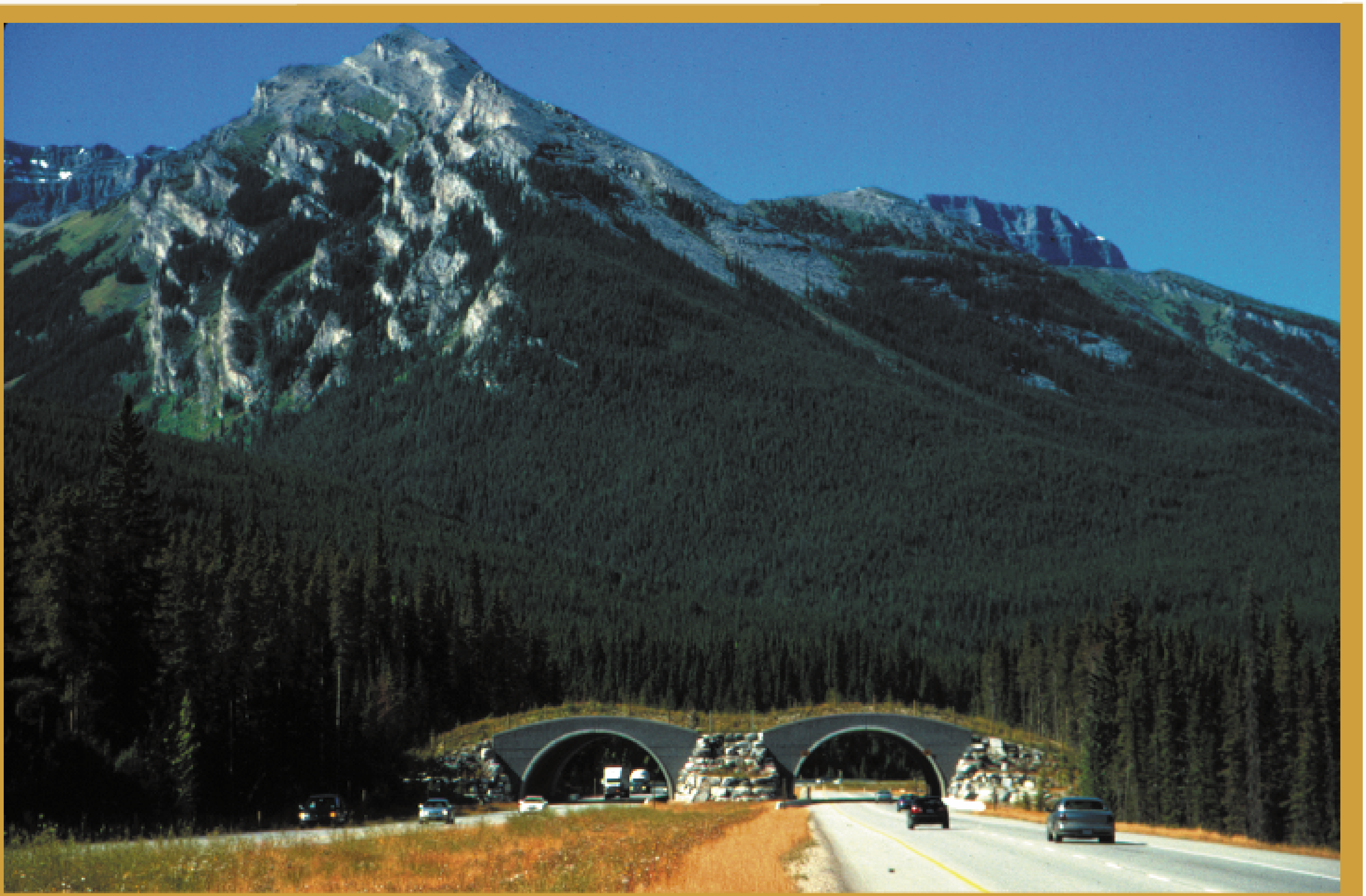
A GIS-Based Approach to Restoring Connectivity Across Banff's Trans-Canada Highway



Yellowstone to Yukon
CONSERVATION INITIATIVE

Technical Report #4
April 2005

By: **Shelley Alexander &**
Jeff Gailus

Yellowstone to Yukon
CONSERVATION INITIATIVE

UNIVERSITY OF
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Cover photograph by Bart Robinson

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Not everything that can be counted counts,
and not everything that counts
can be counted.

– Albert Einstein

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Yellowstone to Yukon Conservation Initiative

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

Parks Canada has begun a process to upgrade the remaining 35-kilometre section of the Trans-Canada Highway (TCH) through Banff National Park, from Castle Junction to the western park boundary at the Alberta-British Columbia border (known as Phase IIIB). As part of the proposal, the project aims to provide adequate mitigations to "reduce habitat fragmentation" caused by the TCH.

However, there is some question whether the proposed twinning project can be implemented without significantly impairing the surrounding ecosystem. According to the *Screening Report for the Trans-Canada Highway Twinning Project, Phase IIIB, Banff National Park*, the proposed widening and fencing of the highway will "adversely affect wildlife's ability to move across the landscape (Golder & Associates 2004)."

Can the proposed mitigations be improved to better meet the project's habitat connectivity goal? This paper was developed in part to help answer that question, serving as an independent, scientific analysis of wildlife movement data collected in the Banff-Bow Valley. It provides important information about where mitigation might be most effectively placed and how much might be constructed to reduce habitat fragmentation along Phase IIIB of the TCH.

Based on the best (in some cases only) available empirical data on four focal carnivores (i.e. marten, lynx, cougar and wolf) and scientifically supported, peer-reviewed analytical techniques, we determined the probability of occurrence for focal species along the Phase IIIB. The occurrence models were used to identify best potential linkage zones for each focal species. Here, we use the term linkage zone to refer to a corridor of land that has high potential for use by a species, and connects habitat on either side of the TCH.

Our results showed that some of the proposed crossing structures are not optimally located, and that the total length of the mitigation (i.e. width of structures) only mitigates a small percentage of the linkage zones available for wildlife along the total length of the Phase IIIB. If all proposed crossing structures and an additional 93 small drainage culverts are constructed, then a total of only 1.7 percent (599.8 metres) of habitat will be maintained for linkages. Of that, primary crossing structures for multi-species are the largest contributor to connectivity (1.3 percent), followed by drainage culverts for marten (0.22 percent); secondary and tertiary structures capture less than 0.1 percent of total highway length (35 kilometres).

On the other hand, if the proposed mitigation included the top 20 percent of habitat as linkage zones for each species, then the project would require a minimum of 2.7 kilometres, and a maximum 6.7 kilometres of mitigation, depending on the species considered.

In this report we prescribe actions to reduce habitat fragmentation caused by the TCH. Our recommendations include moving some structures, widening others, and adding more structures. Our plan would provide an additional 1900 metres of high quality linkage zones. In the optimal locations, our proposed mitigations would increase linkage zones (as a percentage of the entire TCH) from 9.26 to 32.75 percent for wolves, 8.97 to 28.77 percent for marten, 10.78 to 38.11 percent for lynx, and 19.34 to 68.32 percent for cougar.

Part I: The Context

INTRODUCTION

Parks Canada has begun a process to upgrade the remaining 35-kilometre section of the Trans-Canada Highway (TCH) through Banff National Park, from Castle Junction to the western park boundary at the Alberta-British Columbia border (known as Phase IIIB). While it may be necessary to enhance this dangerous stretch of highway to improve the efficiency of traffic flow and reduce the number of motor vehicle accidents and wildlife-vehicle collisions, this project will further degrade habitat connectivity in Canada's first and most famous national park. Our report provides information that Parks Canada can use to ensure that habitat connectivity is maintained and/or restored during the proposed upgrade.

Currently, Phase IIIB is an unfenced two-lane highway. Awarded $50 million by the federal government, Parks Canada plans to twin Phase IIIB to four lanes and construct appropriate mitigation, including wildlife-exclusion fences and 18 major wildlife crossing structures. This proposal is an attempt to meet three goals:

1. To improve public safety;
2. To reduce wildlife mortality and habitat fragmentation; and,
3. To increase transportation service and effectiveness.

One confounding factor is that $50 million is not sufficient to upgrade the entire 35-kilometre stretch of highway. Only a portion of it will be completed – which portion has yet to be determined. Option B, a 12-kilometre stretch from just east of Moraine Creek to the east end of Lake Louise, is being assessed as the preferred alternative for meeting the project goals.

Under the *Canadian Environmental Assessment Act (CEAA) 2003*, Parks Canada must ensure that the project undergoes environmental assessment before determining if the project may proceed. The purpose of such an assessment, in this case an environmental impact statement/screening, is to identify the significance and likelihood of potential adverse environmental impacts of the project, including habitat fragmentation, and propose measures to avoid and mitigate these effects.

There is little question that the proposed twinning project will impair the surrounding ecosystem. According to the *Screening Report for the Trans-Canada Highway Twinning Project, Phase IIIB, Banff National Park*, the proposed widening and fencing of the highway will "adversely affect wildlife's ability to move across the landscape" (Golder & Associates 2004). While the report indicated that the proposed twinning and fencing will reduce highway-vehicle collisions, and reduce wildlife mortality for some species, it will also contribute to an increase in the barrier effect of the highway. This finding suggests it will be difficult if not impossible for the proposed project to meet the project goal of "reducing habitat fragmentation."

More could be done to "reduce habitat fragmentation," such as building larger or more crossing structures. If these options would allow Parks Canada to better meet its habitat fragmentation goal, the question remains whether Parks Canada will commit funds to doing so in light of its legislated mandate to maintain ecological integrity.

BACKGROUND

BROAD STUDY AREA

The Bow Valley is a central connectivity hub in the Yellowstone to Yukon ecosystem (Y2Y). This region is one of the last intact, large-scale mountain ecosystems in North America, if not the world. It stretches from the Greater Yellowstone Ecosystem in the south to the Peel River Watershed in the northern Yukon. It is extraordinary in that it continues to support all of the plants and animals, and the ecosystem processes that were extant when Europeans arrived. The natural assets of this region are also the heart of western North America's economy, supporting hundreds of local and regional communities and providing an unparalleled quality of life for millions of residents and visitors (Willcox *et al.* 1998).

A Fragmented Landscape
Photo: © Peter A. Dettling

Despite the region's social, economic, and ecological significance, a number of anthropogenic activities degrade and disrupt this habitat. Foremost among those threats are the loss and fragmentation of wildlife habitat as a result of human development, particularly roads.

As of 1998, there were 676,957 kilometres of linear disturbances in the Y2Y region – enough to go around the earth 16.8 times. Most of these roads and other linear disturbances (railways, trails, seismic lines, pipelines and powerlines) exist in the southern half of the Y2Y region. The northern 48 percent of the region is located in the Yukon, Northwest Territories, and northern British Columbia, and is relatively pristine (Willcox *et al.* 1998). Four major east-west highways and 13 major north-south highways bisect the Y2Y regions, including the Trans-Canada Highway that runs through Banff and Yoho National Parks (Craighead 2002).

MITIGATING THE EFFECTS OF ROADS

Habitat fragmentation is widely acknowledged as a primary cause of species decline worldwide (Ehrlich 1986, Harris 1984, Lovejoy *et al.* 1986). This fragmentation occurs when portions of a given landscape are transformed or destroyed by natural processes or human activities (Andren 1994, Forman and Godron 1986, Meffe and Carrol 1997). This process is harmful because it leads to smaller and more isolated habitat patches and wildlife populations. Species can become more vulnerable to local extinction due to lack of food or mate resources, periodic extreme events such as fire and disease (Shaffer 1978, 1981; Gilpin and Soulé 1986), and the negative effects of inbreeding depression. As a result, maintaining landscape and habitat connectivity is a primary focus of the Yellowstone to Yukon Conservation Initiative (Y2Y).

