FINAL REPORT

January 2017

TRANS-CANADA HIGHWAY YOHO, NATIONAL PARK: MITIGATION AND OPPORTUNITIES ASSESSMENT FOR WILDLIFE

January 2017

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1. Introduction

Parks Canada Agency has been a world leader in efforts to mitigate the Trans-Canada Highway (TCH) in Banff National Park, Alberta for more than 30 years. TCH upgrades have twinned the highway through Banff National Park during the last three decades and upgrades are currently occurring across the Continental Divide the first 6 kilometers (km 0-6) into Yoho National Park (YNP), British Columbia. Parks Canada Agency has received government funding to start preliminary engineering work for twinning the TCH through YNP.

The current 6 km, and eastern section of the future full length TCH expansion enters subalpine habitats at the spine of the Continental Divide. This high elevation ecosystem in the Canadian Rockies is doubly important given it is acutely impacted by a warming climate and it's north-south axis is bisected by east-west transportation corridors. Recent research in Banff and YNP has underscored the importance of the Continental Divide for wolverine movements, gene flow and population connectivity (Clevenger and Barrueto 2014). The Divide is also recognized as an important juncture of major drainages and ridge systems (Bath, Yoho, Cataract, Bow, Kicking Horse) that promote regional-scale movements of mountain goats, wolverines, grizzly bears and lynx (Austin 1998, Gibeau et al. 1998; Clevenger, unpublished data). For these reasons it will be of paramount importance to ensure the best data, science and methods are used to identify critical areas for mitigating the TCH through the Continental Divide and through YNP.

The Kicking Horse Pass and Continental Divide, however, is only one part of the park. YNP encompasses 1,313 km^2 representing the western slopes of the Main Ranges of the Rocky Mountains. The park shares boundaries with Banff National Park to the east and Kootenay National Park to the south, and is an important component of the 23,069 km^2 Canadian Rocky Mountain Parks World Heritage Site. As a key link in the regional ecosystem, Yoho continues to provide critical movement corridors for wildlife, connecting habitat in British Columbia and Alberta (Parks Canada 2010). The park protects important habitat within the alpine, subalpine and montane ecoregions, and is home to a broad range of terrestrial wildlife, including mountain goat, lynx, wolverine, and grizzly bear.

The mountain landscape of Yoho National Park is characterized by three distinct ecoregions: the montane, subalpine and alpine. The montane ecoregion occupies the lowest elevations in the park, along the valley bottoms of the main rivers and as far east as Spiral Tunnels. The montane makes up 19% of the park, and is critical to the park's ecological integrity as it supports the greatest biodiversity and provides important movement corridors for wildlife (Parks Canada 2010). The Kicking Horse River montane area contains the Ottertail flats and Leanchoil marsh near confluence of the Beaverfoot River, two relatively large wetlands.

The montane valley also contains most of the large infrastructure in the park, including the TCH and Canadian Pacific (CP) railway and the community of Field. Due to the relative rarity of montane habitat in the park, many animals migrate into adjacent lands during the winter. In these migrations wildlife inevitably need to cross the TCH and other park roads.

The effects of an expanded TCH reach beyond individual wildlife populations and pose broader conservation, economic and social consequences, including a considerable human safety risk from wildlife-vehicle collisions. Parks Canada seeks to preserve the ecological integrity in national parks while maintaining safe and efficient mobility of people, goods and services on national park highways and important transportation corridors such as the TCH. Developing proactive, cost-effective approaches to address these three objectives, including reductions in accidents, wildlife mortality, and fragmentation effects of the TCH will allow management to mitigate or minimize the effects of anticipated increases in traffic and associated disturbances.

Parks Canada has a large amount of data from YNP well suited for analysis and identification of key locations for mitigating wildlife mortality and improving connectivity across the TCH. These data consist of records of wildlife-vehicle collisions, wildlife occurrence (camera-trap data), population genetics (wolverine, grizzly bear), roadside snow-tracking surveys, and observation data from multiple species of large mammal residing in YNP and within the TCH corridor. Further, Parks Canada has excellent high resolution GIS data (landcover, digital elevation model, hydrology, roads and infrastructure, etc.) that is essential for identifying and mapping key collision areas, wildlife habitats and modeling dispersal and highway intersections with regional-scale connectivity needs.

The purpose of this project is to develop science-based recommendations for mitigating the TCH for a suite of wildlife species that encompass a range of mobility, habitat needs, and ecological requirements. The work will identify the critical intersections of traffic and wildlife movement (mortality, connectivity) on the TCH. The focal species will be large mammals, primarily ungulates for wildlife-vehicle collision reduction and wide-ranging fragmentation-sensitive carnivores for landscape connectivity. The work will also address the needs of mountain goats, a high elevation, localized species occurring in the study area and close proximity to the TCH. The study is limited to terrestrial wildlife species and does not address aquatic organisms and barriers to hydrological connectivity.

The project objectives are to:

- Identify areas of greatest concern for motorists and wildlife based on wildlife mortality data.
- Compile and summarize wildlife-vehicle collision data,
- Conduct a landscape resistance analysis that will model wolverine, black bear and grizzly bear gene flow across the TCH and other potential barriers to movement (i.e. natural, anthropogenic),
- Map key areas for mitigation impacts on mountain goats,
- Identify and prioritize key areas for ungulate mortality and carnivore movement and mitigation,
- Recommend suitable techniques to mitigate TCH impacts on mortality and regional-scale connectivity of common and fragmentation-sensitive species.

This work will ensure that through a rigorous analysis of multi-species mortality and fragmentation on the TCH appropriate mitigation recommendations will be identified for Parks Canada decision makers in advance of highway twinning and reconstruction. Information from this project will inform Detailed Impact Analysis now under development, project planning, engineering and budgeting. This project directly supports Park Management Planning requirements related to terrestrial connectivity, and supports efforts to stabilize Forest Health Ecological Integrity measures related to reducing human caused wildlife mortality (Parks Canada 2010).

References

Austin, M. 1998. Wolverine winter travel routes and response to transportation corridors in Kicking Horse Pass between Yoho and Banff National Parks. M.Environ. Des. Thesis. University of Calgary, Alberta. 40 pp.

