial Scale

	Young (<10 years)	Mid-Age (10-30 years)	Mature-Old (>30 years)
Young (<10 years)	1		
Mid-Age (10-30 years)		1	
Mature-Old (>30 years)			1

Confidence Score: 10

Clear-Cut Seral Stage (Age)

	Recently cut (<5 years)	5 – 10 years	10 – 20 years	> 20 years
Recently cut (<5 years)	1			
5–10 years		1		
10 – 20 years			1	
>20 years				1

Confidence Score: 10

Proportion of Clear-Cuts on Landscape: Landscape Spatial Scale

	High level (>40%)	Medium Level (10-40%)	Low Level (<10%)
High Level Cut (>40%)	1		
Moderate Level Cut (10-40%)		1	
Low Level Cut (<10%)			1

Confidence Score: 10

Burned Forest Stand Age

	<5 years	5-20 years	>20 years
<5 years	1		
5-20 years		1	
>20 years			1

Confidence Score: 10

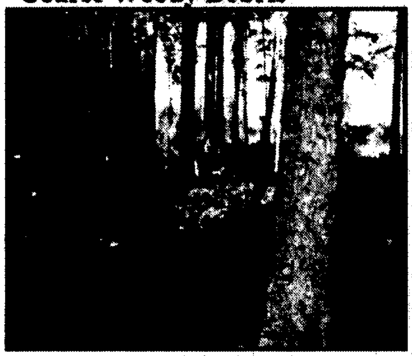
Habitat/Patch Connectivity: Landscape Spatial Scale

	Low	Moderate	High
Low Connectivity	1		
Moderate Connectivity		1	
High Connectivity			1

Confidence Score: 10

Habitat Variable Classification Handout

Coarse Woody Debris



Low CWD Load

Moderate CWD Load

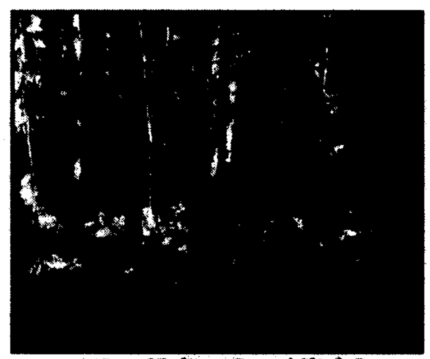
High CWD Load

High CWD Load

Ground Shrub Cover

Low Ground Shrub Cover

Photo: http://www.[illegible]



Moderate Ground Shrub Cover

High Ground Shrub Cover

High Ground Shrub Cover

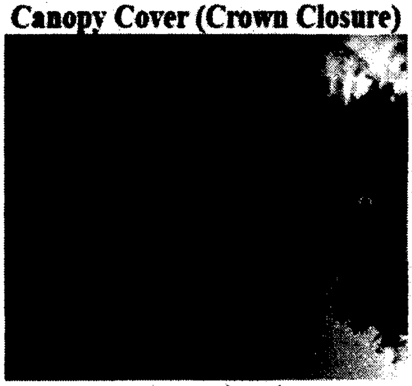
Structural Complexity (Overstory)

Minimal Structural Complexity

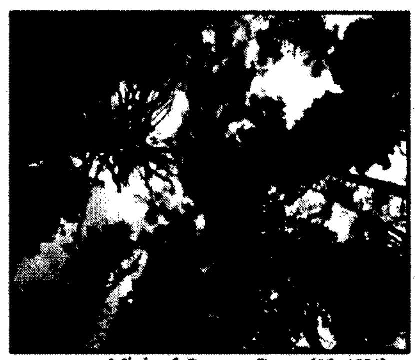
Moderate Structural Complexity

High Structural Complexity

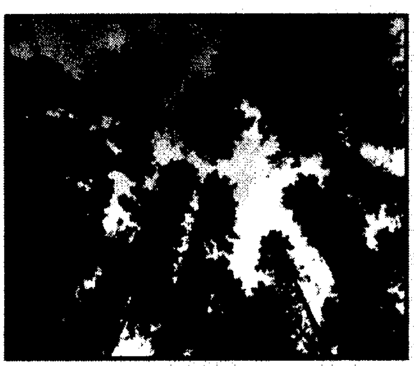
Canopy Cover (Crown Closure)



Open Canopy Cover (<10%)



Minimal Canopy Cover (10-40%)



Moderate Canopy Cover (40-70%)

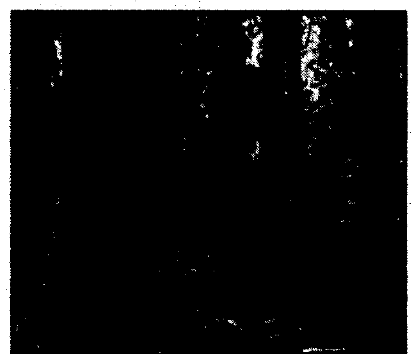
High Canopy Cover (>70%)

Forest Stand Density (Basal Area)

Low density of mature trees (<20 m^2/ha)

Moderate density of mature trees (20-40 m^2/ha)

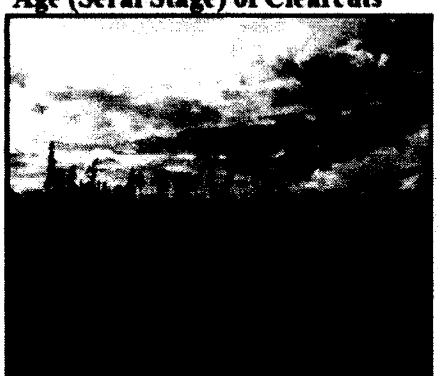
High density of mature trees (>40 m^2/ha)



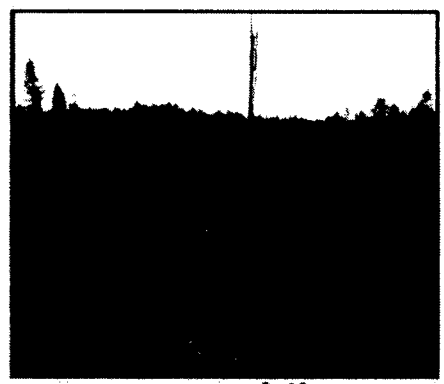
High density of mature trees (>40 m^2/ha)

Photo: [illegible]

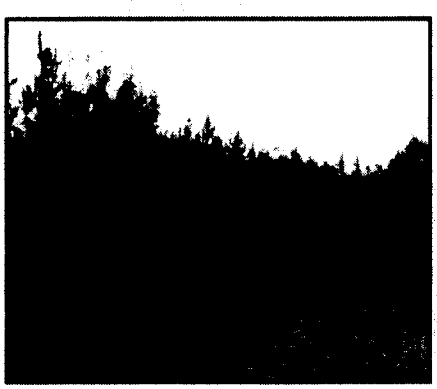
Age (Seral Stage) of Clearcuts



Recently Cut (<5 years)



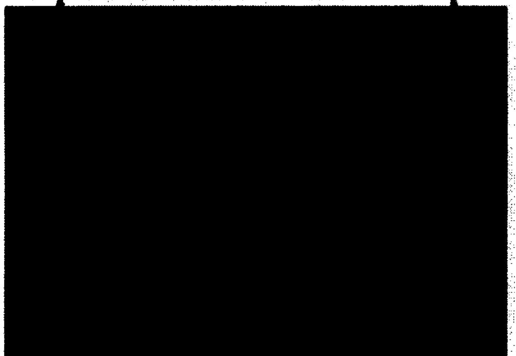
5 - 10 years



10 - 20 years

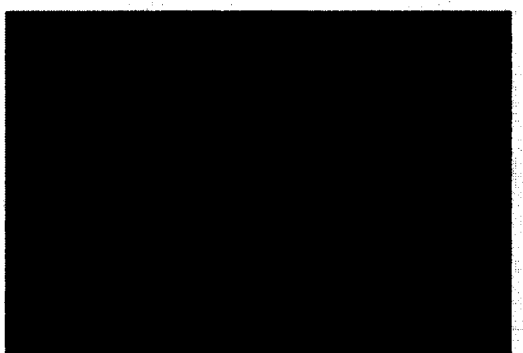
>20 years

Proportion of Clearcuts on Landscape



Low proportion of clearcuts (<10%)

Moderate proportion of clearcuts (10-40%)



High proportion of clearcuts (>40%)

High proportion of clearcuts (>40%)

Habitat/Patch Connectivity Across Landscape

Low Connectivity

Moderate Connectivity

High Connectivity

Appendix C. Description of the classification of habitat variables used to construct expert-based habitat models for each focal species.