January 2005 Big Sky Conservation Institute GIS

Figure 1. The Yellowstone to Yukon Ecoregion. The area of interest is highlighted in red.

Although roads are vital to our economy, they impose severe ecological costs (Saunders *et al.* 1990, Andren 1994) including: habitat loss and fragmentation, road mortality and avoidance, reduced access to vital resources, population fragmentation, and disruption of ecological processes (Forman and Alexander 1998, Spellerberg 1998, Jackson 1999, Trombulak and Frissel 2000).

In the short term, restricted animal movements may reduce access to important resources like food, mates (i.e. breeding opportunities) and prevent individuals from dispersing or immigrating. Based on species sensitivity, these effects can result in local extinction in the short term. Over the long term, these restrictions can reduce gene flow and negatively impact species populations (Craighead 2002).

The degree of disturbance caused by current levels of human development in the Y2Y region means that any increase in the negative short- and long-term impacts of development, such as the construction of additional or expanded roads, will have the cumulative impact of reducing the amount and connectivity of wildlife habitat. As habitat is further reduced and fragmented in the Y2Y region, wildlife populations will become smaller and more isolated, increasing the risk of decline and, in some cases, extinction (Craighead 2002).

This is as true for protected areas as it is for other places. Research indicates that road traffic is a conservation concern for mammals in and near protected areas (Paquet *et al.* 1996). Importantly, the disruption to sensitive species such as carnivores may signal negative effects on the wider community and ecosystem, because of the top-down effects.

To reduce the negative effects of habitat fragmentation, many conservation biologists (Noss 1983, 1987; Noss and Harris 1986; Craighead *et al.* 1998; Paetkau *et al.* 1998) recommend restoring landscape connectivity such that animals can move between remnant patches of habitat. In theory, maintaining connectivity may require the cessation of road construction or removal of roads in critical wildlife habitat. At the very least it is necessary to "make existing roads and other barriers more permeable or 'friendly' to wildlife" by creating enough opportunities for safe passage to restore natural levels of habitat connectivity (Craighead 2002).

Crossing structures can restore habitat connectivity by providing such safe passage opportunities for wildlife. The types of mitigation popularly employed include modified drainage culverts, wildlife/drainage culverts, upland culverts, oversize stream culverts, expanded bridges, viaducts, wildlife underpasses, wildlife overpasses and fencing. Readers should refer to Jackson (1999) for detailed information on these structures and their attributes.

A number of factors influence the effectiveness of crossing structures, and species tolerances to structural design are highly variable (Jackson 1999). Expanded bridges (open spans), viaducts, and wildlife overpasses appear to be the most effective across communities in the Banff National Park. Some studies have argued that crossing structure location, particularly in relation to habitat quality, is the most important feature, while others have shown that structural design is the most influential factor. These discrepancies in animal responses to crossing structures may be explained by taxon- and/or habitat-specific factors (Clevenger and Waltho 2005).

Likely, it is a combination of location and design that will best restore connectivity.

SIGNIFICANCE OF BANFF NATIONAL PARK AND THE BOW RIVER VALLEY

Banff National Park is part of a contiguous block of protected areas straddling the Continental Divide between Alberta and British Columbia. This conglomeration of federal and provincial protected areas forms the Canadian Rocky Mountain Parks Complex (CRMPC), one of Y2Y's 17 Critical Cores and Corridors (CCCs) (www.y2y.net). Based on five years of scientific research, Y2Y identified CCCs as important core areas or critical linkages that performed functions vital to maintaining the biodiversity of the region (www.y2y.net).

The Canadian Rocky Mountain Parks Complex is the largest contiguous landscape protected by legislation (~25,000 km^2) in the entire Y2Y region. The region's sheer size, relative intactness, and protected status make it a core area for the full suite of species that were here when Europeans arrived approximately 200 years ago. Endemic species include grizzly bears, wolves, wolverine, bighorn sheep, mountain goats, and elk, among many others. The CRMPC also contains the Columbia Icefields, the most important hydrological feature on the North American continent, and the headwaters of a number of major river systems, including the Bow (South Saskatchewan) and the Athabasca. Jasper National Park is home to the only mountain caribou herd (the Maligne herd) whose home range lies entirely inside a protected area (www.y2y.net).

At the heart of the CRMPC is Banff National Park, Canada's first and North America's second national park. Banff holds a special place in the annals of conservation: Ostensibly it demonstrates the Canadian government's recognition of the value of healthy natural environments and its commitment to their protection. To this end, Canada's National Parks Act "clearly elucidate[s]" the "priority of protecting ecological integrity" in Canada's national parks (Parks Canada 2000).

Legislation alone will not, and has not, guaranteed the health of Canada's National Parks, especially in the Canadian Rockies. "Major transportation corridors and road networks are of greatest concern, and [are] perhaps the most acute obstruction to conserving large animal populations in the entire area (Noss *et al.* 1996)." Recognizing that "the primacy of ecological integrity in achieving the mandate is not widely understood or followed" by Parks Canada, and that "this has led to the erosion of ecological integrity of Canada's National Parks," the Panel on the Ecological Integrity of Canada's National Parks recommended that "the Minister and Parks Canada … ensure that protecting ecological integrity [be] the first priority of all aspects of national parks management (Parks Canada 2000)."

The Banff-Bow Valley provides excellent montane and subalpine wildlife habitat.
Photo: Stephen Legault

Banff National Park encompasses approximately 6640 km^2 of rugged mountainous terrain, steep valleys, and narrow flat valley bottoms located 110 kilometres west of Calgary, Alberta (Alexander and Waters 1999). Vegetation can be classified into three broad ecoregions: Montane (1300-1600 metres), subalpine (1600-2300 metres) and alpine (above 2300 metres). The montane is dominated by lodgepole pine, Douglas fir, white spruce, aspen and grasslands, while subalpine areas contain mature lodgepole pine, Engelmann spruce, subalpine fir and subalpine larch. Tundra vegetation dominates the alpine ecoregion, including low shrubs, herbs, mosses and lichens (Alexander 2001).

Since its designation in 1885, Banff National Park and the surrounding area have become increasingly developed. Outside the boundaries of the park, on Alberta Crown lands to the east and south, a variety of commercial and recreational land-uses proliferate, including hunting, ranching, oil & gas and forestry development, both motorized and non-motorized recreation, and various tourism activities. Canmore, a town of 11,500 residents (predicted to peak at approximately 30,000) sits just outside the park's east gate.

Banff is now Canada's most heavily visited National Park (Clevenger *et al.* 2002). More than 4.5 million annual visitors make use of the towns of Banff and Lake Louise and other infrastructure that has been designed for their use and enjoyment: hiking, biking and equestrian trails; campgrounds in both the front- and backcountry; day use areas; and downhill skiing and golf facilities. A railway, three highways – the Trans-

Canada Highway (TCH), the Bow Valley Parkway (BVP) and Highway 93 – and a network of secondary roads also contribute to the significant cumulative impact of human development on Banff National Park.

Most of this development occurs in the Bow River Valley, what Dr. Paul Paquet first called the "ecological heart" of Banff National Park and the surrounding region. The Banff-Bow Valley contains "the major elements of biological diversity in a region where most human impacts have been concentrated in biologically significant areas. It provides vital connections to the foothills, plains, and north-south expanse of the Rocky Mountains (Banff-Bow Valley Study 1996)." The Banff-Bow Valley is Banff's most productive habitat and is an important movement corridor for many of the park's most sensitive species, including grizzly bears and wolves.

The Banff-Bow Valley may be as important socially as it is ecologically. According to the Banff Bow Valley Study, it is "a symbol of Canada, a place of great beauty, where nature is able to flourish and evolve…. Above all else, [it is] a place of wonder, where the richness of life is respected and celebrated (Banff-Bow Valley Study 1996)."

THE FRAGMENTATION EFFECTS OF THE TRANS-CANADA HIGHWAY

One of the single most significant impacts on the ecological health of the Banff-Bow Valley, perhaps even the region, is the Trans-Canada Highway (TCH), 83 kilometres of which bisects Banff National Park. Built in the early 1950s, the TCH has become an important part of Canada's economy, connecting goods and people from the Atlantic Coast to Vancouver Island on the West Coast. Spanning more than 7500 km, it covers six time zones and is the world's longest national highway (Clevenger *et al.* 2002). During the same period, the Bow Valley has become a major tourist destination: as of 1998, some 14,500 vehicles per day passed through the park's east gate entrance, peaking at more than 30,000 vehicles per day during the summer (Clevenger *et al.* 2002).

Banff National Park is one of the only protected areas in the world that has a major transportation corridor bisecting it. (By comparison, Highway 16 through Jasper National Park had 3360 vehicles per day annual average daily traffic volume (AADT) and Highway 2 in Montana's Glacier National Park had 1600 vehicles per day AADT (Clevenger *et al.* 2002).) As a result, the busy TCH has a negative impact on Banff's ecosystems, especially its contribution to wildlife mortality, habitat fragmentation (Clevenger *et al.* 2002) and reduced wildlife movement (Alexander 2001).

Strategies have been implemented to mitigate the negative effects of the TCH on the park's ecological integrity. The first 47-kilometre stretch of the TCH in the lower and middle Bow Valley (phases I, II, and IIIA) is four lanes wide. To reduce wildlife-vehicle collisions and the resulting human and wildlife injuries and mortalities on the previous sections, a 2.4-metre-high large-mammal exclusion fence was erected. Twenty-two wildlife underpasses and two wildlife overpasses were constructed to permit wildlife movement across the four-lane section of TCH (Clevenger *et al.* 2002).

These wildlife crossing structures come in various shapes and sizes in an attempt to meet the needs of a variety of species. Some species, such as grizzly bears and wolves, prefer large, open structures; black bears and cougars prefer narrow, closed, dark structures; deer and elk prefer overpasses to underpasses (Clevenger and Waltho 2005).

In theory, poorly designed crossing structures, or well-designed crossing structures in the wrong locations, likely will be ineffective. In general, fencing has decreased wildlife mortality and crossing structures have allowed some animals to cross from one side to the other. Fencing on phases I, II and IIIA resulted in >80 percent decrease in wildlife road kills, especially of ungulates (>95 percent). However, it is important to point out that fencing has not dramatically reduced vehicle-related mortality for all species: Carnivores only saw a 16 percent reduction in road-related mortality. In fact, more black bears, cougars, and coyotes were killed on certain sections of highway (phases I, II, and IIIA; phase II; and phases I and II, respectively) after they were twinned and fenced (Clevenger *et al.* 2002). Such high rates of mortality on mitigated sections of highway may be attributed to the ease with which these animals can scale or jump over, or dig under the 2.4-metre fence (Golder & Associates 2004).

Monitoring between 1997 and 2002 indicated that there were more than 8000 passages by wildlife at the 13 crossing structures on Phase IIIA (Clevenger *et al.* 2002). As a total from approximately 700 sample days, deer used the crossing structures most frequently (3524 crossings), followed by elk (3268) and coyotes (985). Among large carnivores, cougars used the crossing structures most often (170), followed by black bears (142), wolves (132), and grizzly bears (25) (Clevenger *et al.* 2002). Wolverines have not used any of the crossing structures.

To approximate the per annum crossing frequency, the reader may divide any of the previous numbers by 5 for the 35 km section of mitigated highway; or divide by 700 to approximate the number of crossings per sample. For example, there were 25 grizzly crossings in 5 years, which results in (25/5) or 5 crossings per year over 35 km of road.