Clevenger, A.P., M. Barrueto. 2014. Trans-Canada Highway Wildlife and Monitoring Research, Final Report. Part B: Research. Report to Parks Canada Agency, Radium Hot Springs, British Columbia, Canada.

Gibeau, M. et al. 1998. Grizzly Bear Habitat Effectiveness Model for Banff, Yoho, and Kootenay National Parks, Canada. Ursus 10:235-241.

Parks Canada. 2010. Yoho National Park of Canada, Management Plan. Parks Canada, Ottawa, Ontario.

2. Study Area

The work encompasses all of YNP, from the west boundary to the Continental Divide (west boundary of Banff National Park; Figure 2.1). The greater study area for modeling animal movement extends far beyond YNP and is determined by ecological boundaries, e.g., watersheds, topography) rather than political boundaries.

Yoho National Park Description

Yoho National Park (YNP) is situated on the west side of the Continental Divide and is characterized by steep rugged terrain with narrow valleys and continental climate consisting of short, cool summers and long winters with high snowfall. The Kicking Horse River is the main east–west aligned watershed in YNP and parallels the TCH and Canadian Pacific (CP) mainline. Differing from the Bow Valley, the Kicking Horse Valley is sparsely populated, as Field (300 residents) is the only townsite within the national park.

Physical Geography

Kicking Horse Pass runs east-west and crosses the Continental Divide at an elevation of 1627 m. The pass is wide and flat with approximately 2.5 km between the 1829 m contours on the north and south sides of the pass (Figure 2). The study area itself ranges between 1585 m and 1829 m. Within the study area is Wapta Lake, which is approximately 25 ha. Wapta Lake is the headwater of the Kicking Horse River, which flows west through YNP.

Vegetation

The vegetation of YNP is dominated by mature to old stands of Engelmann spruce *(Picea engelmannii)* and subalpine fir *(Abies lasiocarpa)* with some successionally intermediate stands of lodgepole pine *(Pinus contorta*). The shrub layer is dominated by buffaloberry *(Shepherdia canadensis),* green alder *(Alnus crispa)* and regenerating sub-alpine fir and Engelmann spruce.

Human Development and Activity

Substantial human development and activity occur within the study area. Most of this activity is directly associated with the TCH and the CP railway, which run parallel to each other through

YNP. The TCH is a two-lane highway and it receives heavy passenger vehicle and commercial truck use year round as Canada's primary east-west transportation corridor. The average annual daily traffic volume in 2015 was 6905 vehicles per day (Parks Canada, unpublished data). The CP railway is single track for the portion passing through the study area. The railway receives substantial use as one of Canada's two national rail corridors with approximately 25-30 trains/day.

The study is focused on the 40 km TCH transportation corridor that bisects the portion of YNP not already being twinned. The ecological integrity of YNP is impacted by this major transportation corridor (Parks Canada 2010). The TCH runs through the study area, and directly through YNP, with traffic volumes exceeding an average of 6000 vehicles per day year-round (Parks Canada, Highway Service Centre, unpublished data). Additionally, a two-track transcontinental railway runs parallel to the TCH throughout the extent of the study area. Both the TCH and railway are a source of wildlife mortality and habitat fragmentation (Clevenger et al. 2002, 2009; Dorsey 2011).

References

Clevenger, A.P., Chruszcz, B., Gunson, K., and Wierzchowski, J. 2002. Roads and wildlife in the Canadian Rocky Mountain Parks - Movements, mortality and mitigation. Final Report (October 2002). Report prepared for Parks Canada, Banff, Alta.

Clevenger, A.P., A.T. Ford, and M.A. Sawaya. 2009. Banff wildlife crossings project : Integrating science and education in restoring population connectivity across transportation corridors. Final report to Parks Canada Agency, Radium Hot Springs, British Columbia, Canada. 165 pp.

Dorsey, BP. 2011. Factors affecting bear and ungulate mortalies along the Canadian Pacific Railroad through Banff and Yoho National Parks. MSc thesis, Montana State University, Bozeman, Montana USA.

Parks Canada. 2010. Yoho National Park management plan. Parks Canada, Ottawa, Ontario.