TABLE C1. Descriptions of the subclasses, levels, or categories of habitat variables included in the habitat models for fisher, lynx, and marten.

Canopy Cover Classifications adapted from Fuller and Harrison 2005, Proulx et al. 2006, Proulx 2009	**Low =** - Crown closure ≤10% **Minimal =** - Crown closure >10% and ≤40% **Moderate =** - Crown closure >40% and ≤70% **High =** - Crown closure >70%
Coarse Woody Debris Classifications adapted from Clark et al. 1998	**Low =** - Forest age ≤50 years, or forest age >50 and <150 years if leading tree species is lodgepole pine - If fire present, forest age ≤50 years if outside fire polygon, or forest age >50 and <150 years if leading tree species is lodgepole pine - All cutblocks **Moderate =** - Forest age >50 and ≤ 200, or forest age ≥ 150 if leading tree species is lodgepole pine - If fire present, forest age ≤50 if within fire polygon, or forest age >50 and ≤200 years, or forest age ≥150 years if leading tree species is lodgepole pine **High =** - Forest age >200 years and leading tree species is not lodgepole pine
Coniferous Stand Age Classifications adapted from Proulx et al. 2006, Proulx 2009	**Young =** - Coniferous leading tree species and forest age <20 years **Mid-Age =** - Leading tree species and forest age ≥20 and <50 years **Mature =** - Coniferous leading tree species and forest age ≥50 and <80 years **Old =** - Coniferous leading tree species and forest age ≥80 years
Cutblock Age Classifications based on field observations by M.Bridger 2013	**Recent =** <5 years since logging **Young =** 5 – 10 years since logging **Moderate =** 10 – 20 years since logging **Old =** >20 years since logging
Deciduous Stand Age Classifications based on field observations by M.Bridger 2013	**Young =** - Deciduous leading tree species and forest age <10 years **Mid-Age =** - Deciduous leading tree species and forest age ≥10 and <30 years **Mature – Old =** - Deciduous leading tree species and forest age ≥30 years
Forest Fire Age Classifications adapted from Paragi et al. 1997	**Recent =** - Fire age ≤ 5 years **Moderate =** - Fire age >5 and ≤20 years **Old =** - Fire age >20 years

Forest Stand Density Classifications adapted from Fuller and Harrison 2005, Proulx et al. 2006, Proulx 2009	**Low =** - Basal area <20 **Moderate =** - Basal area $\geq$20 and <40 **High =** - Basal area $\geq$40
Ground Shrub Cover Classifications adapted from Proulx 2009	**Low =** - Shrub crown closure <30% and soil type not mesic or hygric - All cutblocks **Moderate =** - Shrub crown closure <30% and soil type mesic or hygric, or shrub crown closure $\geq$30% and <60% **High =** - Shrub crown closure $\geq$60%
Habitat Connectivity Classifications based on GIS landscape metrics, M.Bridger 2013	**Low =** - All forest polygons that intersect cutblocks - High elevation, alpine regions - All cutblocks **Moderate =** - All forest polygons that do not intersect cutblocks and 'proportion of landscape logged' variable is equal to 'high' **High =** - All forest polygons that do not intersect cutblocks and 'proportion of landscape logged' variable is equal to 'low' or 'moderate'
Leading Tree Species for Marten and Lynx Classifications based on dominant leading species found in the SBS and ESSF BEC Zones, Meidinger and Pojar 1991	**Spruce =** - Forest polygons $\geq$60% Engelmann spruce, white spruce, or hybrid spruce, and secondary species is coniferous **Lodgepole Pine =** - Forest polygons $\geq$60% lodgepole pine, and secondary species is coniferous **Black Spruce =** - Forest polygons $\geq$60% black spruce, and secondary species is coniferous **Other Conifers =** - Forest polygons $\geq$60% Douglas fir, subalpine fir, balsam (true) fir, hemlock, or western cedar, and secondary species is coniferous **Deciduous =** - Forest polygons $\geq$60% birch, aspen, cottonwood, or poplar **Mixed =** - Forest polygons <60% deciduous - Or, forest polygons <60% coniferous and secondary species is deciduous

Leading Tree Species for Fisher Classifications based on dominant leading species found in the SBS and ESSF BEC Zones, Meidinger and Pojar 1991	**Spruce =** - Forest polygons ≥60% Engelmann spruce, white spruce, or hybrid spruce, and secondary species is coniferous **Douglas Fir =** - Forest polygons ≥60% Douglas fir, and secondary species is coniferous **Lodgepole Pine =** - Forest polygons ≥60% lodgepole pine, and secondary species is coniferous **Black Spruce =** - Forest polygons ≥60% black spruce, and secondary species is coniferous **Other Conifers =** - Forest polygons ≥60% subalpine fir, balsam (true) fir, hemlock, or western cedar, and secondary species is coniferous **Cottonwood =** - Forest polygons ≥60% cottonwood **Deciduous =** - Forest polygons ≥60% birch, aspen, or poplar **Mixed =** - Forest polygons <60% deciduous - Or, forest polygons <60% coniferous and secondary species is deciduous
Proportion of Landscape Logged/Harvested Classifications adapted from Hargis et al. 1999, Cheveau et al. 2013	**Low Level =** - Trapline area divided by total cutblock area equals ≤10% **Moderate Level =** - Trapline area divided by total cutblock area equals >10% and ≤40% **High Level =** - Trapline area divided by total cutblock area equals >40%
Structural Complexity Classifications adapted from Proulx et al. 2006	**Low =** - Forest age ≤80 - All cutblocks **Moderate =** - Forest Age >80 and ≤ 150, or forest age ≥150 if leading tree species is lodgepole pine **High =** - Forest age >150 if leading tree species is not lodgepole pine

Appendix D. Mean eigenvector scores (representing relative importance) resulting from the expert evaluation of fisher, lynx, and marten habitat variables.