West of Castle junction, the remnant two-lane unfenced portion of the TCH (Phase IIIB) services daily tourists and trans-continental commercial traffic. This remaining 35-km section of the TCH in BNP (ending at Kicking Horse Pass), like other unmitigated highways in the area, poses genuine problems for wildlife movement within the Central Canadian Rocky Mountain region (Clevenger *et al.* 2002).

The upper Bow Valley differs from the lower and middle sections of the Bow Valley where Phases I, II and IIIA are found. It is characterized by an assemblage of large mammal species with inherently low population densities, and more sensitive to human disturbance than typical fauna occupying the middle and lower Bow Valley (Stevens 1996, Austin 1998, Apps 1999, Gibeau 2000, Alexander 2001, see review by Tremblay 2001).

Key species considered when designing Phase IIIB mitigation passages consisted of wolverine, moose, lynx and grizzly bear, although cougars, wolves, black bears, marten, elk and deer also frequent the area. Meeting the needs of the latter species on Phase IIIB will require a mitigation strategy that provides for greater highway permeability.

Roads pose a variety of threats to wildlife in Banff National Park, including direct mortality, habitat fragmentation, and habitat alienation.
Photo: © John E. Marriott

EFFECTIVENESS OF TRANS-CANADA HIGHWAY MITIGATIONS

Although there is a growing emphasis on testing the effectiveness of highway mitigations, most research has addressed only the relative benefit of crossing structure types; none have assessed the effectiveness of the entire mitigation effort (i.e. the entire road segment) relative to intrinsic connectivity, which is a critical distinction.

This distinction is reinforced by Tischendorf and Fahrig (2000), who argue that structural and functional connectivity must be preserved in order for a corridor restoration effort to be considered successful. To illustrate, if only a subset of resident species uses a crossing structure, or fewer movements occur than are observed normally, then functional connectivity has not been achieved fully.

While there is general agreement that mitigation efforts on the TCH have reduced some portion of wildlife mortality and habitat fragmentation for some species (Clevenger *et al.* 2002), there is considerable disagreement about exactly how effective the mitigation effort has been in the larger ecological context (i.e. has it restored functional connectivity at the system level – across the 35 km). Indeed, some evidence suggests fragmentation effects have worsened as a result of highway twinning, even with accompanying mitigations (Alexander 2001). More importantly, there remains some question about whether, given the TCH's location in a National Park, Parks Canada should be reducing the ecological impacts still further.

Part II: The Research

PURPOSE

This paper was developed for the Trans-Canada Highway Twinning Project (Phase IIIB) Stakeholder Advisory Process. It provides an independent, science-based assessment of where mitigation for multiple species might be placed most effectively. Based on the best (in some cases the only) available empirical data for four focal carnivores (marten, lynx, cougar and wolf) and using rigorous analytical techniques, we determined the location, total number and length of species-specific and multi-species linkage zone(s) on Phase IIIB of the TCH, which we then contrasted with the proposed mitigation (Golder & Associates 2004).

Our data is perhaps the best available because it was collected specifically to determine optimal placement for mitigation and represents the baseline activity across and adjacent to Phase IIB, as it was collected pre-twinning (1997-2000). Our research has immediate conservation relevance; it provides interest groups the means to compare the proposed mitigation design with independent analyses. Moreover, it complements research in Banff that addresses mitigation design requirements for like species along this highway corridor (Clevenger *et al.* 2002).

RESEARCH RATIONALE

Habitat modeling has been advanced by Geographic Information Systems (GIS). GIS is an excellent tool for identifying areas of conservation significance and assessing the habitat potential of unstudied sites (Lenton *et al.* 2000). Many studies have applied GIS in the Y2Y region to define wildlife-environment relationships, but few have examined the spatial attributes of road crossing sites. None have examined multi-species interactions or identified linkage zones based on empirical data (Alexander *et al.* 2004).

GIS analysis has been used with mortality hotspot data to guide mitigation planning. However, mortality hotspots have never been demonstrated to reflect crossing preferences; hotspots may reflect road alignment or sightability factors that increase vehicle-wildlife collisions. Instead, we suggest that actual species movement data should be integrated in GIS to predict the location of high probability linkage zones. Here, we use the term “linkage zone” to refer to corridors of highly suitable habitat that connect patches of suitable habitat. Our approach will more aptly reflect wildlife movement requirements and potentially enhance connectivity restoration efforts.

Most research relating to linkage zones and all research along the TCH (except for grizzly and black bear) have used modeling or expert opinion to determine optimal placement of mitigation. Crossing data collected by Alexander (2001) for the Phase IIIB was used in the mitigation plans (see Clevenger *et al.* 2002), but was not used to develop a predictive model to determine where wildlife might prefer to move. Moreover, crossing data alone (without occurrence data away from roads) represent only where animals were moving at the interface with the TCH; this may reflect human disturbance more than preference (Alexander, personal observation) and is not representative of habitat selection in the valley. For example, Alexander (2001) found multiple cases of carnivores paralleling highways for some distance before choosing to cross from one side to the other. Consequently, it is important to understand species-environment relationships throughout the landscape of the Bow Valley and not just on the TCH, Phase IIIB.

METHODS

To redress the above deficiencies, Alexander (2001) collected winter-based track data throughout the Banff-Bow Valley on and adjacent to the TCH and the Bow Valley Parkway.

MULTI-SPECIES DATA COLLECTION

Track data were collected between November and April, from 1997 to 2000. (Figure 2) Surveys occurred on roads of varying traffic levels, including the TCH (very high volume) and Bow Valley Parkway (moderate volume) in Banff and the Highway 40 (high volume) and the Smith-Dorrien Trail (low volume) in Kananaskis Country. The present analysis used data collected on all Banff roads, and predicts movement only on the Phase IIIB. These track data have been shown to be an effective substitute for developing species-environment models (Alexander et al. in press).

Roads were surveyed between 18 and 48 hours after the end of every snowfall. Tracks were observed from a field vehicle, while driving 15-20 km/hr and verified on foot (Beier and Cunningham 1996, VanDyke *et al.* 1986). Tracks entering or exiting the road right-of-way were recorded for coyote (*Canis latrans*), fox (*Vulpes vulpes*), wolf (*Canis lupus*), cougar (*Felis concolor*), bobcat (*Lynx rufus*), lynx (*Felis lynx*), marten (*Martes americana*), fisher (*Martes pennanti*), wolverine (*Gulo gulo*), elk (*Cervus elaphus*), moose (*Alces alces*), sheep (*Ovis canadensis*) and deer *(Odocoileus virginianus and Odocoileus hemionus*). Tracks were observed in each right-of-way (ROW) only. We assumed that tracks entering the ROW were attempting to cross the road. Data for wolf, cougar, lynx and marten were analyzed in this report. See Alexander (2001) for other species habitat associations. Data collected at crossing sites included a geographic location collected with a handheld GPS unit (Garmin II, non-differentially corrected), species type, number of individuals, and a range of behavioural parameters not used herein. Repeat road surveys were conducted three to four days after initial surveys until the next new snowfall. During the latter surveys we only recorded large carnivore tracks.

Transects of one-kilometre length were fixed perpendicular to roads; transects are straight survey lines across a study area that are marked (with flagging) to allow the researcher to repeat surveys in exactly the same area. Forty 1-km transects were surveyed in Banff National Park, between 24 and 120 hours after snow (Thomson *et al.* 1988). Transects were surveyed on foot and required an extended survey period relative to the road survey. A one-metre resolution differential GPS (Trimble Pathfinder) was used to collect UTM coordinates every 50-m for each transect. These data were used to georeference track counts for GIS analyses. Data were standardized by the number of times a site was sampled. For example, the track count for a site surveyed five times was divided by five, while another surveyed three times was divided by three.

One key assumption of the focal species approach is that the needs of the focal species may be extended to the habitat needs of other species. Marten, lynx, cougar and wolf were assumed to represent various functional scales of ecosystem organization. In our case, the guild approach assumed focal carnivores also will capture the needs of prey (Alexander 2001).

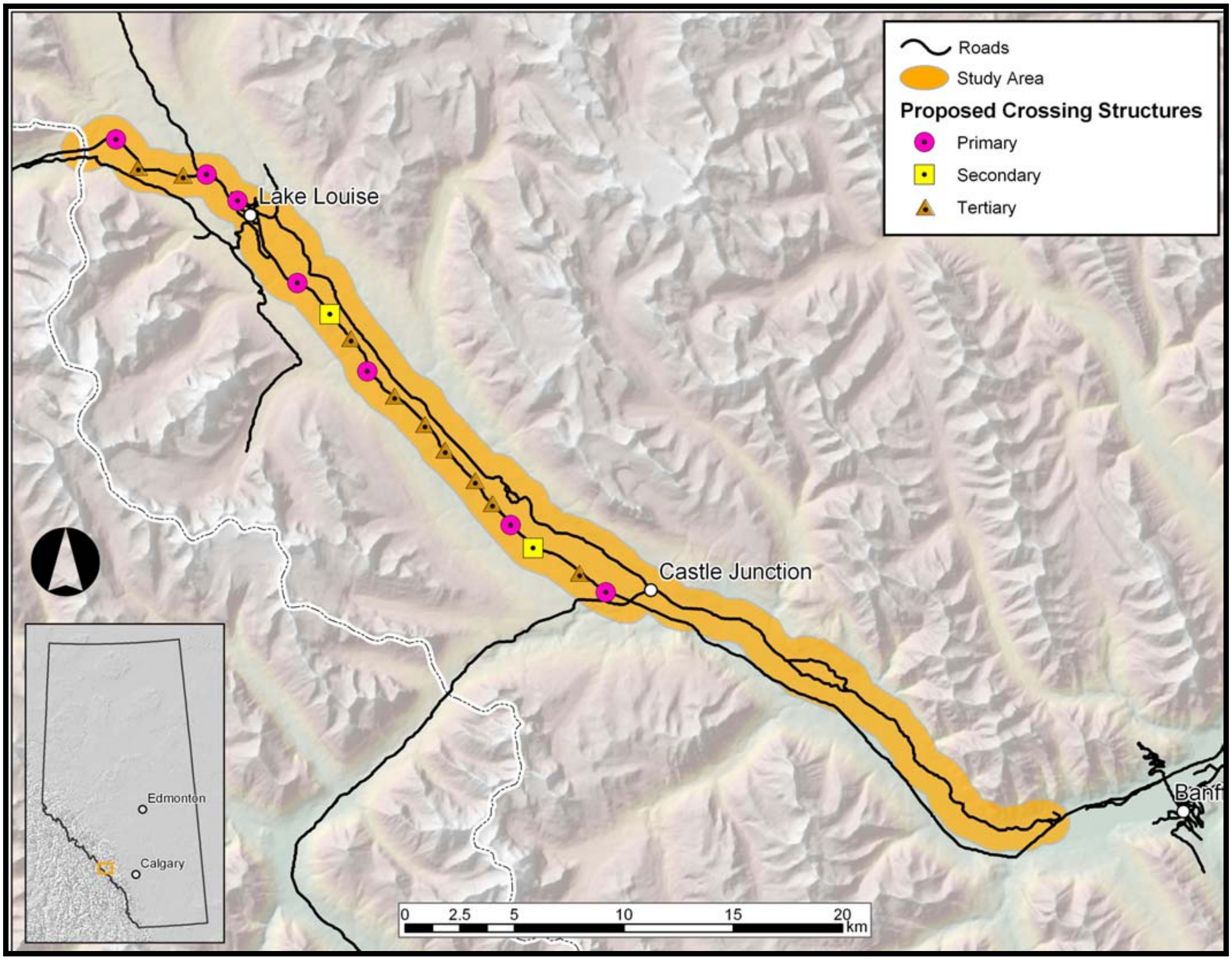

Figure 2. The Study Area. The research study area ranges from Vermillion Lakes in the east to the Alberta-B.C. border in the west. Phase III of the Trans-Canada Highway begins at Castle Junction and ends at the provincial boundary.