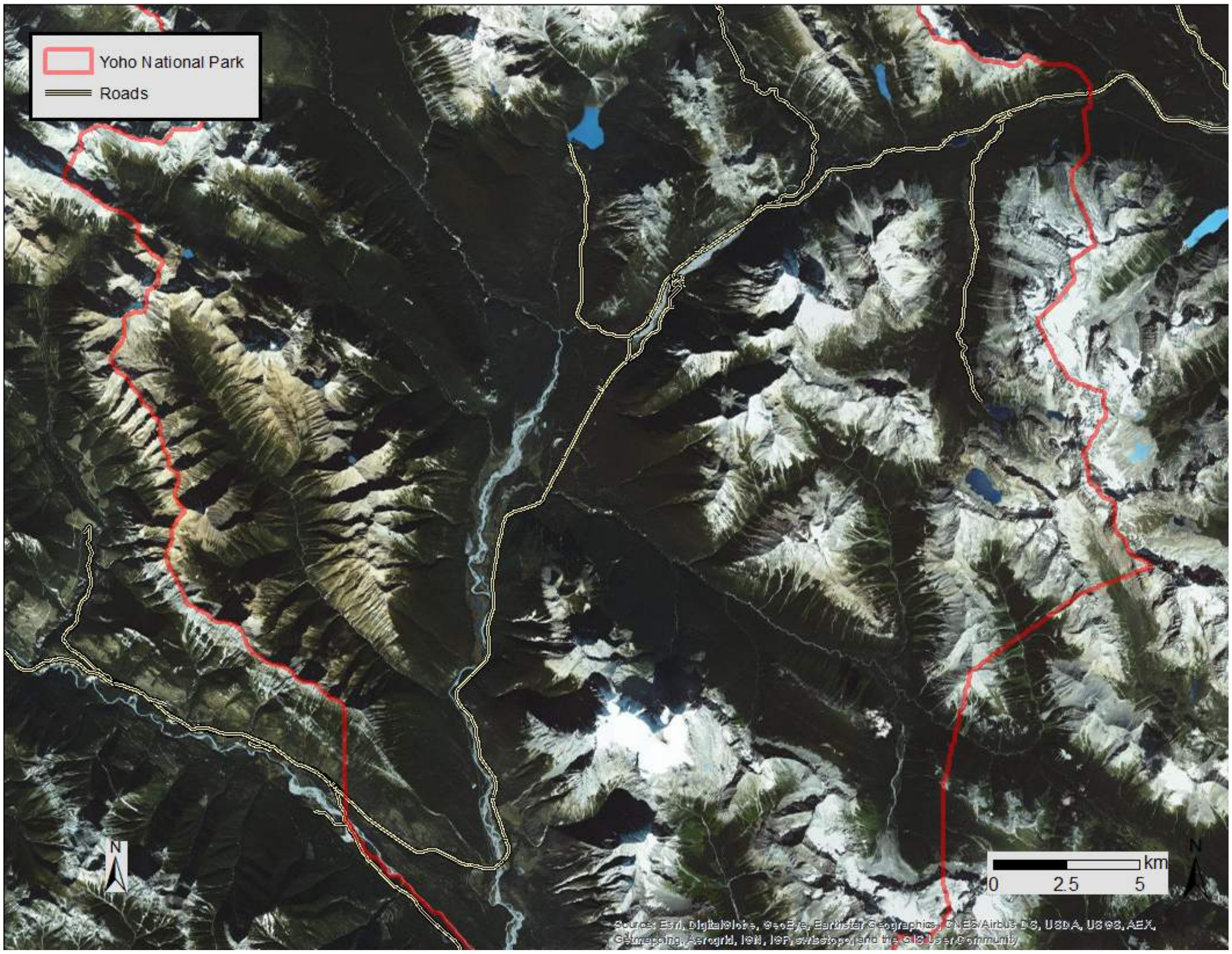


Figure 2.1: Map of Yoho National Park and the Trans-Canada Highway corridor in the Rocky Mountains of British Columbia and Alberta.

3. Occurrence of Wildlife-Vehicle Collisions

Introduction

The TCH through Yoho National Park (YNP) takes a toll on animals crossing the road in the Rocky Mountains, British Columbia. Most wildlife agencies collect wildlife-vehicle collision (WVC) data as part of their routine objectives to monitor wildlife, but often data are patchy, inconsistent, and unreliable. Parks Canada has been collecting WVC data consistently in YNP for almost 40 years (Damas and Smith 1982, Bertch and Gibeau 2010). During the last 15 years the data has been spatially accurate as global positioning system (GPS) units were used in the field by Parks Canada staff (Gunson et al. 2009). WVC data can be used to identify locations where large animals are killed and public safety is at risk, and in some instances can be the primary driver of highway mitigation strategies. WVC data is also a useful measure of where animals cross roads, albeit unsuccessfully. We examined spatial and temporal patterns of road mortality and highway strikes of large mammals in YNP.

Methods

We compiled WVC data for wildlife species in YNP from all available sources provided by Parks Canada. We used road-kill data from querying Parks Canada's mortality database for mortality types that were recorded as "highway" for road-caused mortality. In our tabulations we used confirmed "mortalities" and also records that were reported as "strikes". We included vehicle strikes because, in addition to confirmed mortality data, it provides important information where wildlife are interacting with and tend to cross highways. Records with erroneous spatial information (i.e. located >50 m from TCH) were removed from analysis.

The Parks Canada database is rich with information on the abundance and diversity of wildlife that have been recorded as road-kill on the TCH. Many of these small and medium-sized vertebrate species will benefit to some extent by having a mitigated highway for safe passage (Clevenger et al. 2001, 2003) and are of interest to exhibit as part of the report. We tabulated all recorded road-related mortality and strikes by decade for wildlife along the TCH.

We also examined the spatial and temporal patterns of road-caused mortality of large mammal species. We plotted locations of mortalities and strikes in NAD 83 UTM Datum using ArcGIS 10 (ESRI, Redlands, California, USA). Records from 2006-2016 were categorized as “recent”, while prior to 2006 were classified as “non-recent”. We used all records of large mammals in the database collected between 1981 and 2016.

Results

The mortality locations with all wildlife species were evenly distributed throughout the national park (Figure 3.1). A total of 30 wildlife species were recorded as killed on the highway, including small and large mammals, birds, and reptiles (Table 3.1).

We found a total of 981 useable records (315 recent records) for WVCs (52 strikes, 929 mortalities), including road-related mortality of six large mammal taxa in the database: Bears (black and grizzly), canids (coyotes, wolves), deer (white-tailed and mule), felids (lynx, cougars), elk, moose and mountain goats. WVCs occurred between 12 January 1981 and 15 September 2016.