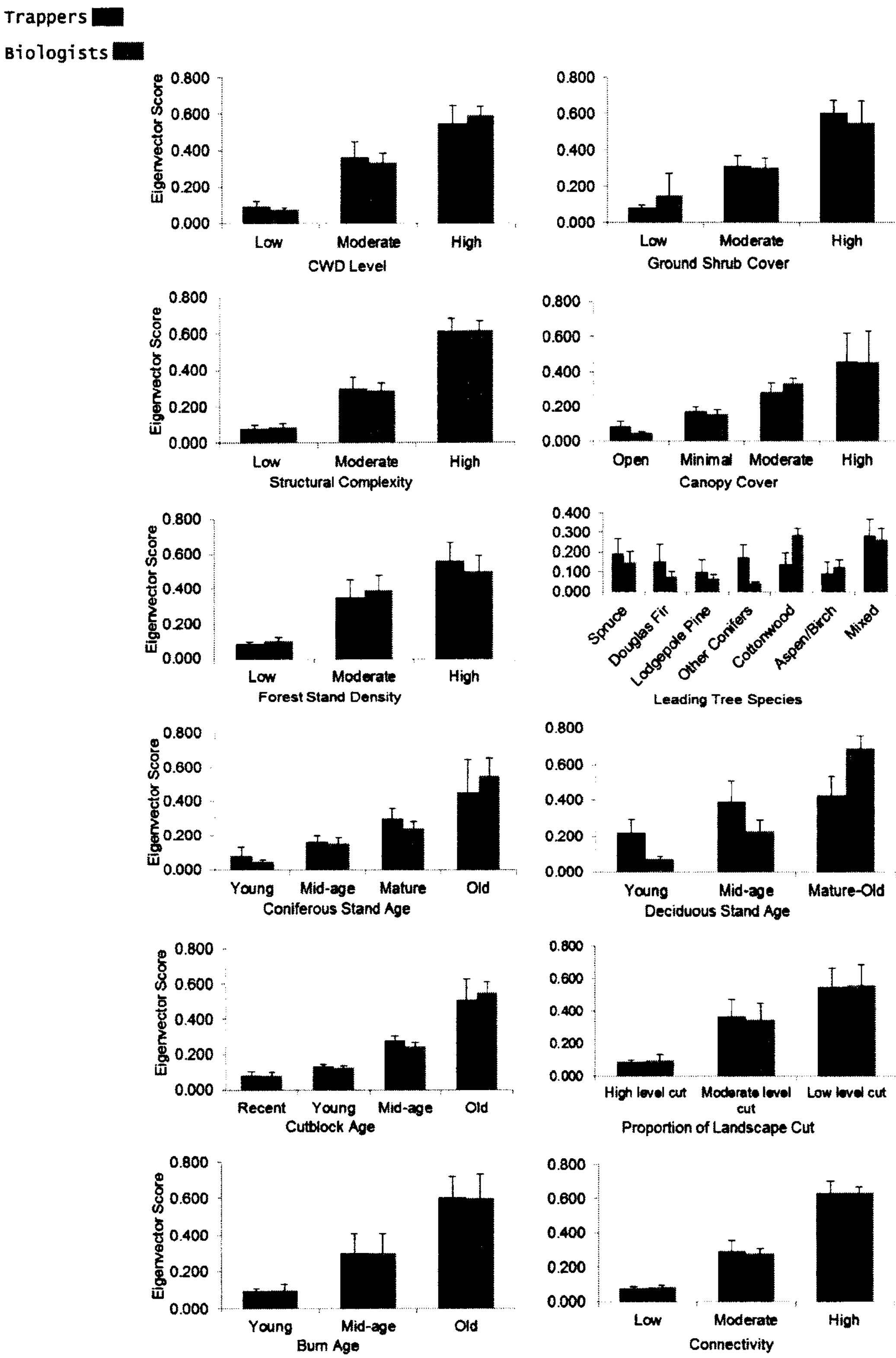


FIG. D1. Mean eigenvector scores (representing relative importance) resulting from the expert evaluation of fisher habitat variables. The data represents the mean scores and 95% confidence intervals.

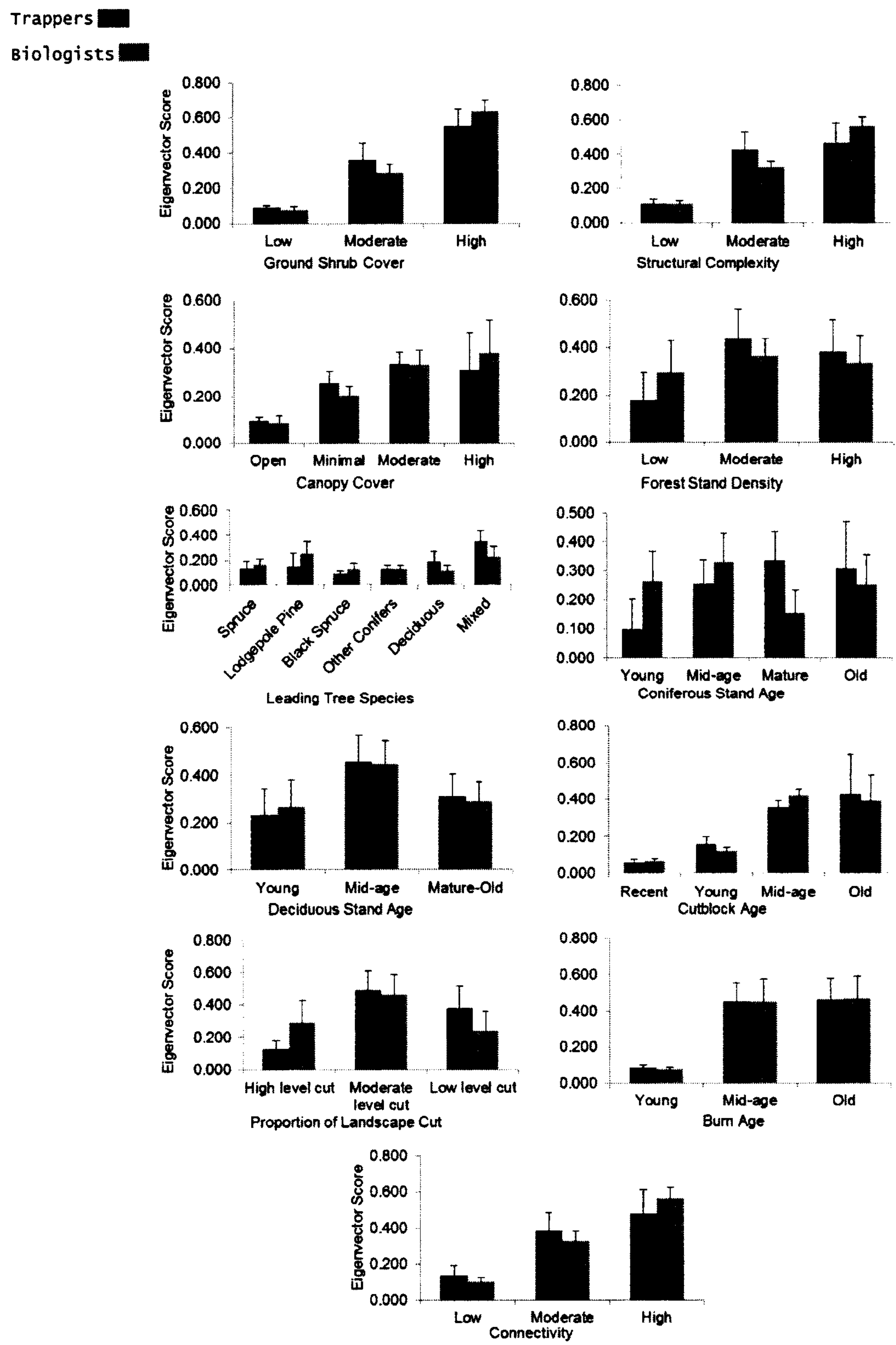


FIG. D2. Mean eigenvector scores (representing relative importance) resulting from the expert evaluation of lynx habitat variables. The data represents the mean scores and 95% confidence intervals.