SPATIAL DATA ANALYSIS

Readers interested in the scientific details of species-environment model (probability maps) development and statistical analysis background and methods please refer to Appendix I.

RESULTS

Detailed model results (logistic regression equations) and discussion relative to scientific literature also are presented in Appendix I. The section below briefly details the species-specific and multi-species results.

SPECIES-ENVIRONMENT RELATIONSHIPS

Marten

In the Bow Valley, we found marten occurred closer to roads (i.e. at lower elevation within 1 km of roads), and associated with areas of high wetness. Wetness is a variable derived from satellite imagery related to moisture content in vegetation, older growth forests, forest stand complexity (i.e. forests that contain a variety of species of different ages and a variety of layers in tree heights) and higher amounts of coarse woody debris on the ground (i.e. dead, down trees that provide access to areas under the snow in winter time). We also found that marten occurred more often in areas characterized by highly variable terrain (i.e. undulating topography, possibly multiple drainages in a very small area). Finally, marten were detected frequently on southern aspects.

Marten (*Martes Americana)*
Photo: © John E. Marriott

Figure 3 shows the habitat potential or probability of finding marten, based on the variables noted above. There are frequent intercept zones of high probability marten habitat and Phase IIIB. Habitat on the Bow Valley Parkway east of Castle Junction has the greatest suitability to marten, but that does not preclude the need to mitigate Phase IIIB. There is highly suitable habitat for marten along the IIIB (ranging from 0 to 96 percent probability of use).

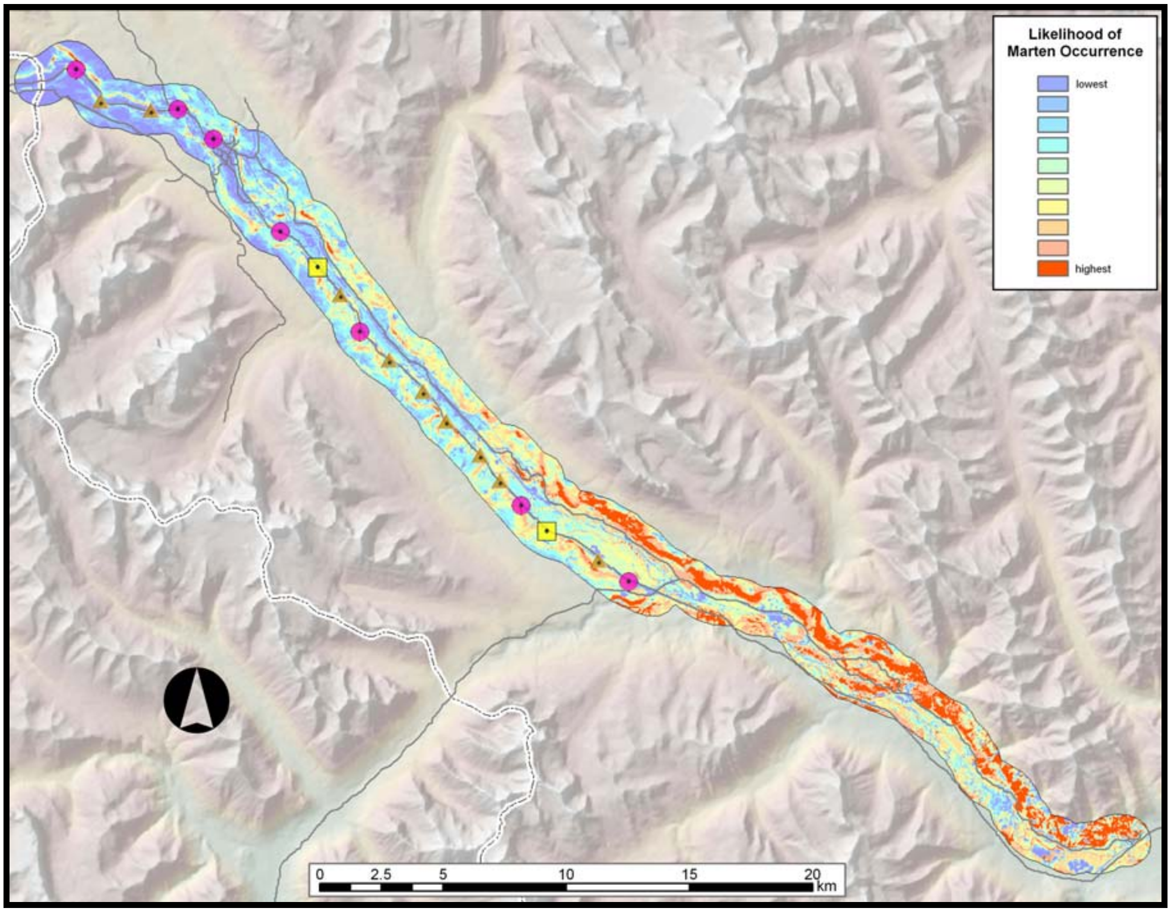

Figure 3. Probability of Marten Occurrence. This map shows the probability of occurrence model for marten along the Trans-Canada Highway between Banff Townsite and the Alberta-B.C. border.

We describe the spatial extent and periodicity in the section on single and multi-species linkage zones. Figure 3 also shows the types of mitigation and placement of mitigation for the IIIB. The reader may compare our linkage zones with the proposed linkage zones to determine agreement.

Marten are ubiquitous and have a high likelihood of being included in the proposed mitigation. High probability linkage zones for marten are consistent with drainage basins, which often are selected as mitigation sites (see Figure 3).

Lynx

We found that within one kilometre of roads lynx most often occurred in sites with a higher wetness index (i.e. likely older forests with greater stand complexity and/or moisture) and more complex terrain. Lynx differed from marten, however, as marten selected highly variable terrain within a radius of 90 metres, whereas lynx selected for the same within 210 metres. What this suggests is that lynx were selecting for more undulating terrain rather than troughs, pits or drainages.

Although lynx showed an affiliation for more complex terrain, they were distributed more frequently in areas of low slope. This suggests lynx selected areas that are easy to move through within more complex terrain. Elevation and canopy closure were included in the analysis, but did not influence where we found lynx. This result was not consistent with the secretive nature of lynx and we expect vegetative cover will be relevant for mitigation design. Most of our lynx track data were observed farther from roads (Alexander 2001) and represented movement, rather than hunting or denning. Movement through less complex terrain would reduce the energetic cost of travel.

Lynx (*Felis lynx*)
Photo: Stephen J. Krasemann

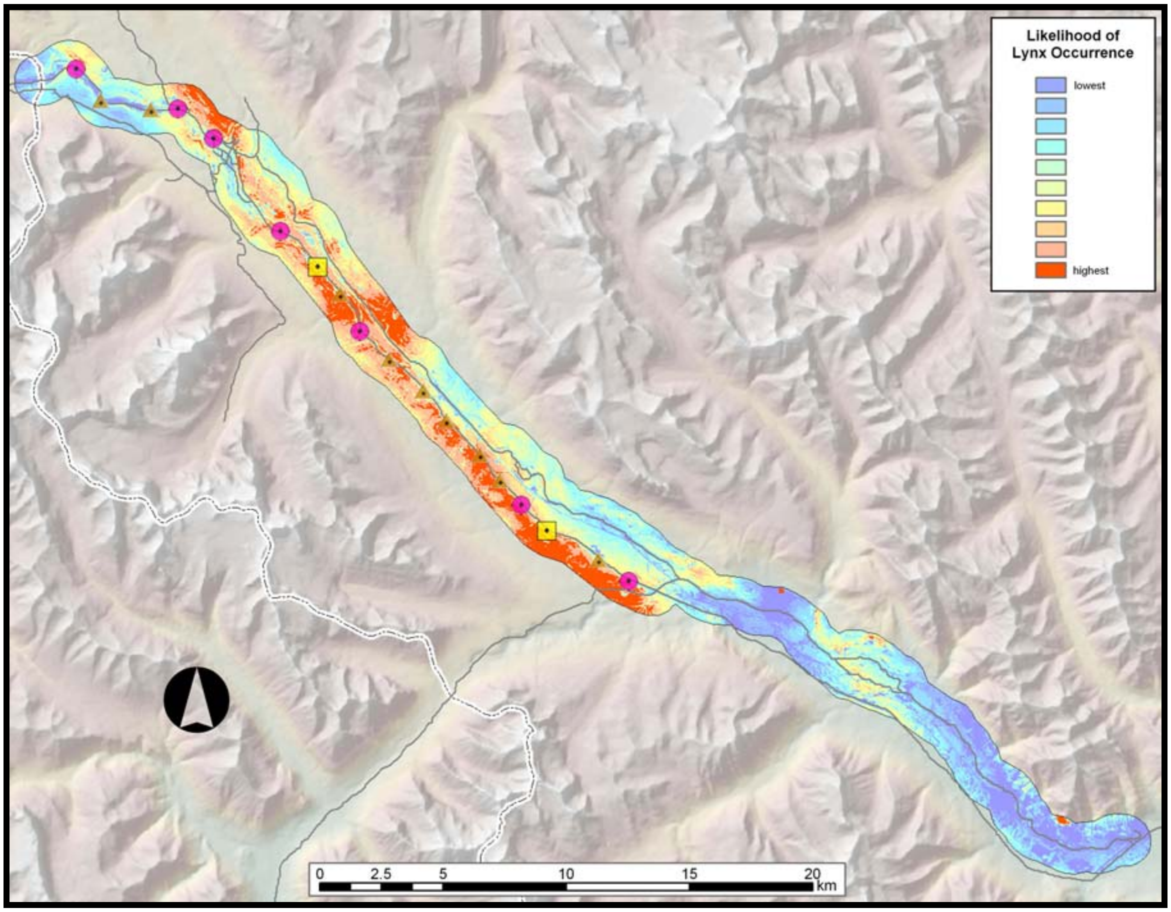

Figure 4. Probability of Lynx Occurrence. This map shows the probability of occurrence model for lynx along the Trans-Canada Highway between Banff Townsite and the Alberta-B.C. border.

Figure 4 shows the probability of detecting lynx based on the identified environmental associations. Clearly, Phase IIIB is some of the best lynx habitat in the valley (high probability). Figure 4 suggests that lynx should be a key species considered during the IIIB mitigation, as it bisects the best lynx habitat in the Bow Valley. In addition, Alexander (2001) found that the TCH had significantly lower movement rates for all species relative to all other roads – except for lynx.

Figure 4 shows a pattern of large scale lynx-habitat connectivity, with a series of smaller connections embedded in these zones. From west to east the major zones occur just east of Lake Louise, midway along the IIIB to Castle Junction, and a zone of a few kilometres just prior to Castle Junction. Within each zone there are multiple sites with high crossing potential for lynx. We discuss the dimensions and frequency of these sites in the section on linkage zones (below).

Cougar

Within one kilometre of roads, cougar most often were associated with lower elevation sites (Figure 5). They occurred more frequently in forests with a high wetness index (i.e. moister, older, or characterized by greater stand complexity), forests characterized by complex (i.e. gently undulating) terrain, and in close proximity to cover. Although cougar affiliated with more complex terrain and forest structure, we found that cougar did not select for areas of highly productive vegetation (i.e. high greenness). This means that the forests likely were less dense.

Cougar (*Puma concolor*) The best cougar habitat on Phase IIIB is at the east end, near Castle Junction. Photo: © John. E. Marriot

Consequently, we suggest cougar may have selected most strongly for more mature forests that have higher moisture content rather than greater stand complexity. Such forests might be consistent with drainages, or more mature forests on northern aspects, or perhaps areas close to rivers.