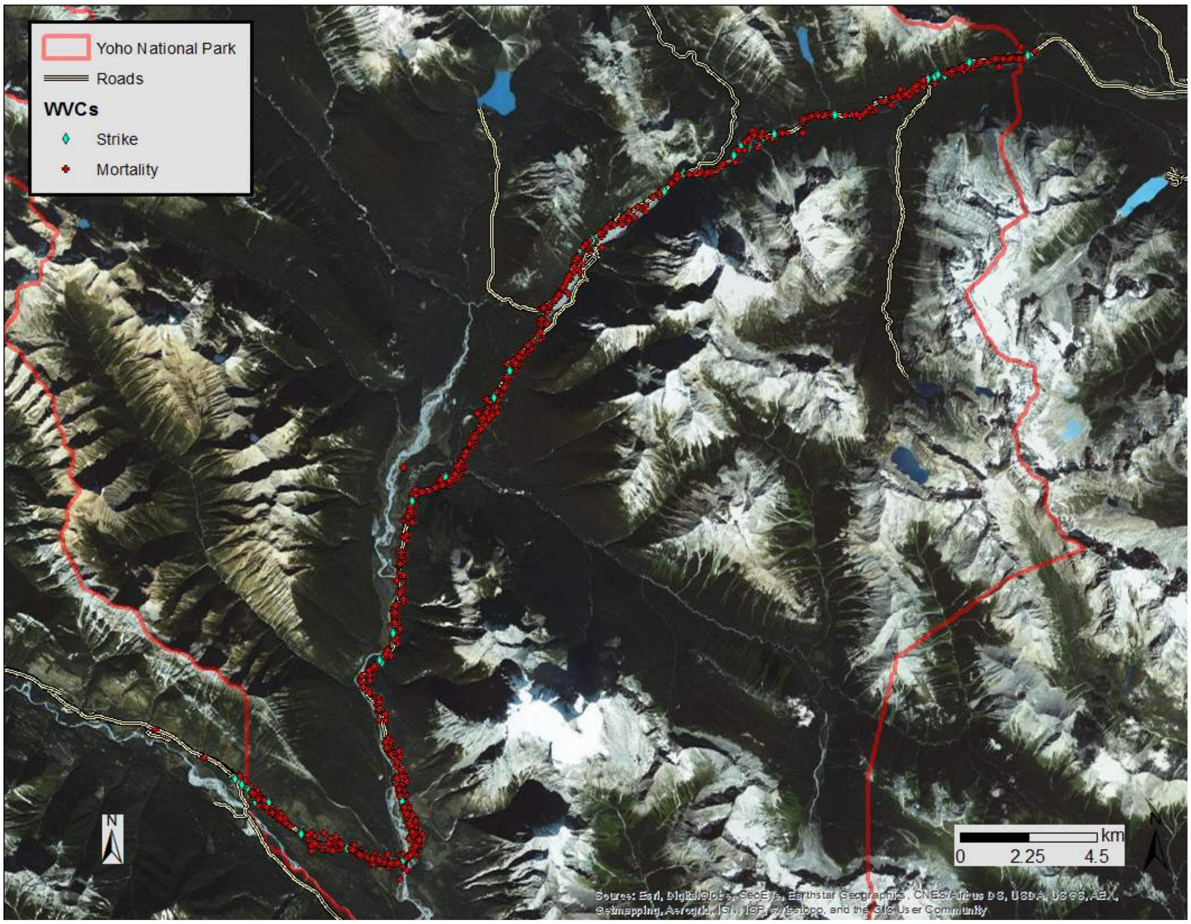


Figure 3.1: Road-related mortality and strikes of wildlife on the Trans-Canada Highway in Yoho National Park, British Columbia, 1981-2016.

Table 3.1: Road-related mortality and strikes by decade for wildlife along the Trans-Canada Highway in Yoho National Park, British Columbia. Species in **RED** show increases in road-related mortality.

Species	Total	1980s	1990s	2000s	2010s*
American marten	10	5	3	2	0
Badger	1	0	0	1	0
Bear sp.	4	1	1	1	1
Beaver	2	1	0	0	1
Bighorn sheep	1	0	0	1	0
Black bear	**60**	**1**	**14**	**21**	**24**
Boreal owl	1	1	0	0	0
Columbian ground squirrel	1	1	0	0	0
Cougar	3	0	1	1	1
Coyote	72	18	23	19	12
Deer sp.	35	7	5	12	11
Elk	300	166	62	48	24

Golden eagle	1	0	0	0	1
Great grey owl	2	0	1	1	0
Great horned owl	4	0	3	0	1
Grizzly bear	2	0	0	1	1
Herring gull	1	1	0	0	0
Hoary marmot	7	3	1	1	2
Lynx	7	0	0	5	2
Merlin	1	0	0	1	0
Mink	1	0	1	0	0
Moose	**105**	**24**	**15**	**33**	**33**
Mountain goat	**17**	**1**	**1**	**6**	**9**
Mule deer	121	35	31	38	17
Owl sp.	1	1	0	0	0
Porcupine	20	14	3	2	1
Ptarmigan	1	0	1	0	0
Raven	3	0	0	2	1
Snowshoe hare	7	4	1	1	1
Unknown ungulate	2	0	0	2	0
White-tailed deer	167	21	50	55	41
Wolf	29	3	5	14	7

*Decade is incomplete and only includes 2010-2016

***Bears** (black bears and grizzly bears)*

In Parks Canada's mortality database, we found 66 bear-vehicle collisions, including 60 black bears, 2 grizzlies and 4 unknown species. Black bear WVCs occurred between 15 July 1988 and 21 June 2016; the two grizzly bear mortalities occurred on 2 June 2004 and 26 October 2014. Black bear mortalities were concentrated during summer months when bears were most active (Figure 3.1). The locations of WVCs with bears were not clustered and were well distributed along the TCH (Figure 3.2).

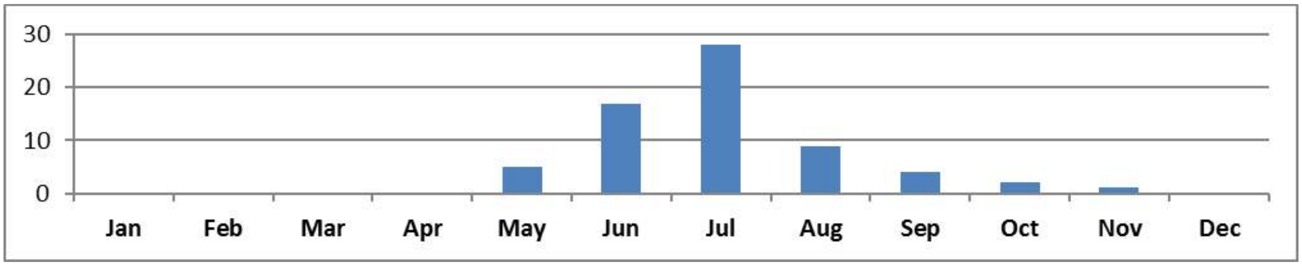


Figure 3.1: Road-caused bear mortalities and strikes by month along the Trans-Canada Highway in Yoho National Park, British Columbia.