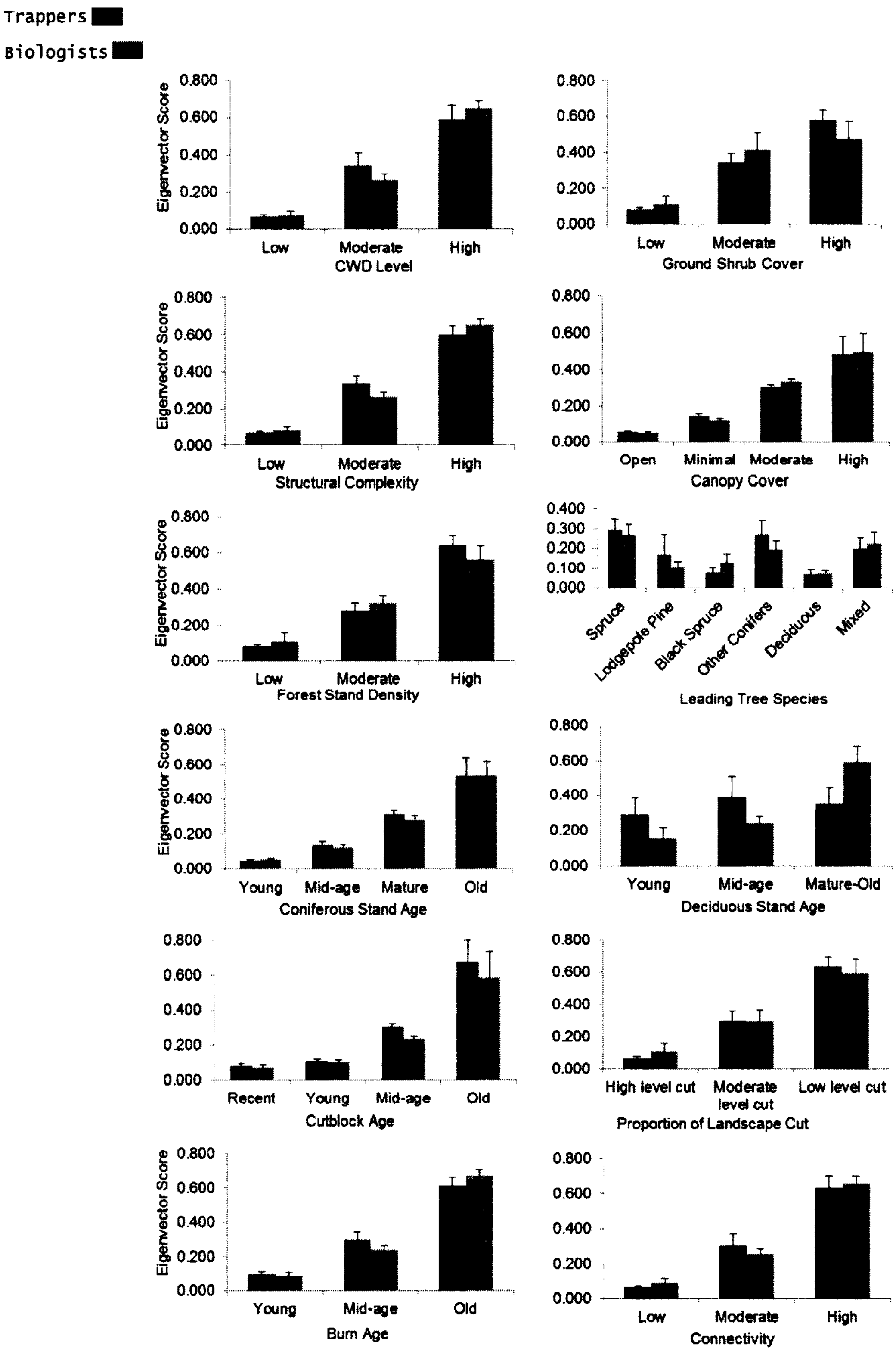
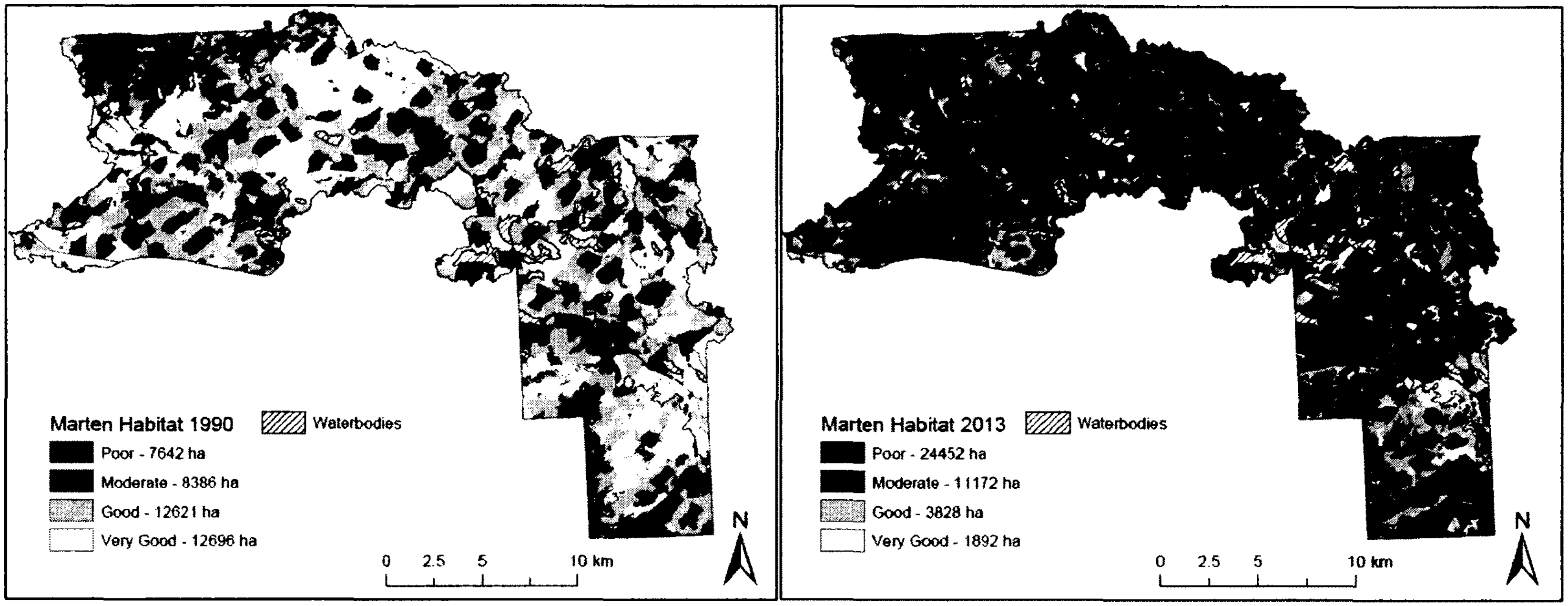
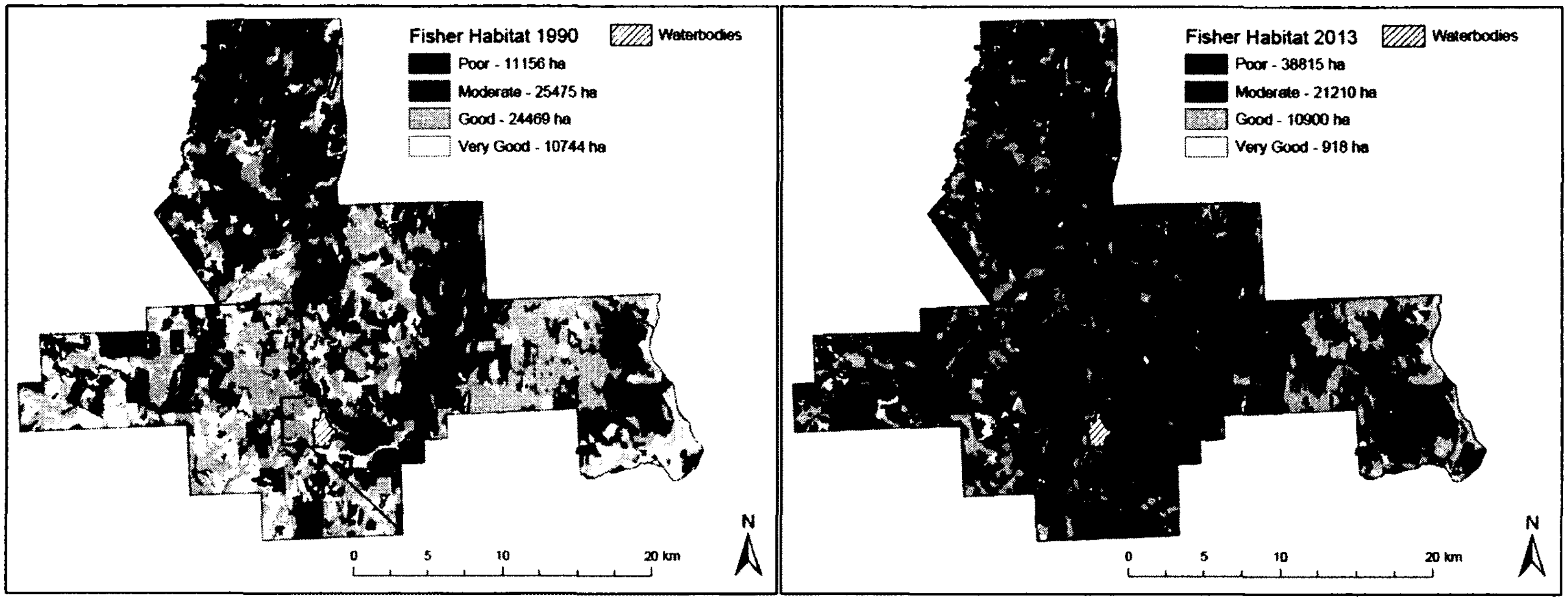


FIG. D3. Mean eigenvector scores (representing relative importance) resulting from the expert evaluation of marten habitat variables. The data represents the mean scores and 95% confidence intervals.