Figure 5 shows the probability of detecting cougar, based on the above mentioned environmental variables. Most striking is that habitat west of Castle Junction along the IIIB is not highest quality for cougar within the valley. The highest rated habitat for cougars occurs on the Bow Valley Parkway east of Castle Junction, from Hillsdale to the Vermillion Lakes. This does not preclude the need to mitigate the IIIB. Cougar were observed in habitat adjacent to the IIIB on the north and south sides. This occurred during a period of expansion within the local population (1999-2000). Depending on the point in time cougar distribution is observed, the habitat on IIIB may be more or less important.

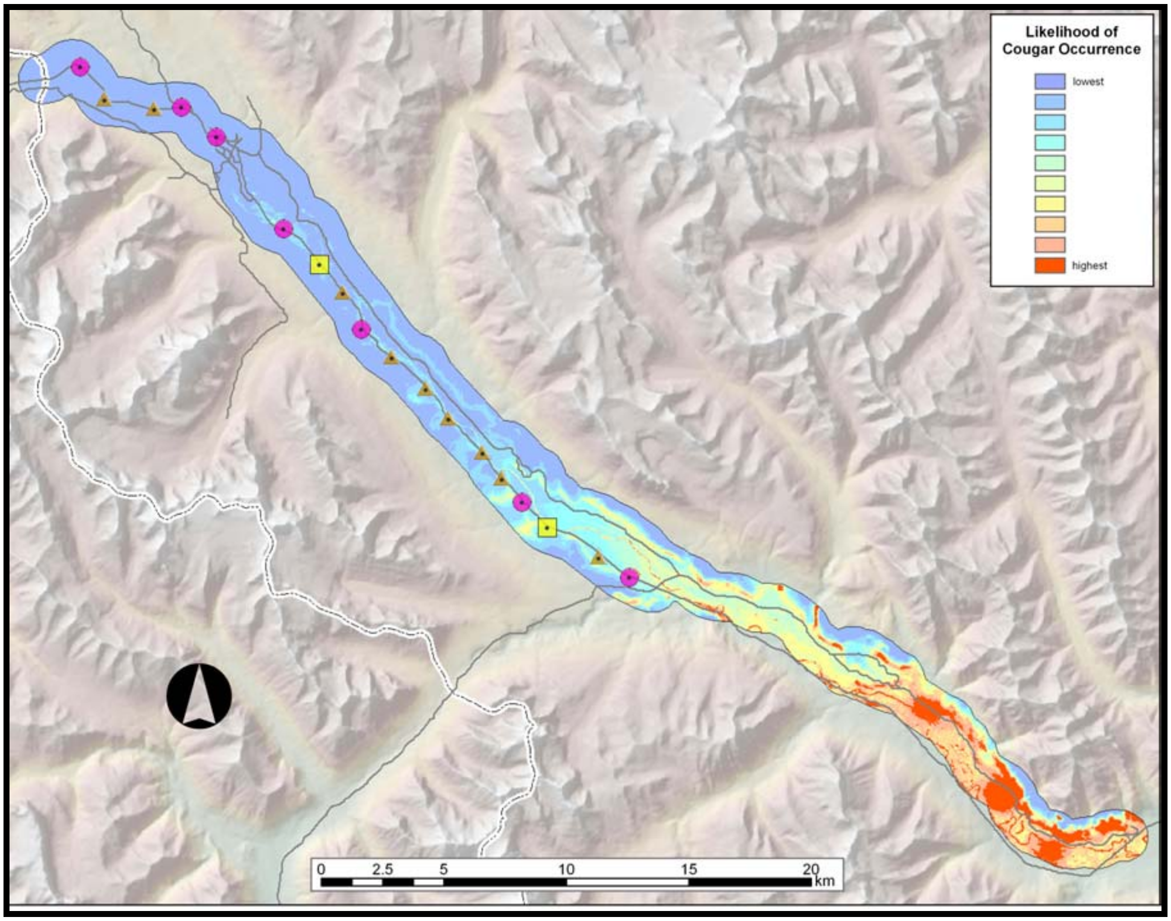

Figure 5. Probability of Cougar Occurrence. This map shows the probability of occurrence model for cougar along the Trans-Canada Highway between Banff Townsite and the Alberta-B.C. border.

Wolf (*Canis lupus*)
Photo: © Peter A. Dettling

Wolf

Wolves most often occurred at lower elevation within one kilometre of roads (Figure 6). They were associated with lower wetness values (i.e. less moisture, lower stand complexity, or less coarse woody debris) and areas characterized by relatively flat topography.

Western slopes positively affected wolf distribution and there was a lack of relationship to southerly facing slopes. This was unique among the four species studied and likely related to selection of drier slopes and the need to select different resources than the other carnivores (to partition habitat). We also found that proximity to forest cover and rugged terrain were not significant predictors of wolf distribution. This may have related to the need for more open forest for movement and sighting of prey. Wolves hunt in packs, running down prey and hence require open habitat to hunt efficiently.

Wolf habitat is excellent in the Banff-Bow Valley, providing adequate prey remain on the landscape. The Bow Valley Parkway east of Castle Junction is the best wolf habitat, and has been an area of high occurrence of active wolf densities (Alexander 2001, Paquet 1993).

Habitat quality along the IIIB is moderate, but the best wolf habitat occurs on the northern side of the IIIB. However, wolves use travel routes on the south of the IIIB and cross the TCH. Wolves are wide ranging and use all suitable areas in the Bow Valley (Paquet 1993); movement across the IIIB appears critical for wolves to access resources throughout the valley (Alexander 2001, and pers. obs.).

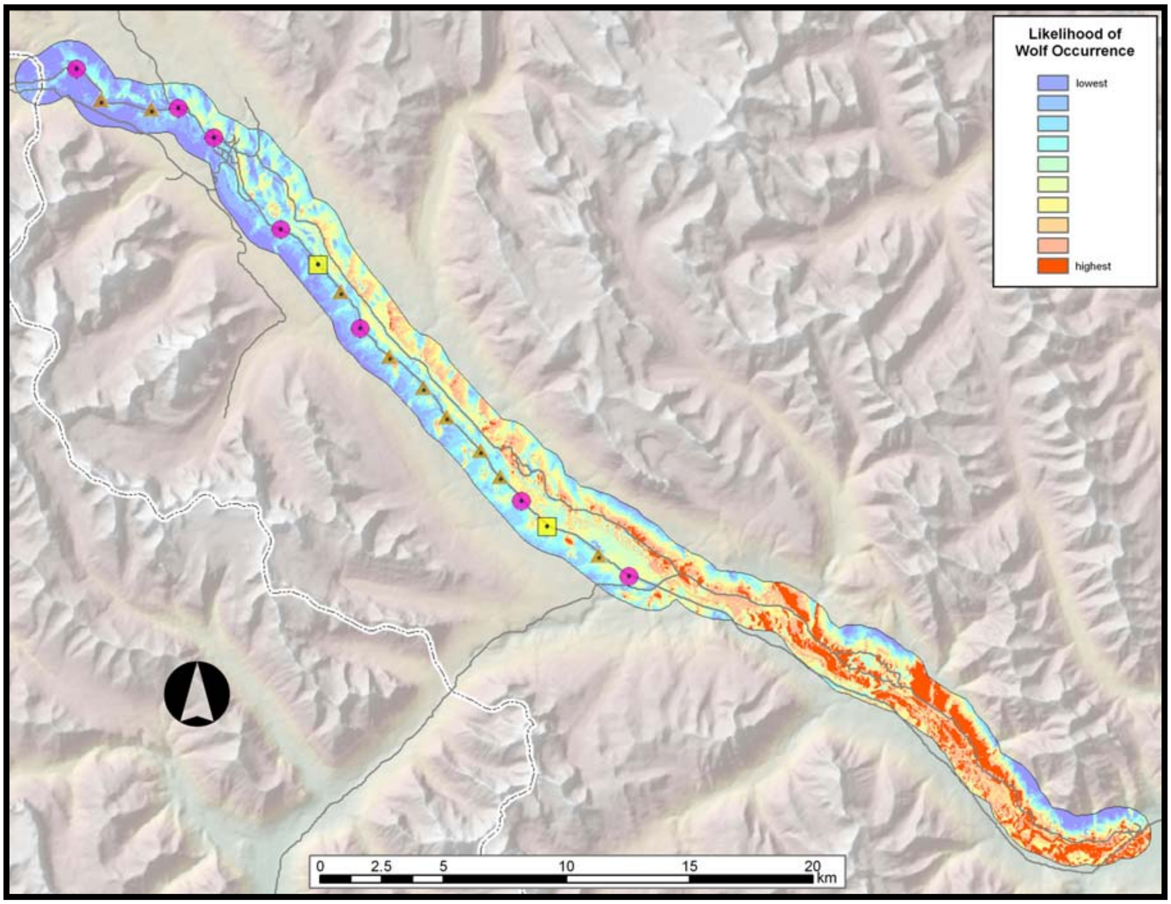

Figure 6. Probability of Wolf Occurrence. This map shows the probability of occurrence model for wolf along the Trans-Canada Highway between Banff Townsite and the Alberta-B.C. border.

SINGLE- AND MULTI-SPECIES LINKAGE ZONES

Within the Banff-Bow Valley, our models indicated there was a full range of habitat capability for each focal species. The highest ranked habitat for marten, wolf and cougar occurred along the Bow Valley Parkway in the eastern section of the Banff study area (from the TCH Phase IIIA intersections with the Bow Valley Parkway through to Castle Junction).

Throughout the valley, the highest ranked lynx habitat was most frequently found west of Castle Junction on the southern side of the TCH. Arguably, the Phase IIIB of the TCH bisects the highest ranked lynx habitat in the valley.

The linkage zones in Figure 7 represent the upper 20 percent of habitat quality along the Phase IIIB; defined by the potential to find use by a species in each individual model. This does not mean that the rest of the 80 percent of habitat is not usable; it is simply a threshold value we chose to represent the "best habitat" for movement. Notably, the upper 20 percent does not necessarily mean 80-100 percent probability of detecting a species, because the range of habitat values varied and was not the full spectrum (0-100 %) for all species. As noted above, the highest ranked habitat for three of the four focal carnivores was in the eastern section of the park and not on the Phase IIIB. For instance, the upper range of cougar habitat on the IIIB might have a probability of 0.45 out of 1.00.

We superimposed the proposed mitigation sites on top of our predicted linkage zones (Figure 7). The individual types of structures are also shown. The spatial extent, frequency, and range of linkage zones available are summarized for each species in Table 1.

Figure 7 shows that few sites exist that reflect multiple species movement. Moreover, it is evident that some proposed mitigation sites do not correspond with high movement probability for any species (i.e. are placed in low use zones for all indicators.) Figure 7 may be used to confirm where the proposed mitigation matches predictions, to make necessary adjustments to the proposed mitigation plan and to identify critical zones for the focal species, which the existing plan has missed.

Table 1: Summary of linkage zone frequency and extent on the TCH Phase IIIB (Shows upper 20 percent of habitat quality on TCH for species, in metres.)

	Number of Linkages	Total Length (m)	Mean Length (m)	Maximum Length (m)	Minimum Length (m)
Marten	66	6686.23	104.03	917.58	1.05
Wolf	32	5638.73	176.21	972.51	12.90
Lynx	49	4846.42	98.91	1255.58	1.04
Cougar	17	2702.91	158.99	1122.07	22.21

The frequency (number) of intercepts or linkage zones appears to correspond with the functional scale each species represents (Table 1). That is, species with smaller home range (marten) have more intercepts with the road, followed by lynx, then wolf, then cougar. Cougar home ranges generally are smaller than wolves. Their lower frequency of intercept may be a result of the abundance of low and moderate ranked habitat quality for cougar on Phase IIIB.