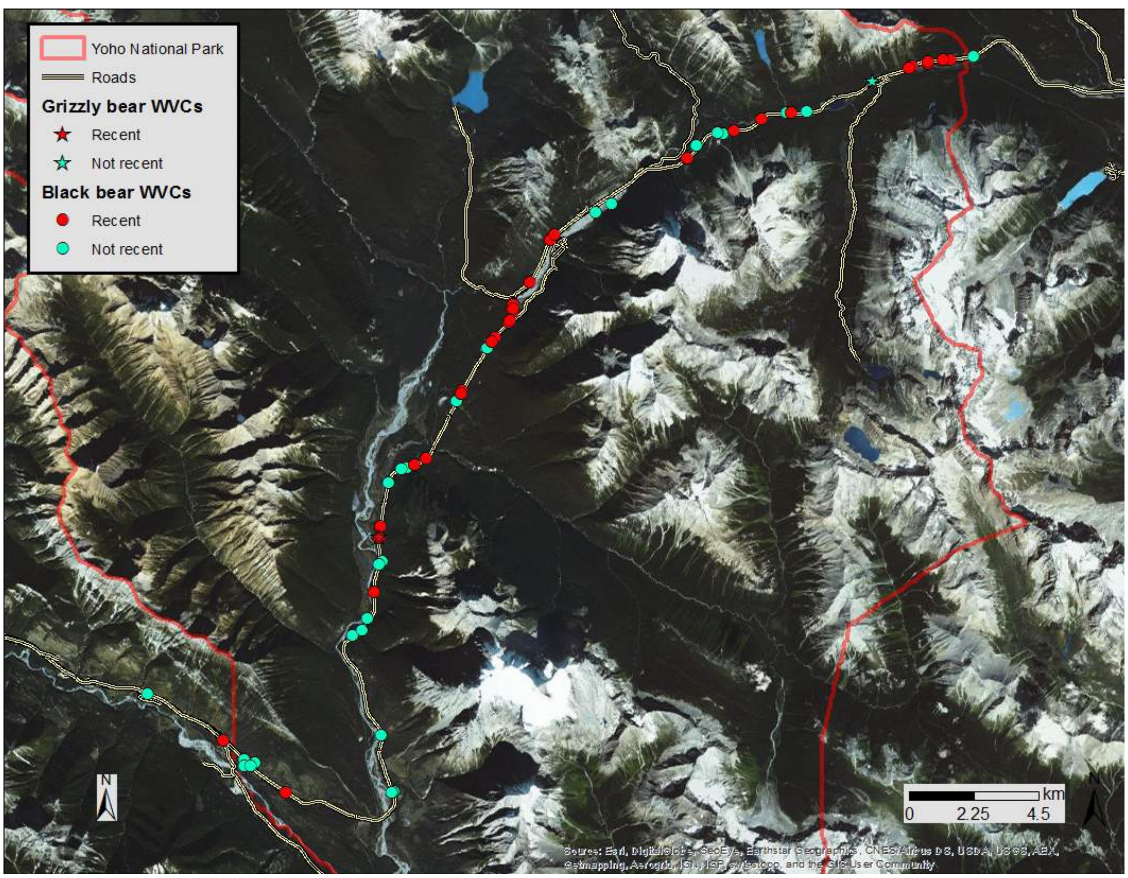


Figure 3.2: Road-caused mortalities and strikes of bears on the Trans-Canada Highway in Yoho National Park, British Columbia.

***Canids** (coyotes and wolves)*

In Parks Canada's mortality database, we found 101 canid-vehicle collisions, including 72 coyotes and 29 wolves. Canid mortalities occurred between 1 August 1981, and 5 September 2016. Canid mortalities were concentrated during summer months (Figure 3.3). The locations of vehicle collisions with coyotes were not clustered and were almost uniformly distributed along the entire length of the TCH in our study area, whereas wolf mortalities were concentrated near Kicking Horse Pass and along the Kicking Horse River (Figure 3.4).

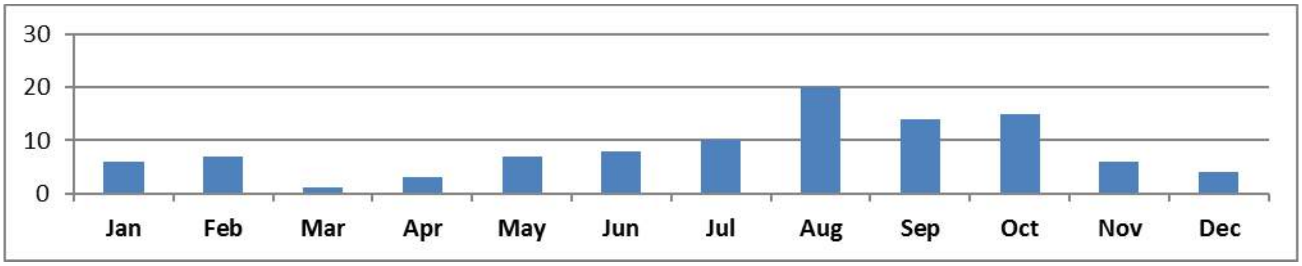


Figure 3.3: Road-caused canid mortalities and strikes by month along the Trans-Canada Highway in Yoho National Park, British Columbia.