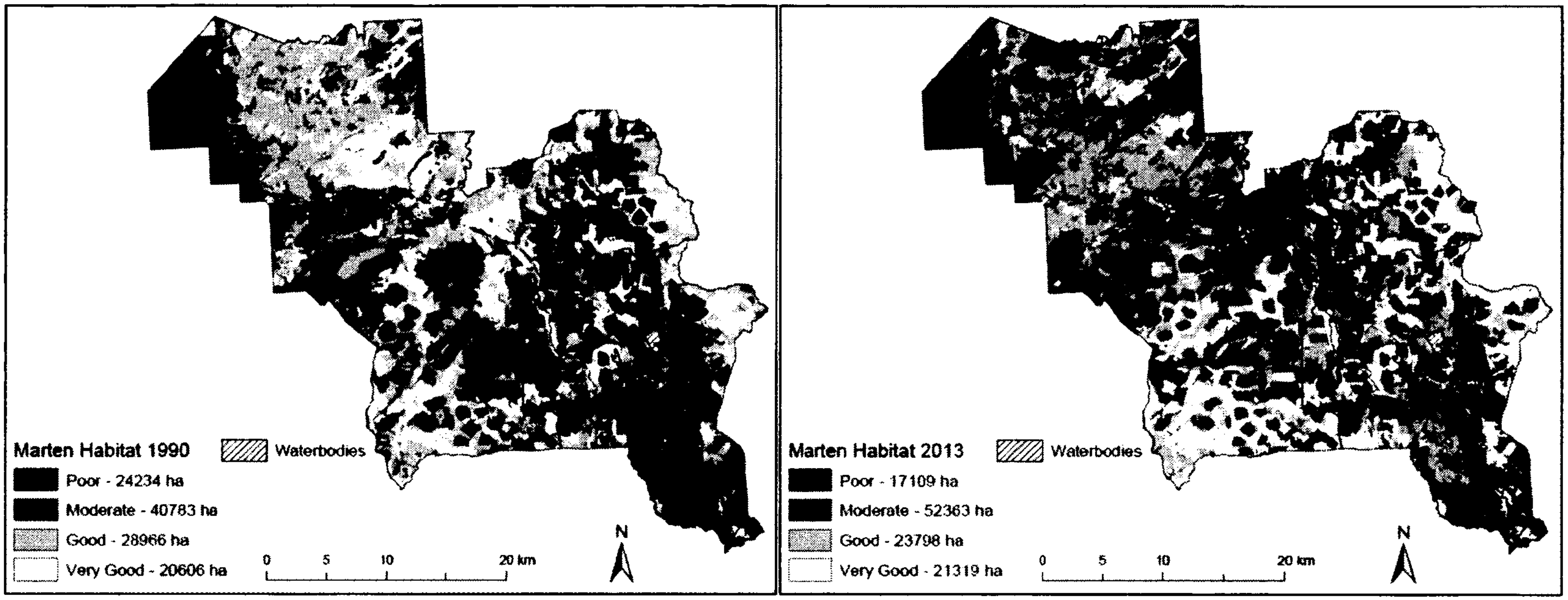
Appendix E. Examples of expert-based habitat maps, providing a spatial representation of change in the availability and quality of habitat from 1990 to 2013.



Example of the expert-based habitat model for marten applied to a trapline in the West Study Area. The maps show the availability and quality of habitat in 1990 and 2013.



Example of the expert-based habitat model for fisher applied to a trapline in the West Study Area. The maps show the availability and quality of habitat in 1990 and 2013.



Example of the expert-based habitat model for marten applied to a trapline in the East Study Area. The maps show the availability and quality of habitat in 1990 and 2013.

Appendix F. Candidate *a priori* model selection for predicting lynx and marten captures in the West and East Study Areas across central-interior BC, Canada.

TABLE F1. Candidate *a priori* models used to select the most parsimonious count model for understanding captures of lynx and marten by trappers in the West and East Study Areas across central-interior BC, Canada

Parameter Definitions

Parameter	Abbreviation	Description
Effort	E	Measure of trapping effort on a scale from 0 – 10
Standardised Effort	SE	Measure of trapping effort relative to trapline area, where 'Effort' was multiplied by 'Trapline Area'
Trapline Area	TA	Trapline area in hectares
Habitat Value	HV	Sum total of the raster habitat values on each respective trapline, according to expert-based habitat maps
Standardised Habitat Value	SH	Habitat relative to trapline area, where 'Habitat Value' was divided by 'Trapline Area'
% Good and Very Good Habitat	GVGH	Percent of the respective trapline area composed of 'Good' or 'Very Good' habitat, according to expert-based habitat maps
Fur Price	FP	The average fur price from the previous year's trapping season
Mean Minimum Temperature	MMT	Average daily minimum air temperature recorded at Prince George Airport weather station (Nov – Jan for marten; Dec – Feb for lynx)
Extreme Minimum Temperature	EMT	Average monthly extreme minimum air temperature recorded at Prince George Airport weather station (Nov – Jan for marten; Dec – Feb for lynx)
Snow Depth Sum	SMS	Cumulative snow depth recorded at Prince George Airport weather station (Nov – Jan for marten; Dec – Feb for lynx)

Candidate *a priori* count models for predicting lynx captures in the West Study Area.

Effort

Model	Rank	AIC_{ci}	AIC_cw_i	$\Delta_i AIC_c$
E + TA	1	412.83	1.000	0.000
E	2	430.79	<0.001	17.968
E + FP	3	431.47	<0.001	18.640
SE + TA	4	434.63	<0.001	21.800
SE + FP	5	451.77	<0.001	38.940
SE	6	455.01	<0.001	42.188

Habitat

Model	Rank	AIC_{ci}	AIC_cw_i	$\Delta_i AIC_c$
GVGH + TA	1	468.41	0.673	0.000
SH	2	470.83	0.200	2.428
SH + TA	3	472.45	0.089	4.040
HV	4	474.77	0.028	6.368
HV + TA	5	476.87	0.010	8.460
GVGH	6	489.99	<0.001	21.588

Effort and Habitat

Model	Rank	AIC_{ci}	AIC_cw_i	$\Delta_i AIC_c$
E + TA + GVGH	1	398.14	1.000	0.000
E + TA + SH	2	414.50	<0.001	16.360
E + SH	3	416.71	<0.001	18.569
E + GVGH	4	432.91	<0.001	34.769
SE + TA + HV	5	435.50	<0.001	37.360
SE + HV	6	444.43	<0.001	46.289

Effort and Weather

Model	Rank	AIC_{ci}	AIC_cw_i	$\Delta_i AIC_c$
E + EMT	1	428.93	0.671	0.000
E + SDS + EMT	2	431.02	0.236	2.091
E + SDS	3	432.89	0.093	3.960
SE + SDS	4	456.55	<0.001	27.620
SE + MMT	5	456.61	<0.001	27.680
SE + SDS + EMT	6	457.34	<0.001	28.411

Habitat and Weather

Model	Rank	AIC_{ci}	AIC_cw_i	Δ_i AIC_c
SH + EMT	1	470.39	0.388	0.000
SH + SDS	2	471.49	0.224	1.100
SH + SDS + EMT	3	471.78	0.194	1.391
SH + SDS + MMT	4	472.34	0.146	1.951
HV + EMT	5	476.01	0.023	5.620
HV + SDS	6	476.75	0.016	6.360
HV + SDS + EMT	7	478.16	0.008	7.771
GVGH + MMT	8	491.79	<0.001	21.400
GVGH + SDS	9	492.07	<0.001	21.680
GVGH + SDS + MMT	10	493.96	<0.001	23.571

Effort, Habitat, and Weather

Model	Rank	AIC_{ci}	AIC_cw_i	Δ_i AIC_c
E + TA + GVGH + EMT	1	397.97	0.615	0.000
E + TA + GVGH + SDS	2	400.29	0.194	2.312
E + TA + GVGH + MMT	3	400.32	0.191	2.344
E + TA + SH + EMT	4	412.44	<0.001	14.462
E + TA + SH + MMT	5	414.61	<0.001	16.636
E + TA + SH + SDS	6	416.33	<0.001	18.353
SE + TA + HV + EMT	7	435.77	<0.001	37.792
SE + TA + HV + MMT	8	437.14	<0.001	39.168
SE + TA + HV + SDS	9	437.15	<0.001	39.178

Candidate *a priori* count models for predicting lynx captures in the East Study Area.