It is critical to understand that the frequency of intercept alone is not an adequate measure for mitigation. Placement of these intercept zones is critical. For example, most of the wolf and cougar linkage zones occur at the eastern end of the IIIB and are much larger in extent, whereas marten linkages occur in a more even placement along for the entire length of the IIIB, but tend to be smaller. In addition, Alexander (2001) observed marten using small- to medium-sized (2 to 5 metre) drainage culverts to

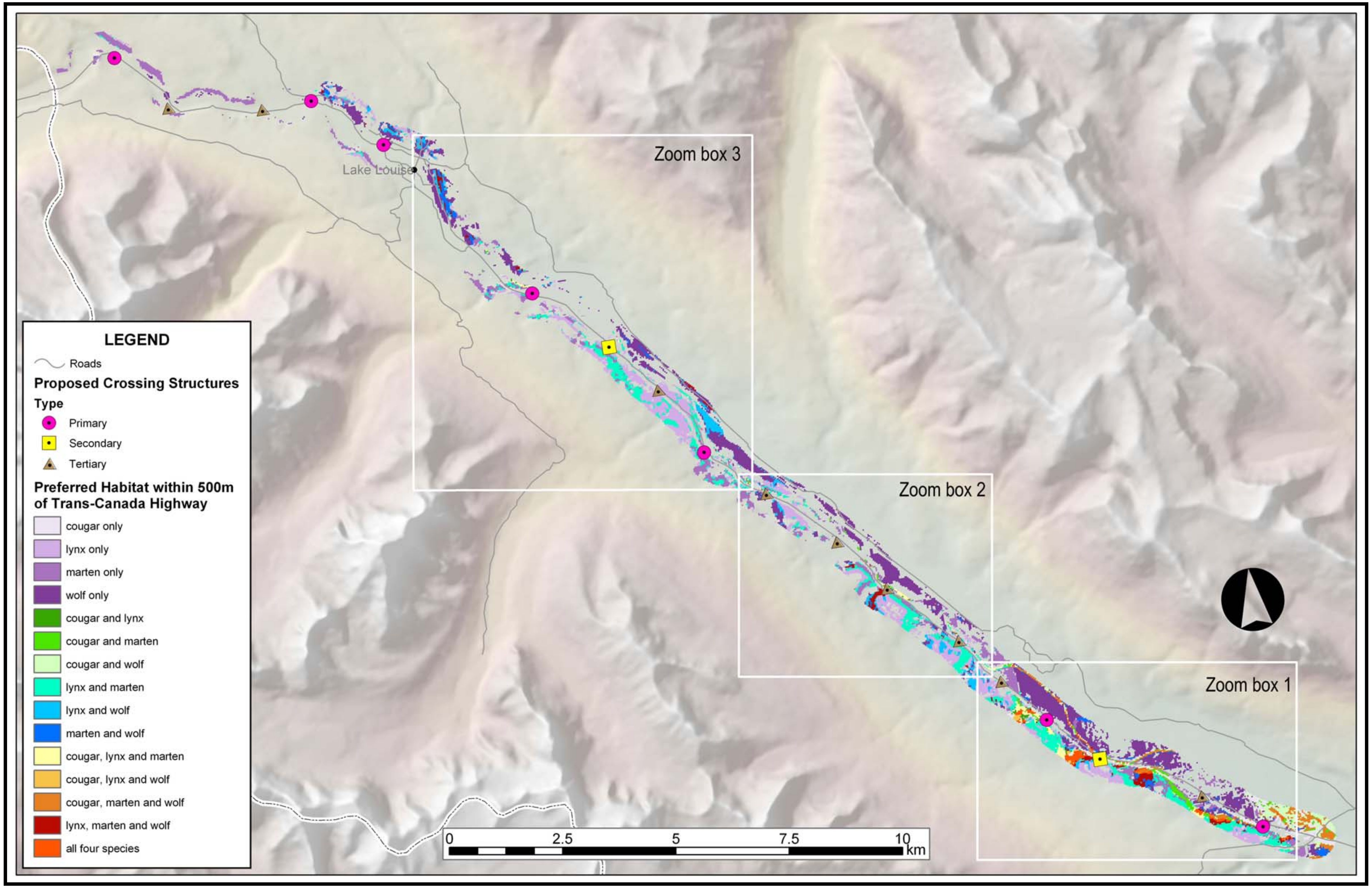

Figure 7: Multi-species linkage zones and proposed crossing structures on Phase IIIB of the Trans-Canada Highway. See figures 8, 9 and 10 for more detailed images of zoom boxes 1-3

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cross the highway on a regular basis. She observed that marten regularly excavated those culverts that were covered by snowplow spray. Thus, the minimum dimension may be acceptable for marten movement.

Importantly, there are commonalities in habitat selection for some of the carnivores, and there are sites where multiple species movement may be captured in one mitigation effort. Thus, the entire length of the upper 20% habitat intercepting the TCH likely is less than the sum of total mitigation length for each species (Table 1). Lastly, it is essential that the maximum, mean, and minimum size statistics in the above table not be taken for exact mitigation measurements, for the following reasons:

1. The length statistics correspond with the upper 20 percent of habitat potential. There is no guiding science to suggest what threshold of probability is essential for a linkage zone. This measure could be increased (e.g. 30 %) or decreased (e.g. 10 %) to examine alternatives.
2. The greatest strength of this method is that it employs a spatially explicit, scientifically rigorous and repeatable method to identify sites with high probability of focal species use.
3. The minimum length does not suggest mitigation could be built to that size (e.g. lynx linkage at 1 m). This measure indicates that small linkage zones exist; but successful mitigation needs to be large enough to meet the physiological and psychological constraints of the species (Clevenger and Waltho 2005).
4. The maximum length is the greatest spatial extent of linkage zones. These are zones where species may have multiple options for crossing the highway. Again, we do not suggest that mitigation must be that size. However, given that anything less than 100 percent of habitat connectivity is an ecological compromise, connecting the upper 20 percent is not extreme.
5. The mean length is useful for comparing amongst species, as an index of the general trend in linkage zone extent. We suggest the mean length should be the minimum acceptable spatial extent for mitigation.

Part III: The Implications

WHAT, WHERE AND HOW MUCH?

The Trans-Canada Highway Phase IIIB screening report indicated that the proposed mitigations will not maintain or restore connectivity across this stretch of highway after it is twinned. Hence, the proposed project cannot meet its stated goal to do so (Golder & Associates 2004).

This leaves the question of "how much is enough?" Research has shown the minimum dimensions and vegetative characteristics of a crossing structure that focal species in the Bow Valley are willing to tolerate to cross the TCH (Clevenger 2005). However, this does little to show how the same species might choose to move through a landscape with a full range of "natural" choices. Nor does it tell us whether the minimum is enough to guarantee persistence.

We defined connectivity as an essential component of a functional system that allows species to persist over time. We know with certainty that species assemblages developed and thrived over millennia when the valley was connected across all range of habitat quality (0-100 percent probability). Arguably, if we maintain all possible linkages in the upper 20 percent threshold, we have not achieved ecological integrity in its entirety, not as it evolved in this system.

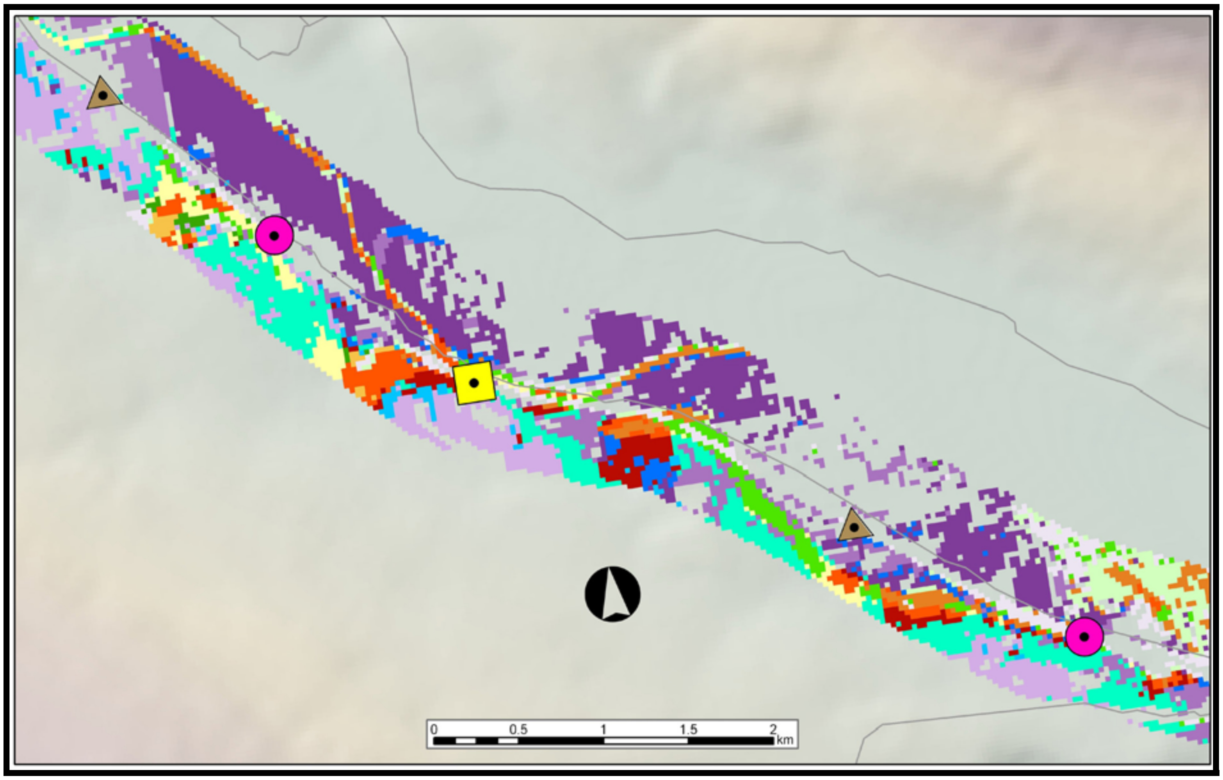

Figure 8: Zoom Box 1 - Multi-species Linkage Zones. Zoom box 1 shows the probability of use for marten, lynx, cougar and wolf on the eastern-most section (nine kilometers) of Phase IIIB (Legend on Figure 7).

If we cannot maintain all connectivity in the valley (i.e. 100 percent of habitat potential), then we believe the sites we have selected (i.e. the upper 20 percent) reasonably represent the minimum amount that should be maintained as linkages. If properly mitigated (i.e. the right structures for the species), these linkage zones have the greatest likelihood of maintaining connectivity.

It must be noted that the 20-percent threshold was arbitrarily defined and could be a point of discussion among stakeholders, especially the public, to determine what is the minimum "acceptable" range of habitat to protect in a national park. That said, we contend it should remain the ecological minimum.