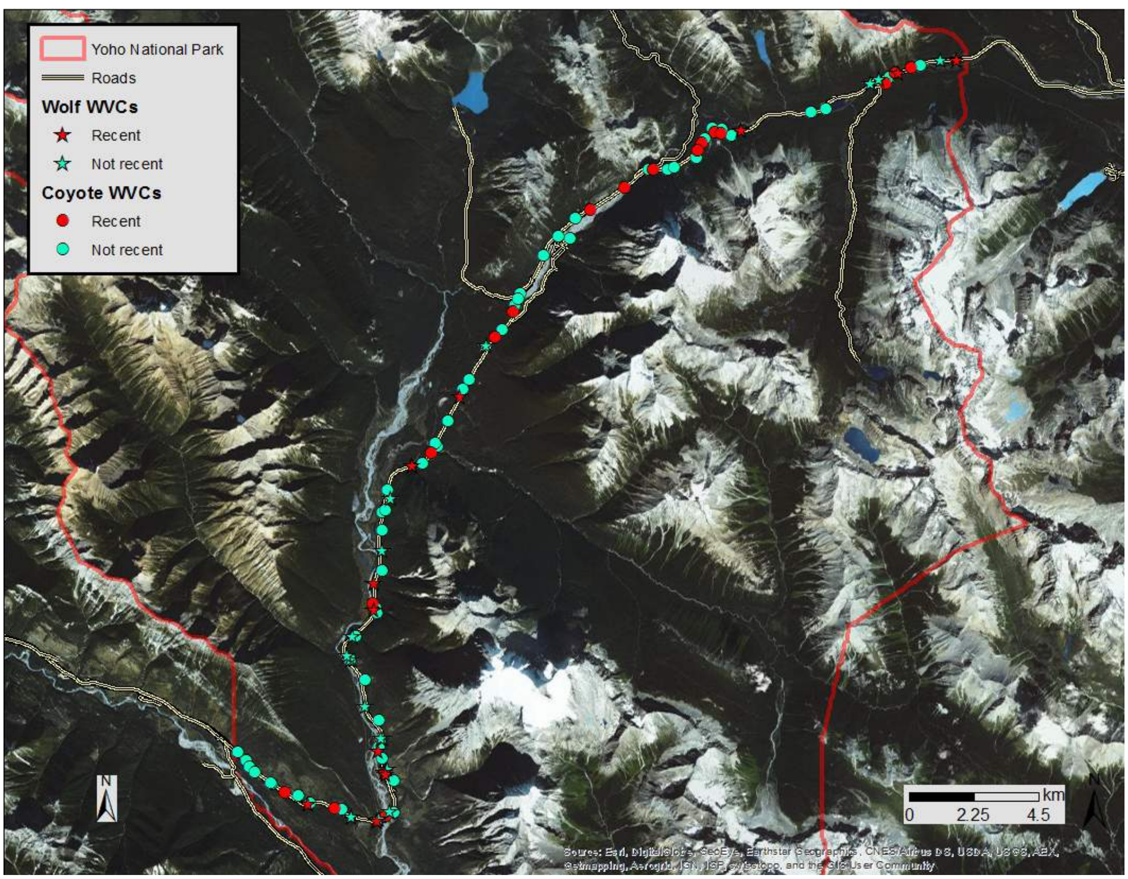


Figure 3.4: Road-caused mortalities and strikes of canids on the Trans-Canada Highway in Yoho National Park, British Columbia.

Deer Species *(mule deer and white-tailed deer)*

In Parks Canada's mortality database, we found 323 deer-vehicle collisions, including 121 mule deer, 167 white-tailed deer, and 35 unknown deer species. Deer WVCs occurred between 4 April 1981 and 15 September 2016. Deer WVCs were concentrated during early summer and late fall when deer are most active and movements are high (Figure 3.5). The locations of vehicle collisions with deer were well distributed along the TCH, with a dense cluster in the lower elevations along the Kicking Horse River (Figure 3.6).

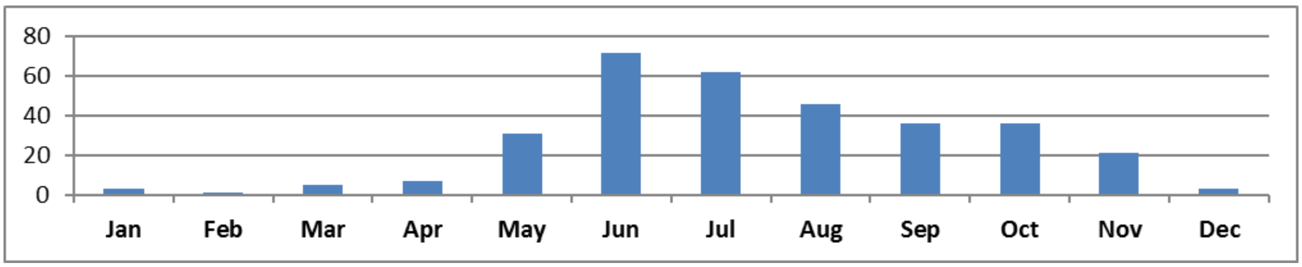


Figure 3.5: Road-caused deer mortalities and strikes by month along the Trans-Canada Highway in Yoho National Park, British Columbia.

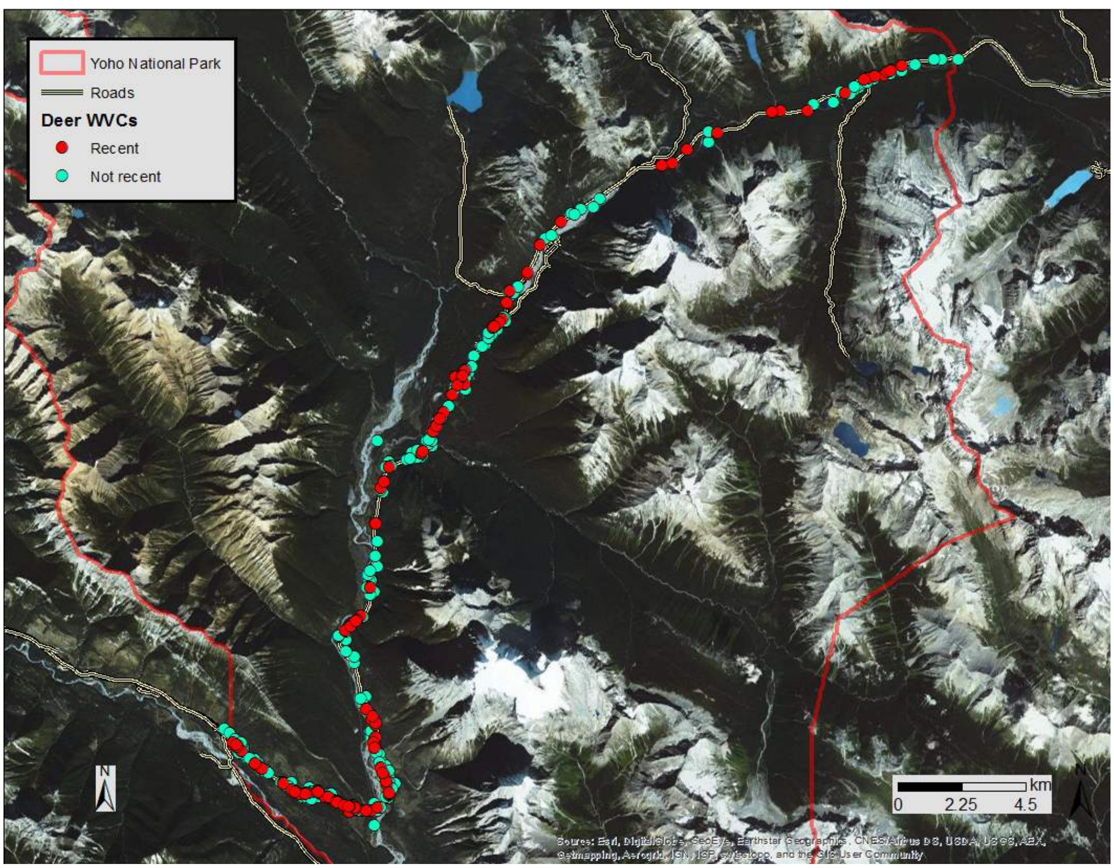


Figure 3.6: Road-caused mortalities and strikes of deer on the Trans-Canada Highway in Yoho National Park, British Columbia.