Effort

Model	Rank	AIC_{ci}	AIC_cw_i	$\Delta_i\, AIC_c$
E + TA	1	127.26	0.947	0.000
E	2	134.96	0.020	7.700
SE + TA	3	135.82	0.013	8.560
SE	4	136.84	0.008	9.580
E + FP	5	137.00	0.007	9.740
SE + FP	6	137.90	0.005	10.640

Habitat

Model	Rank	AIC_{ci}	AIC_cw_i	$\Delta_i\, AIC_c$
HV	1	168.52	0.662	0.000
HV + TA	2	170.72	0.239	0.204
SH	3	173.50	0.059	4.820
GVGH	4	174.30	0.040	5.620

Effort and Habitat

Model	Rank	AIC_{ci}	AIC_cw_i	$\Delta_i\, AIC_c$
E + SH	1	127.48	0.386	0.000
E + TA + SH	2	127.90	0.312	0.423
E + TA + GVGH	3	129.38	0.149	1.903
E + GVGH	4	129.42	0.147	1.940
SE + HV	5	136.26	0.005	8.780
SE + TA + HV	6	138.20	0.002	10.723

Effort and Weather

Model	Rank	AIC_{ci}	AIC_cw_i	$\Delta_i\, AIC_c$
E + TA + MMT	1	124.90	0.522	0.000
E + TA + EMT	2	125.10	0.472	0.200
SE + MMT	3	135.18	0.003	10.277
E + SDS	4	137.26	0.001	12.357
SE + SDS + MMT	5	137.68	0.001	12.780
SE + SDS	6	138.90	0.001	13.997

Habitat and Weather

Model	Rank	AIC_{ci}	$AIC_c w_i$	Δ_i AIC_c
HV + SDS	1	169.70	0.383	0.000
HV + EMT	2	170.64	0.240	0.940
SH + SDS	3	172.14	0.113	2.440
HV + SDS + EMT	4	172.22	0.109	2.523
GVGH + SDS	5	173.80	0.049	4.100
SH + SDS + MMT	6	174.60	0.033	4.903
GVGH + EMT	7	175.54	0.021	5.840
SH + MMT	8	175.66	0.019	5.960
GVGH + SDS + MMT	9	175.92	0.017	6.223
GVGH + SDS + EMT	10	176.12	0.015	6.423

Effort, Habitat, and Weather

Model	Rank	AIC_{ci}	$AIC_c w_i$	Δ_i AIC_c
E + SH + SDS	1	129.32	0.244	0.000
E + SH + EMT	2	129.56	0.216	0.240
E + SH + MMT	3	129.82	0.190	0.500
E + GVGH + EMT	4	130.58	0.130	1.260
E + GVGH + MMT	5	130.98	0.106	1.660
E + GVGH + SDS	6	131.86	0.068	2.540
SE + HV + MMT	7	133.50	0.030	4.180
SE + HV + EMT	8	135.20	0.013	5.880
SE + HV + SDS	9	138.44	0.003	9.120

Candidate *a priori* count models for predicting marten captures in the West Study Area.

Effort

Model	Rank	AIC_{ci}	AIC_cw_i	Δ_i AIC_c
E + TA	1	676.34	0.702	0.000
E + FP	2	678.78	0.207	2.440
E	3	680.43	0.091	4.083
SE + TA	4	718.66	<0.001	42.320
SE	5	738.79	<0.001	62.443
SE + FP	6	740.88	<0.001	64.540

Habitat

Model	Rank	AIC_{ci}	AIC_cw_i	Δ_i AIC_c
HV	1	745.75	0.288	0.000
SH + TA	2	746.56	0.191	0.817
HV + TA	3	746.76	0.173	1.017
GVGH + TA	4	746.96	0.157	1.217
GVGH	5	747.01	0.153	1.260
SH	6	749.79	0.038	4.040

Effort and Habitat

Model	Rank	AIC_{ci}	AIC_cw_i	Δ_i AIC_c
E + TA + SH	1	662.79	0.996	0.000
E + TA + GVGH	2	673.89	0.004	11.100
E + GVGH	3	680.68	<0.001	17.892
E + SH	4	682.38	<0.001	19.592
SE + TA + HV	5	694.95	<0.001	32.160
SE + HV	6	736.78	<0.001	73.992

Effort and Weather

Model	Rank	AIC_{ci}	AIC_cw_i	Δ_i AIC_c
E + EMT	1	680.78	0.497	0
E + SDS + EMT	2	681.83	0.294	1.048
E + SDS	3	682.52	0.208	1.740
SE + MMT	4	740.20	<0.001	59.420
SE + SDS	5	740.82	<0.001	60.040
SE + SDS + MMT	6	742.35	<0.001	61.568

Habitat and Weather

Model	Rank	AIC_{ci}	AIC_cw_i	Δ_i AIC_c
HV + EMT	1	746.38	0.276	0.000
HV + MMT	2	746.98	0.205	0.600
HV + SDS	3	747.44	0.163	1.060
GVGH + MMT	4	748.38	0.102	2.000
GVGH + SDS	5	749.00	0.075	2.620
HV + SDS + MMT	6	749.07	0.072	2.688
SH + EMT	7	750.26	0.040	3.880
GVGH + SDS + MMT	8	750.53	0.035	4.148
SH + SDS	9	751.64	0.020	5.260
SH + SDS + EMT	10	752.31	0.014	5.928

Effort, Habitat, and Weather

Model	Rank	AIC_{ci}	AIC_cw_i	Δ_i AIC_c
E + TA + SH + EMT	1	660.83	0.486	0.000
E + TA + SH + MMT	2	661.41	0.364	0.582
E + TA + SH + SDS	3	663.20	0.149	2.367
E + TA + GVGH + EMT	4	674.37	0.001	13.537
E + TA + GVGH + MMT	5	674.69	<0.001	13.861
E + TA + GVGH + SDS	6	676.10	<0.001	15.272
SE + HV + MMT	7	692.43	<0.001	31.599
SE + HV + EMT	8	692.79	<0.001	31.956
SE + HV + SDS	9	693.50	<0.001	32.673

Candidate *a priori* count models for predicting marten captures in the East Study Area.

Effort

Model	Rank	AIC_{ci}	AIC_cw_i	$\Delta_i AIC_c$
SE	1	468.23	0.431	0.000
SE + FP	2	470.17	0.163	1.944
SE + TA	3	470.19	0.161	1.964
E + TA	4	470.91	0.113	2.684
E	5	471.21	0.097	2.980
E + FP	6	473.21	0.036	4.984

Habitat

Model	Rank	AIC_{ci}	AIC_cw_i	$\Delta_i AIC_c$
GVGH + TA	1	439.31	1.000	0.000
GVGH	2	464.37	<0.001	25.056
HV	3	469.11	<0.001	29.796
SH + TA	4	470.47	<0.001	31.160
HV + TA	5	470.57	<0.001	31.260
SH	6	474.85	<0.001	35.536

Effort and Habitat

Model	Rank	AIC_{ci}	AIC_cw_i	$\Delta_i AIC_c$
E + TA + GVGH	1	429.84	1.000	0.000
E + GVGH	2	451.81	<0.001	21.975
SE + TA + HV	3	465.90	<0.001	36.060
E + TA + SH	4	467.72	<0.001	37.880
SE + SH	5	468.43	<0.001	38.595
SE + HV	6	469.67	<0.001	39.835

Effort and Weather

Model	Rank	AIC_{ci}	AIC_cw_i	$\Delta_i AIC_c$
SE + SDS	1	470.15	0.361	0.000
SE + EMT	2	470.31	0.334	0.160
SE + SDS + EMT	3	472.38	0.119	2.225
E + SDS	4	473.13	0.081	2.980
E + MMT	5	473.21	0.078	3.060
SE + SDS + MMT	6	475.38	0.027	5.225

Habitat and Weather

Model	Rank	AIC_{ci}	$AIC_c w_i$	$\Delta_i\, AIC_c$
GVGH + EMT	1	466.25	0.409	0.000
GVGH + SDS	2	466.41	0.377	0.160
GVGH + SDS + EMT	3	468.54	0.130	2.285
HV + MMT	4	471.23	0.034	4.980
HV + SDS	5	471.27	0.033	5.020
HV + SDS + MMT	6	473.36	0.012	7.105
SH + EMT	7	476.91	0.002	10.660
SH + SDS	9	476.99	0.002	10.740
SH + SDS + EMT	10	479.18	0.001	12.925

Effort, Habitat, and Weather

Model	Rank	AIC_{ci}	$AIC_c w_i$	$\Delta_i\, AIC_c$
E + TA + GVGH + SDS	1	431.96	0.364	0.000
E + TA + GVGH + EMT	2	432.22	0.319	0.266
E + TA + GVGH + MMT	3	432.23	0.317	0.276
SE + TA + HV + SDS	4	467.80	<0.001	35.849
SE + TA + HV + EMT	5	468.09	<0.001	36.132
SE + TA + HV + MMT	6	468.22	<0.001	36.261
E + TA + SH + SDS	7	469.63	<0.001	37.680
E + TA + SH + EMT	8	469.84	<0.001	37.886
E + TA + SH + MMT	9	470.01	<0.001	38.059

Appendix G. Coefficients and statistical parameters generated from the top ranked negative binomial regression models for the prediction of lynx and marten captures in the West and East Study Areas across central-interior BC, Canada.