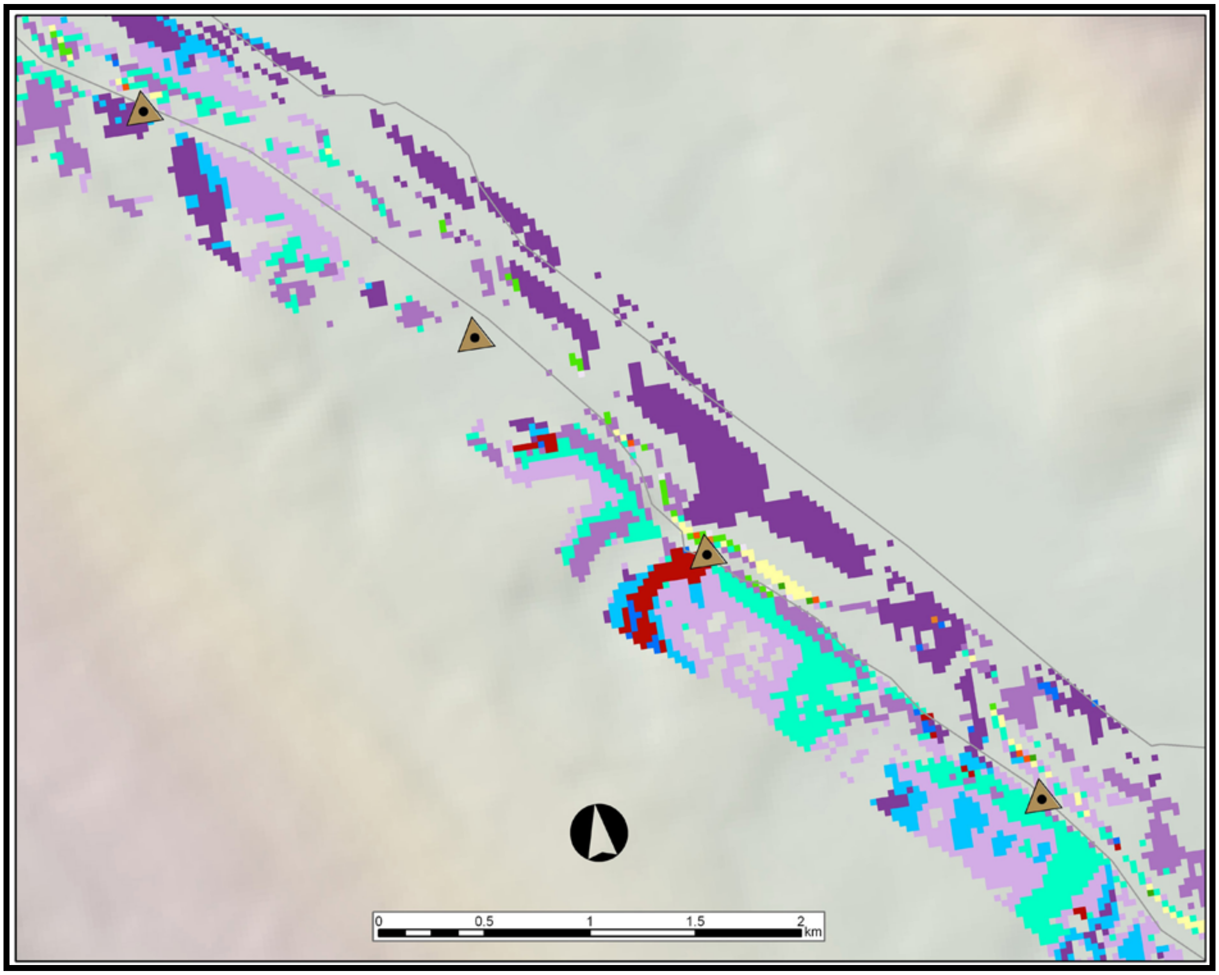

Figure 9: Zoom Box 2 - Multi-species Linkage Zones. Zoom box 2 shows the probability of use for marten, lynx, cougar and wolf four kilometer east and west of Taylor Lake trailhead, Phase IIIB (Legend on Figure 7).

ASSESSING THE CURRENT PROPOSAL

How do the proposed mitigations measure up? We draw conclusions based on the proposed crossing structures (Tables 2a and 2b) and our linkage zone assessments (Figures 7-10). We contrast the proposed mitigation types with our identified linkage zones, based on spatial extent and placement.

Figure 7 showed the entire study area and indicate substantially more single or dual species linkage zones (blues to purples) than tri- or multi-species zones (orange to reds) linking habitat across Phase IIIB. Figures 8, 9 and 10 are “close-ups” of Figure 7, in segments (approximately 10 kilometre lengths) running east-to-west from Castle Junction.

The preponderance of single- rather than multi-species zones supports the need for species-specific mitigation. The rarity of multiple species linkage zones emphasizes that placement of primary mitigation structures is critical.

Table 2a summarizes the proposed mitigation types by frequency and length. We calculated the total amount of mitigation provided by each type of structure (using mean width) and the total amount of mitigation by all structures, relative to the total highway length. This estimates the percentage of habitat that potentially will be maintained for movement across the TCH.

If all proposed crossing structures are constructed, then a total of 600 metres (1.7 percent) of habitat will be maintained for linkages. Of that, primary crossing structures for multi-species (1.3 percent) are the largest contributor to connectivity (if placed in optimal locations), followed by drainage culverts for marten (0.22 percent); secondary and tertiary structures capture less than 0.1 percent of total highway length.

Table 2b provides a species-specific breakdown for each type of mitigation. The types of species likely to use each mitigation structure are listed, followed by a calculation of the percentage of known linkage zones that would be maintained and/or restored by the proposed mitigations *if they were located in the appropriate linkage zones*. These measures also are detailed for each focal species. Of the upper 20 percent of habitat that actually intercepts the TCH (see Table 1), approximately one-fifth (1/5) of cougar habitat, one-tenth (1/10) of lynx habitat, less than one-tenth (1/10) of wolf habitat and less than one-tenth (1/10) of marten habitat will be maintained by the proposed mitigation.

Again, it is critical to note that these connectivity values (in metres) assume that structures will be placed in the optimal locations. Unfortunately, this assumption is not met in some cases (see below), which means the actual connectivity of the proposed mitigation is even lower that stated above. Table 1 provides an estimate of the total length of mitigation required to protect the upper 20 percent of habitat. At a minimum, this would require 2.7 kilometres of mitigation, and at a maximum 6.7 kilometres of mitigation.

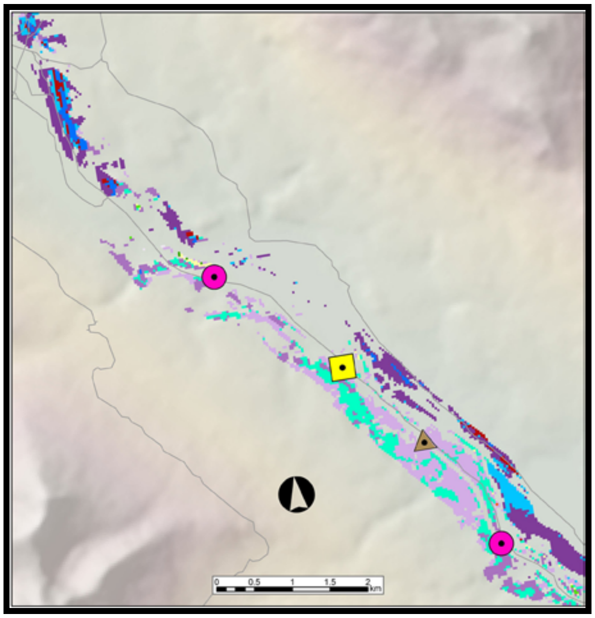

Figure 10: Zoom Box 3 - Multi-species Linkage Zones. Zoom box 3 shows the probability of use for marten, lynx, cougar and wolf from Moraine Creek to Lake Louise (Option B) on Phase IIIB (Legend on Figure 7).

Table 1a: Amount of Phase IIIB mitigated by proposed crossing structures.

Type	Number	Dimensions (width)			Total mitigation provided (m)	Proportion of the 35-km Phase IIIB (%)
		Min (m)	Max (m)	Mean (m)		
Primary	7	50	107	65.3	457.1	1.31
Secondary	2	18	18	18	36.0	0.10
Tertiary	9	2.4	4	3.3	29.7	0.08
Drainage	93	.75	.90	.83	77.2	0.22
Total	111				600.0	1.71

Table 2b: Amount of species-specific linkage zones mitigated by proposed crossing structures. Refers to species-specific linkage zones listed in Table 1.

Mitigation type	Total mitigation provided (m)	Species likely to use mitigation	Maximum of total species-specific linkage zones mitigated by proposal (%)			
			Wolf	Marten	Lynx	Cougar
Primary	457.1	ALL	8.10	6.84	9.43	16.91
Secondary	36.0	ALL	0.64	0.54	0.74	1.33
Tertiary	29.7	ALL	0.52	0.44	0.61	1.10
Drainage	77.2	Marten	0.00	1.15	0.00	0.00
Total	600.0		9.26	8.97	10.78	19.34

Table 3 compares proposed mitigation types with our predicted linkage zones (Figure 7). These are reviewed in sequence from east to west, as indicated by the ID number, which may be cross-referenced to the Phase IIIB screening report (Golder & Associates 2004).

The current proposal does not realize our proposed minimum goal (i.e. protecting all linkage zones for the upper 20 percent of habitat quality by species that intercepts the TCH). Thus, we suggest a number of revisions to both the number and size of proposed crossing structures and their locations (Table 3, column 3). These changes range from minor changes in location (i.e. shift east or west) to changes in structure type (i.e. upgrade a tertiary structure to a secondary one). The mitigation and connectivity improvements for each species are detailed in Tables 4a and 4b.

We detail where mitigation has not been proposed for multiple species zones (column 1), although we do not consider the multitude of single, dual and tri-species linkage zones where no mitigation has been proposed. Hence, the changes we recommend to the existing proposed structures are only a starting point.

Of the five obvious multi-species linkage zones located between Castle Junction and Lake Louise, only two zones have been proposed to receive primary crossing structures (1 and 4), though structure 4 needs to be shifted to the west. One predicted multi-species linkage zone occurs where no mitigation is proposed (located between structures 2 and 3), one is close to a proposed secondary structure (3), and one coincides with a tertiary structure (6) that could be upgraded.

Table 3: Alternative mitigation strategy (Comparison of proposed vs. predicted linkages).

Proposed structure ID# and type	Predictive model results	Species present	Suggested structures and revisions
1. Primary	Multi-species zone	Marten, lynx, cougar, wolf	Widen primary (min. 175 m wide)
2. Tertiary	Multi-species zone	Marten, lynx, cougar, wolf	Upgrade to secondary
2a. Nothing	Multi-species zone	Cougar, lynx, marten	Add primary (min. 175 m wide)
3. Secondary	Near multi-species zone	Cougar, lynx, marten	Upgrade to primary, shift to east (min. 175 m wide)
4. Primary	Near multi-species zone	Lynx, wolf, marten	Widen primary, shift to west (min. 175 m wide)
4a. Tertiary	No linkages		Move to suitable location
5. Tertiary	Multi species zone	Lynx, marten, wolf	Upgrade to secondary
6. Tertiary	Multi-species zone	Wolf. Lynx, marten	Upgrade to primary (min. 175 m wide)
7. Tertiary	No linkages		Move to suitable location
8. Tertiary	Single/dual species zone	Wolf, lynx, marten	Upgrade to secondary
9. Primary	Single/dual species zone	Lynx, marten	Widen primary (min. 175 m wide)
10. Tertiary	Single/dual species zone	Marten, lynx, wolf	Tertiary
11. Secondary	Single/dual species zone	Marten, lynx, wolf	Secondary
12. Primary	Multi-species zone	Lynx, wolf, cougar	Widen primary (min. 175 m wide)
12a. Nothing	Multi-species zone	Lynx, wolf, cougar	Fence as part of Lake Louise bubble fence
13. Primary	Multi-species zone	Lynx, wolf, marten; wolverine known to use area	Widen primary (open span, min. 175 m wide)
14. Primary	Multi-species zone	Lynx, wolf, marten; wolverine known to cross TCH	Widen primary (open span to west, min. 175 m wide).
15. Tertiary	Single species	Lynx	Tertiary
16. Tertiary	Single/dual species zone	Lynx	Upgrade to secondary
17. Primary	Dual-species zone	Lynx, marten	Widen primary (min. 175 m wide)

The increased spatial extent and improved placement of crossing structures as defined by our plan (Table 3) would result in an increase of approximately 1900 metres of mitigated linkage zone on the Phase IIIB.