Elk

In Parks Canada's mortality database, we found 300 elk-vehicle collisions (the highest number for a single wildlife species in the database). Elk WVCs occurred between 12 January 1981 and 24 July 2016. WVCs with elk were concentrated during late fall and early winter (Figure 3.7). The locations of recent vehicle collisions with elk on the TCH were primarily clustered near Field Flats and along the Kicking Horse River (Figure 3.8); whereas older WVCs were more concentrated to the west of Field Flats.

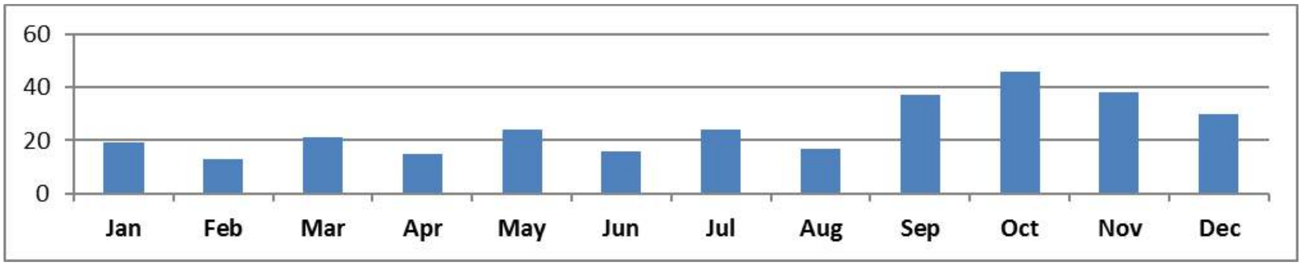


Figure 3.7: Road-caused elk mortalities and strikes by month along the Trans-Canada Highway in Yoho National Park, British Columbia.

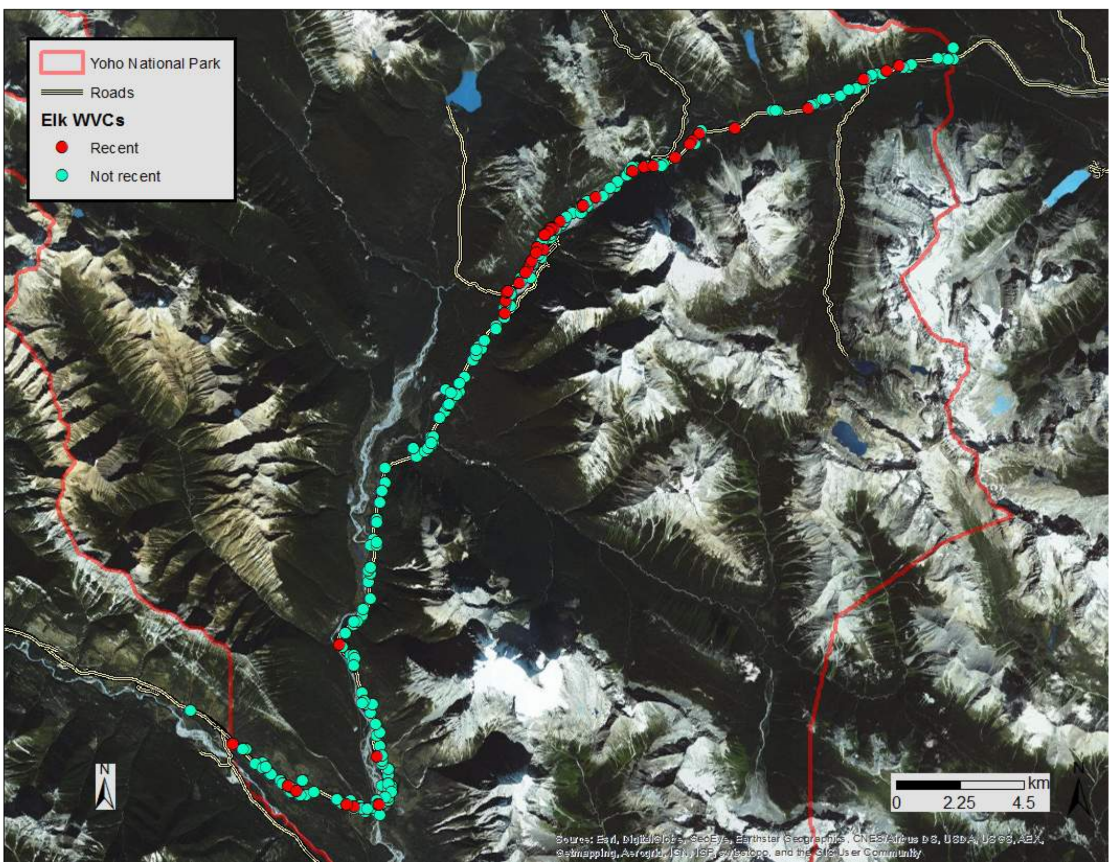


Figure 3.8: Road-caused mortalities and strikes of elk on the Trans-Canada Highway in Yoho National Park, British Columbia.

Felids

In Parks Canada's mortality database, we found 10 felid-vehicle collisions, including 3 cougars and 7 lynx. Felid mortalities occurred between 28 May 1998 and 18 September 2014. Felid mortalities occurred sporadically throughout the year (Figure 3.9). The locations of vehicle collisions with cougars occurred only between the west boundary of YNP and the Kicking Horse River Bridge near the confluence with the Beaverfoot River, whereas lynx mortalities were more evenly distributed on the TCH, including 1 at Kicking Horse Pass (Figure 3.10).