TABLE G1. Coefficients and statistical parameters generated from the top ranked negative binomial regression models for the prediction of lynx captures in the West Study Area across central-interior BC, Canada.

Parameter	β	Standard Error	Z	P	95% CI Lower	95% CI Upper
AIC_c Rank #1						
Effort	0.391	0.037	10.60	<0.001	0.319	0.464
Trapline Area	0.003	<0.001	6.93	<0.001	0.002	0.004
GVG Habitat	0.017	0.004	4.22	<0.001	0.009	0.025
Extreme Min. Temp.	0.029	0.019	1.54	0.123	-0.008	0.066
Constant	-2.488	0.633	-2.71	0.007	-2.952	-0.472
AIC_c Rank #2						
Effort	0.391	0.037	10.50	<0.001	0.318	0.464
Trapline Area	0.003	<0.001	7.10	<0.001	0.002	0.004
GVG Habitat	0.018	0.004	4.38	<0.001	0.010	0.025
Constant	-2.488	0.399	-6.24	<0.001	-3.270	-1.706

TABLE G2. Coefficients and statistical parameters generated from the top ranked negative binomial regression models for the prediction of lynx captures in the East Study Area across central-interior BC, Canada.

Parameter	β	Standard Error	Z	P	95% CI Lower	95% CI Upper
AIC_c Rank #2						
Effort	0.422	0.045	9.37	<0.001	0.334	0.510
Trapline Area	0.002	<0.001	3.73	<0.001	0.001	0.002
Mean Min. Temp.	-0.099	0.044	-2.25	0.024	-0.186	-0.013
Constant	-3.396	0.726	-4.67	<0.001	-4.821	-1.971
AIC_c Rank #2						
Effort	0.443	0.048	9.30	<0.001	0.349	0.537
Trapline Area	0.002	<0.001	3.63	<0.001	0.001	0.002
Extreme Min. Temp.	-0.050	0.023	-2.19	0.029	-0.094	-0.005
Constant	-3.720	0.870	-4.27	<0.001	-5.426	-2.014

TABLE G3. Coefficients and statistical parameters generated from the top ranked negative binomial regression models for the prediction of marten captures in the West Study Area across central-interior BC, Canada.

Parameter	β	Standard Error	Z	P	95% CI Lower	95% CI Upper
AIC_c Rank #1						
Effort	0.278	0.023	12.05	<0.001	0.233	0.323
Trapline Area	0.002	<0.001	5.12	<0.001	0.001	0.002
Standardized Habitat	0.068	0.015	4.47	<0.001	0.038	0.098
Extreme Min. Temp.	-0.025	0.012	-2.04	0.041	-0.048	-0.001
Constant	-1.412	0.654	-2.92	0.003	-3.760	-0.740
AIC_c Rank #2						
Effort	0.280	0.023	12.08	<0.001	0.235	0.326
Trapline Area	0.002	<0.001	5.09	<0.001	0.001	0.002
Standardized Habitat	0.067	0.015	4.40	<0.001	0.037	0.097
Mean Min. Temp.	-0.048	0.025	-1.90	0.058	-0.098	0.002
Constant	-2.071	0.738	-2.81	0.005	-3.517	-0.626
AIC_c Rank #3						
Effort	0.279	0.023	11.94	<0.001	0.233	0.325
Trapline Area	0.002	<0.001	4.87	<0.001	0.001	0.002
Standardized Habitat	0.062	0.015	4.08	<0.001	0.032	0.091
Constant	-1.412	0.654	-2.16	0.031	-2.694	-0.130

TABLE G4. Coefficients and statistical parameters generated from the top ranked negative binomial regression models for the prediction of marten captures in the East Study Area across central-interior BC, Canada.

Parameter	β	Standard Error	Z	P	95% CI Lower	95% CI Upper
AIC_c Rank #1						
Effort	0.116	0.032	3.63	<0.001	0.054	0.179
Trapline Area	0.002	<0.001	5.51	<0.001	0.001	0.002
GVG Habitat	0.095	0.011	8.71	<0.001	0.073	0.116
Constant	-2.262	0.649	-3.48	<0.001	-0.990	-0.990

Appendix H. Difference in observed from predicted fur harvest records generated using negative binomial count models for lynx and marten from the West and East Study Areas across central-interior BC, Canada. A value of zero suggests perfect prediction while negative values mean over-prediction and positive values mean under prediction.

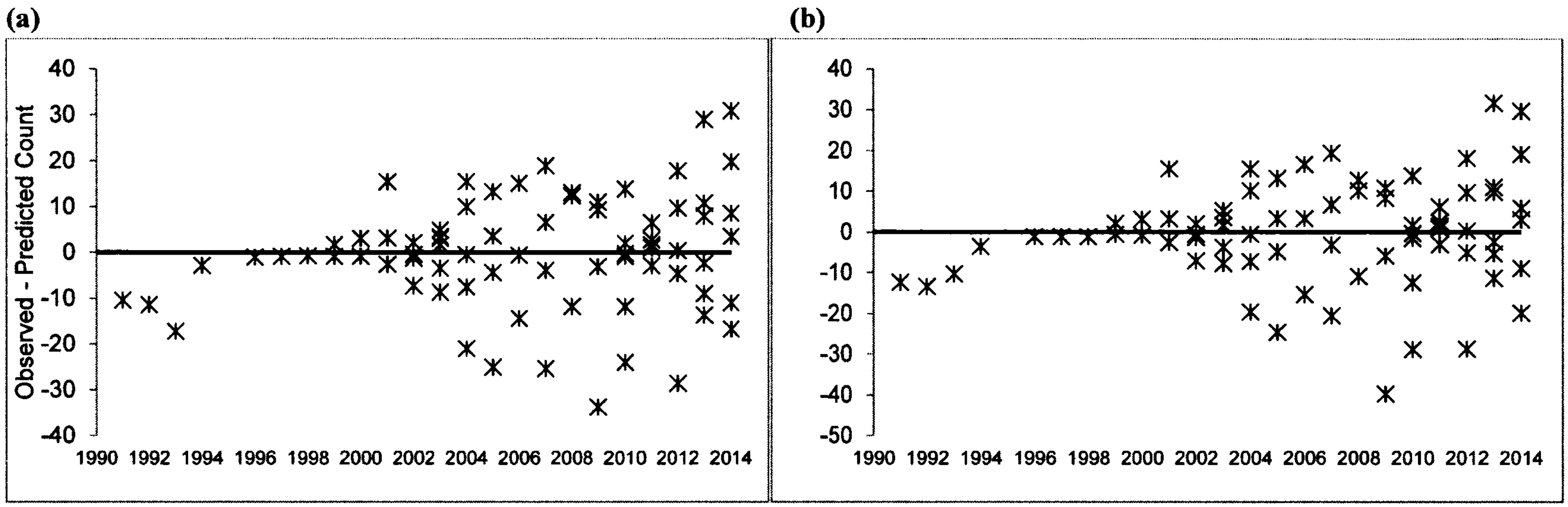


FIGURE H1. Difference in observed from predicted fur harvest records generated using the top ranked negative binomial count models E+TA+GVGH+EMT (a) and E+TA+GVGH (b) for lynx from the West Study Area across central-interior BC, Canada. A value of zero suggests perfect prediction while negative values suggest over-prediction and positive values suggest under-prediction