Assuming these mitigation upgrades are placed according to the optimal locations for each species on Phase IIIB (Figure 7), we should see an increase in habitat connectivity from 9.26 to 32.75 percent for wolves, 8.97 to 28.77 percent for marten, 10.78 to 38.11 percent for lynx, and from 19.34 to 68.32 percent for cougar. The reader must remember that even if we achieve our revised plan, we still will fall far below our "ecological minimum" (maintaining *all single and multi-species linkage zones* delineated by the top 20 percent of habitat on the Phase IIIB).

Table 4a: Summary of maximum total species-specific linkages according to Parks Canada proposed mitigation (by structure type).

Type	**Species likely to use**	**Maximum of total species-specific linkage zones mitigated by Parks Canada proposal (%)**			
		Wolf	**Marten**	**Lynx**	**Cougar**
Primary	ALL	8.10	6.84	9.43	16.91
Secondary	ALL	0.64	0.54	0.74	1.33
Tertiary	ALL	0.52	0.44	0.61	1.10
Drainage	Marten	0.00	1.15	0.00	0.00
Total		9.26	8.97	10.78	19.34

Table 4b: Summary of maximum total species-specific linkages according to linkage zone mitigation by our alternative proposal (by structure type).

Type	**Species likely to use**	**Maximum of total species-specific linkage zones mitigated by alternative proposal (%)**			
		Wolf	**Marten**	**Lynx**	**Cougar**
Primary	ALL	30.48	25.71	35.47	63.60
Secondary	ALL	2.01	1.69	2.34	4.19
Tertiary	ALL	0.26	0.22	0.30	0.53
Drainage	Marten	0.00	1.15	0.00	0.00
Total		32.75	28.77	38.11	68.32

A FEW CLOSING WORDS

Despite the negative ecological effects, highways continue to proliferate and traffic volumes continue to increase in Canada's protected areas. Hence, managers need information and tools to rapidly assess disturbance, to determine disturbance thresholds, to identify optimal sites for single and multi-species linkage zones, and to inform management decisions. We have provided an objective, repeatable, and transparent method, based on empirical data and scientifically rigorous analysis. Our plan provides managers with the information necessary to make ecologically-based decisions. We believe our approach and recommendations are an improvement on those used thus far to determine placement and frequency of mitigation on the TCH Phase IIIB.

We have identified the locations of linkage zones for single, multiple and all possible combinations of four focal species. We provided estimates of the spatial dimensions of these linkage zones, and evaluated the proposed plan in light of our results. The number and spatial extent of our linkage zones exceeds that of the proposed mitigations. It is important to note that our approach uses ecological minimums.

The Banff-Bow Valley is an ecologically compromised system. Were all linkage zones specified in this report to be maintained, connectivity would still be impaired. This does not mean we should "lower the bar" on mitigation. Our recommended changes to Parks Canada's mitigation plan remain a compromise from what we suggest is a reasonable "ecological minimum." However, if implemented, our recommendations would be a substantial improvement over the current Phase IIIB mitigation proposal.

With regards to mitigation type, we ascribe to "the Cinderella Principle"— making the road fit the movement corridor, rather than the corridor fit the road (Bissonette 2004). As such, we recommend the most frequent type of structure used in highway mitigation, in National Parks, should be the open-span bridge or elevated sections of highway. The photo shown below illustrates this concept.

Large open span bridge on the Grevena–Panagia section of highway in Croatia.
Photo: Reno Sommerhalder

Appendix I

SPATIAL DATA DEVELOPMENT: SPECIES PRESENCE AND PREDICTIVE ATTRIBUTES

We created two series of maps including species presence data (from transect/road track data for multi-species data, as described in the methods) and predictive attribute data (e.g., slope, aspect, etc.), defined below. Our dependent variable was species presence and absence. Independent environmental variables included landscape and vegetation characteristics, listed in the table below.

Table 5: Independent Variables

Topographic	
	Terrain Ruggedness: TRI_3, TRI_5, TRI_7
	Distance to Ruggedness: from TRI_7 (upper 10% ruggedness)
	Elevation within 1km of Roads: ELEV
	Slope angle: SLOPE
	Extent of Northern exposure: NORTHNESS
	Extent of Eastern exposure: EASTNESS
Vegetation	
	Vegetation Productivity: GREENNESS and NDVI
	Structural Complexity/Stand Maturity: WETNESS
	Distance to Closed Canopy: CANOPY

DETAILS OF DEPENDENT VARIABLES

Topographic metrics consisted of elevation, slope, terrain ruggedness index (TRI), and measures of aspect (northness and eastness):

TRI is a measure of variation in elevation within a neighborhood (Riley *et al.* 1999), using the equation: $\mathrm{TRI} = [\Sigma(X_{ij} - X_{00})^2]^{1/2}$, where X_{ij} = elevation of each neighbor pixel to the center pixel (0,0). We developed this for three different local neighborhoods: 3x3, 5x5, and 7x7 = TRI_3, TRI_5, TRI_7. Distance to High Ruggedness was developed by selecting the upper 10 percent of pixels in the 7x7 TRI and running distance from those sites.

Northness and Eastness were derived using cosine and sine transformations of aspect, respectively. People that are not familiar with these types of analyses are likely to be confused by these variables (they are usually the ones I get the most questions on when I present similar analysis. I suggest adding a little more description here.

Vegetation metrics included greenness (proportionate to green biomass) and wetness (correlated with vegetation structure and soil moisture) (Alexander 2001). Greenness and wetness were derived using a Tassel Cap Transformation of Landsat 7 ETM imagery.

The Normalized Difference Vegetation Index (NDVI) also was derived from Landsat imagery (Jensen 1996) for comparison as a vegetation surrogate.

We employed a canopy closure metric that classified the landscape on the basis of proximity to closed canopy. In the latter case, a circular moving window was passed over the image and quantified the percent of open and closed forest within a 500 metre radius. This addressed problems that may arise when species locations occur along the edges of forest stands (i.e., the fuzzy versus discrete boundary problem in GIS).

SPATIAL DATA ANALYSIS: LOGISTIC REGRESSION AND PREDICTIVE MODELS

Spatial data analysis was conducted for marten, lynx, wolf and cougar using ArcGIS 8.3. Attribute values of the independent variables were extracted for species presence and pseudo-absence points. One thousand pseudo-absence points were drawn randomly from our survey frame and those overlapping with known presence excluded from analysis. Only sites within the Banff Bow Valley were considered in this analysis.

We tested independent variables for multi-collinearity using Pearson's correlation coefficient. When pairs of variables exhibit values greater than 0.7, we removed the variable with the lowest predictive power (highest p-value), determined with a univariate logistic model. We employed a forward stepwise logistic regression with a 0.2 exit threshold.

Finally, we created a Bow Valley scale probability surface for each species by extrapolating the optimal model across the survey frame (+/- 1 km from the TCH, Phase IIIB), thus incorporating sites not surveyed initially. Equation 1 can then be rearranged to solve for p (equation 2).

$$p = 1/[1+ \exp(-1*(a + bX1 + cX2.....))] \quad [2]$$

Each probability surface was divided into quartiles and the upper 20 percent of probability cells were displayed for each species (see the Results section.)

MODEL RESULTS AND DISCUSSION

SPECIES ENVIRONMENT RELATIONSHIPS

(Coefficients are available upon request to Dr. S. M. Alexander.)

Marten
Variables considered: Greenness, Wetness, Elevation, Slope, Northness, Eastness, TRI_5, Dist to Ruggedness, Canopy.

$$\ln(p/(1-p)) = \beta_0 + \beta_1 * \text{Wetness} - \beta_2 * \text{Elevation} - \beta_3 * \text{Northness} + \beta_4 * \text{TRI\_3}$$

Our analysis of marten track data indicated their distribution was related to the environmental variables as follows:

1) marten were influenced positively by wetness (structural complexity or older age) of vegetation, and to rugged terrain (TRI_3). The relationship to wetness indicates an association with forest stands with higher structural complexity (Crist and Ciccone 1984) or more mature (old growth) forest types.

A positive response to terrain ruggedness was observed, which suggests marten affiliate more with complex terrain (perhaps more undulating terrain or drainages). Importantly, marten were most strongly influenced by the smallest scale of terrain ruggedness.

2) marten responded negatively to elevation and northness, which means they select lower elevation habitat within 1km of roads and are associated more strongly with slopes with more southern exposure.

Lynx

Variables considered: Greenness, Wetness, Elevation, Slope, Northness, Eastness, TRI_7, Dist2Rug, Canopy.

$\mathbf{ln(p/(1-p))} = -\beta_0 + \beta_1$*Wetness – β_2*Slope + β_3*TRI_7 + β_4*Dist2Rug

We found that lynx distribution was related to the environmental variables as follows:

1) lynx were influenced positively by vegetation wetness (or structural complexity of the forest stand), rugged terrain (TRI_7), and distance to rugged terrain.

As with marten, the relationship to wetness indicates an association with forest stands with higher structural complexity or more mature (old growth) forest types. A positive response to terrain ruggedness suggests an affiliation more with complex terrain, but as this was a value averaged over greater distance, it suggests lynx respond to ruggedness at broader scale than marten. This fact was further substantiated by the selection for areas closer to rugged terrain.

2) lynx responded negatively to slope, which may relate to ease of movement within more complex terrain.

Cougar

Variables considered: NDVI, Wetness, Elevation, Northness, Eastness, TRI_7, Dist2Rug, Canopy.

$\mathbf{ln(p/(1-p))} = \beta_0 - \beta_1$*NDVI + β_2*Wetness + β_3*TRI_7 + β_4*Canopy – β_5*Elevation

We found that cougar distribution was related to the environmental variables as follows:

1) cougar were influenced positively by vegetation wetness (or structural complexity of the forest stand), rugged terrain (TRI_7), and distance to canopy cover. As with marten and lynx, the relationship to wetness indicates an association with forest stands with higher structural complexity or mature (old growth) forest types. The positive response to terrain ruggedness suggests an affiliation more with complex terrain, at broader scale than marten but similar to lynx.

2) cougar responded negatively to NDVI and elevation. Hence, within 1km of roads cougar tended to occur in the lower elevations (i.e. closer to the roads and river), where habitat had lower biomass (lower NDVI correlates with Greenness or vegetative productivity).

Wolf

Variables considered: Brightness, Greenness, Elevation, Northness, Eastness, TRI_7, Dist2Rug, Canopy.

$\mathbf{ln(p/(1-p))} = \beta_0 - \beta_1$*Brightness – β_2*Elevation – β_3*Eastness

Our analysis showed that wolf distribution was related to the environmental variables as follows:

1) wolves were influenced positively by no variables but distance to canopy. However, this relationship was small enough at the precision level required (i.e. 0.000 coefficient), so as to render it useless in model prediction.

2) wolves responded negatively to brightness, elevation and eastness. The avoidance of high brightness indicates they avoid areas with no vegetation. However, brightness was highly correlated with wetness and was selected because of its slightly greater univariate predictive ability. As such, our results also may indicate that wolves select for stands with low structural complexity. The negative association with elevation indicates that wolves selected areas closer to the valley floor within 1 km of roads. Lastly, wolves tended to select for more western facing slopes, which tend to be somewhat drier and their selection by wolves may relate to ease of movement or prey availability.

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