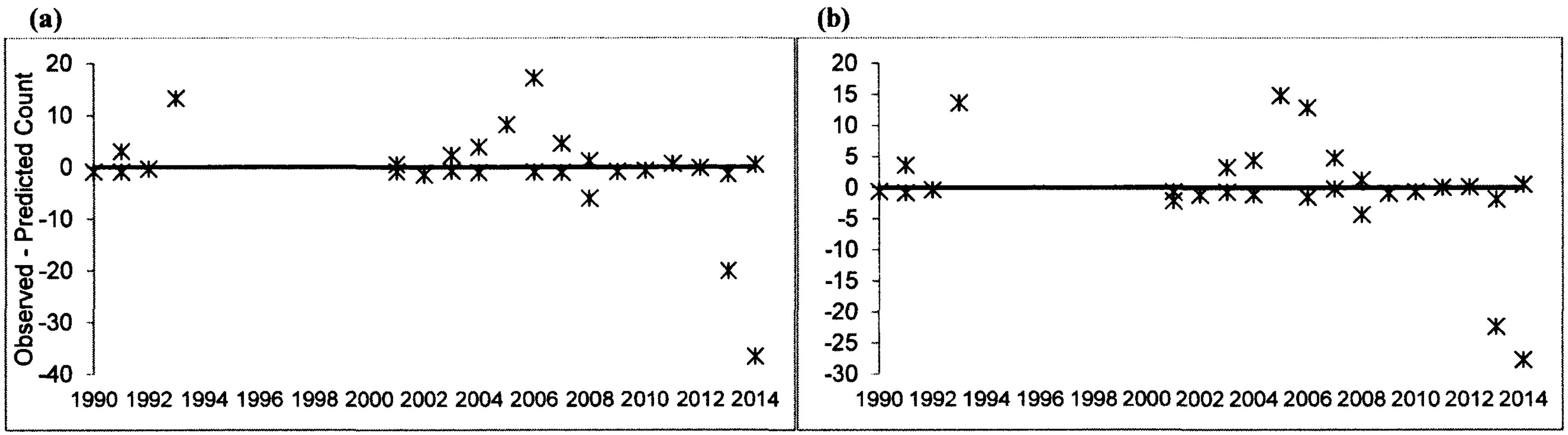


FIGURE H2. Difference in observed from predicted fur harvest records generated using the top ranked negative binomial count models E+TA+EMT (a) and E+TA+MMT (b) for lynx from the East Study Area across central-interior BC, Canada. A value of zero suggests perfect prediction while negative values suggest over-prediction and positive values suggest under-prediction.

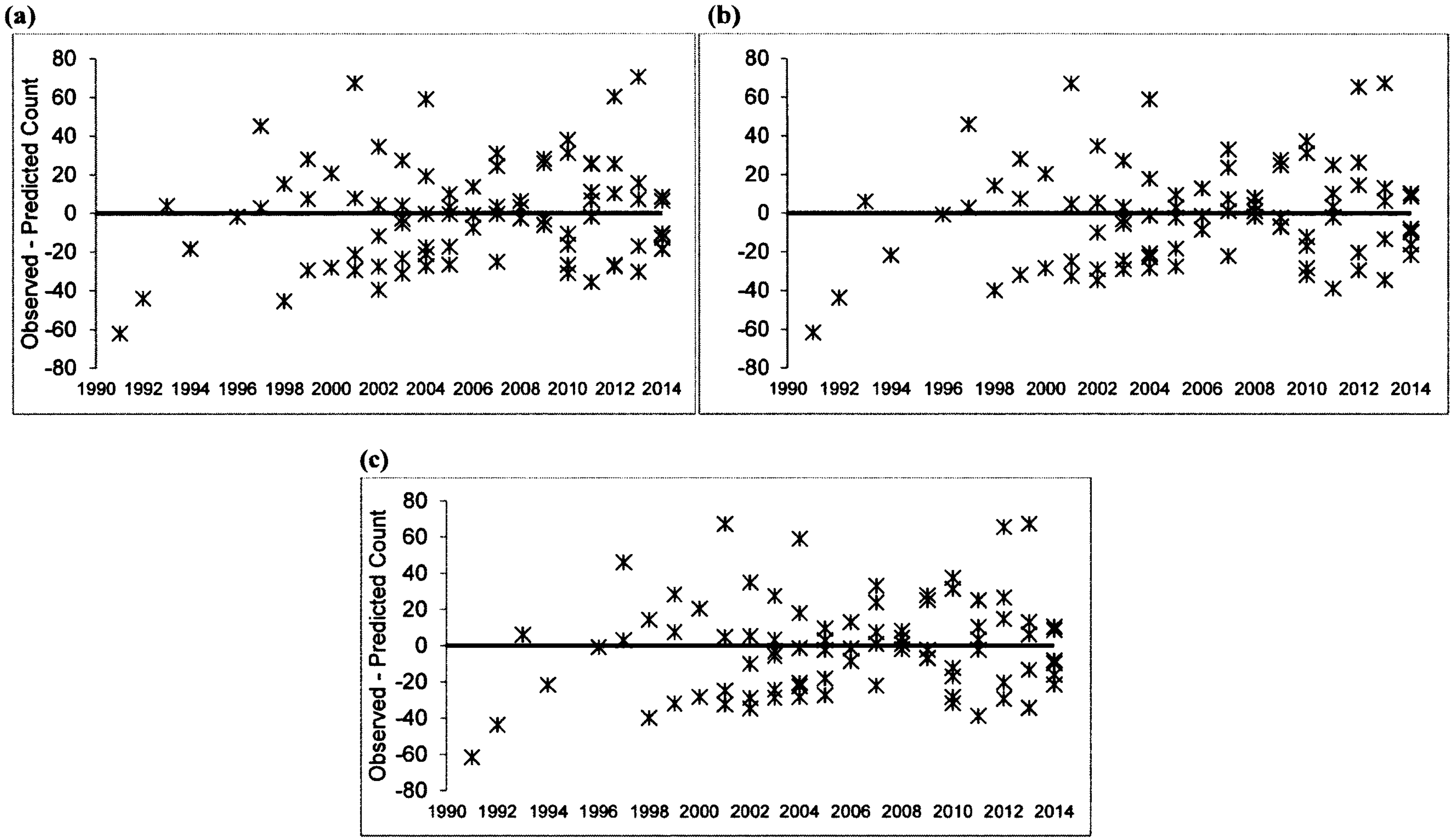


FIGURE H3. Difference in observed from predicted fur harvest records generated using the top ranked negative binomial count models E+TA+SH+EMT (a), E+TA+SH+MMT (b), and E+TA+SH (c) for marten from the West Study Area across central-interior BC, Canada. A value of zero suggests perfect prediction while negative values mean over-prediction and positive values mean under-prediction.

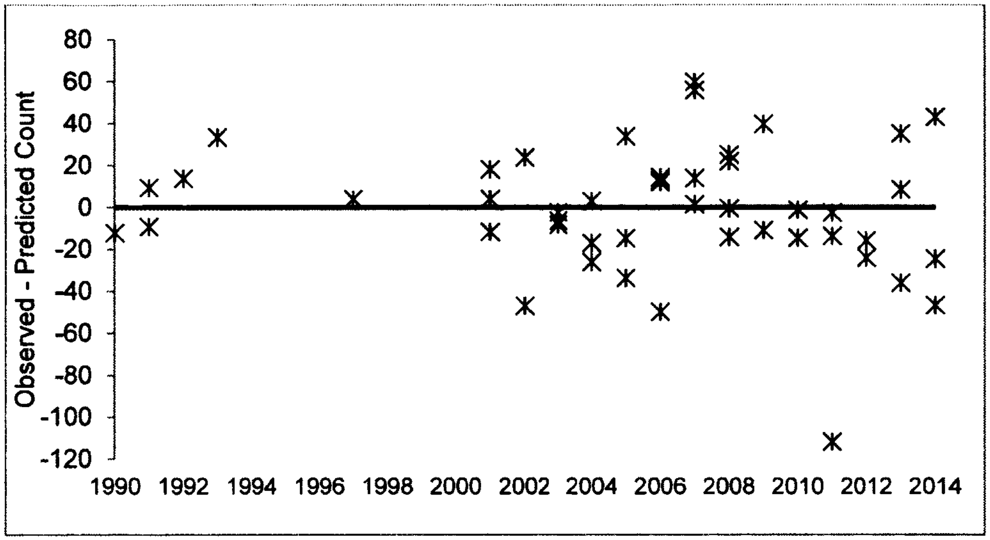


FIGURE H4. Difference in observed from predicted fur harvest records generated using the top ranked negative binomial count models E+TA+GVGH for marten from the East Study Area across central-interior BC, Canada. A value of zero suggests perfect prediction while negative values mean over-prediction and positive values mean under-prediction.