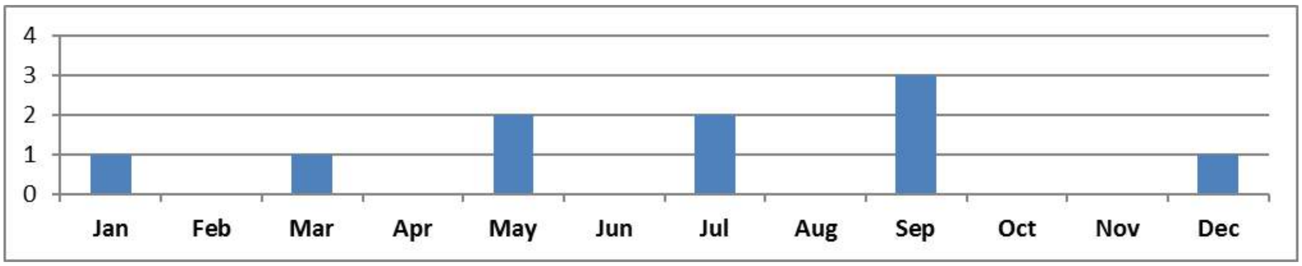


Figure 3.9: Road-caused felid mortalities and strikes by month along the Trans-Canada Highway in Yoho National Park, British Columbia.

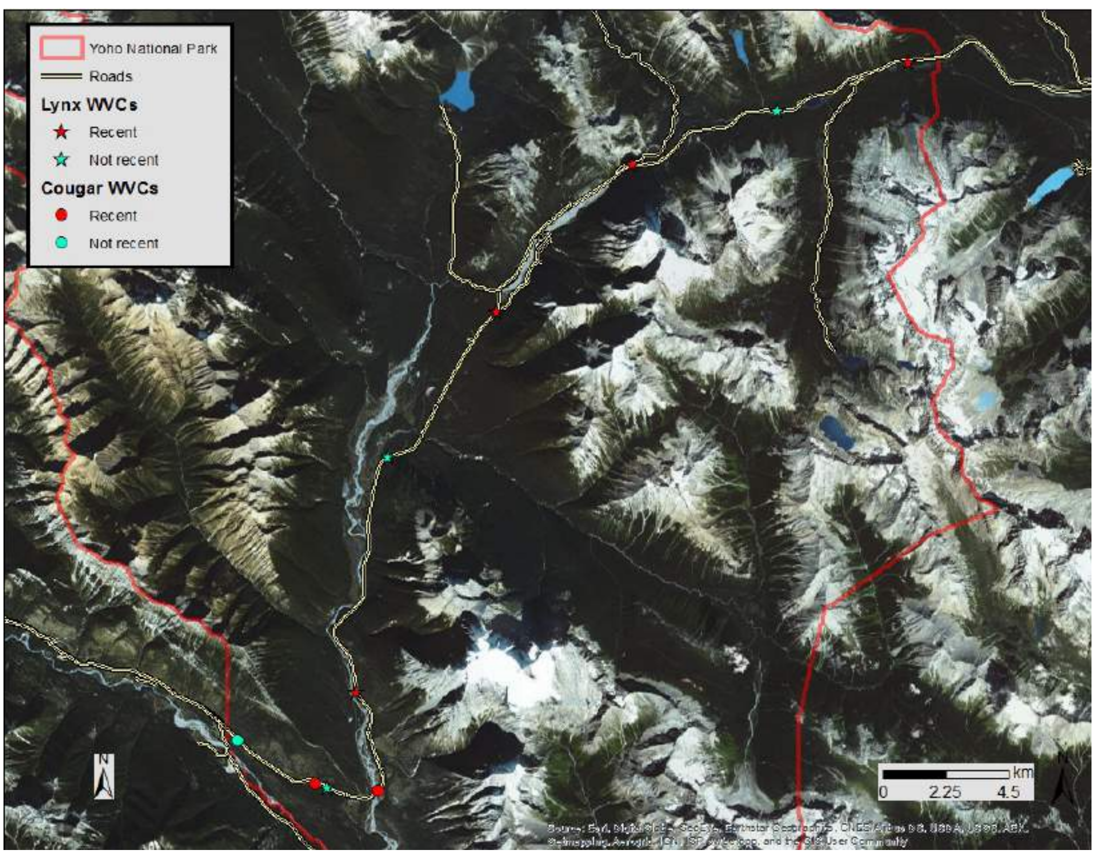


Figure 3.10: Road-caused mortalities and strikes of felids on the Trans-Canada Highway in Yoho National Park, British Columbia.

Moose

In Parks Canada's mortality database, we found 105 moose-vehicle collisions. Moose WVCs occurred between 17 July 1981 and 10 September 2016. Moose mortalities have been increasing since the 1990s, including 33 between 2010-2016. Mortalities were concentrated during summer and fall and winter, but occurred during every month (Figure 3.11). The locations of vehicle collisions with moose were clustered in two areas: 1) the Kicking Horse Pass and 2) west of the Field Flats to the west boundary of YNP (Figure 3.12).

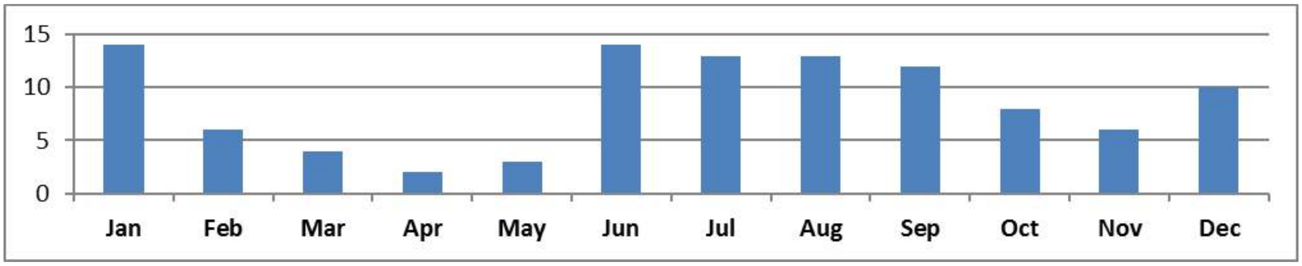


Figure 3.11: Road-caused moose mortalities and strikes by month along the Trans-Canada Highway in Yoho National Park, British Columbia.

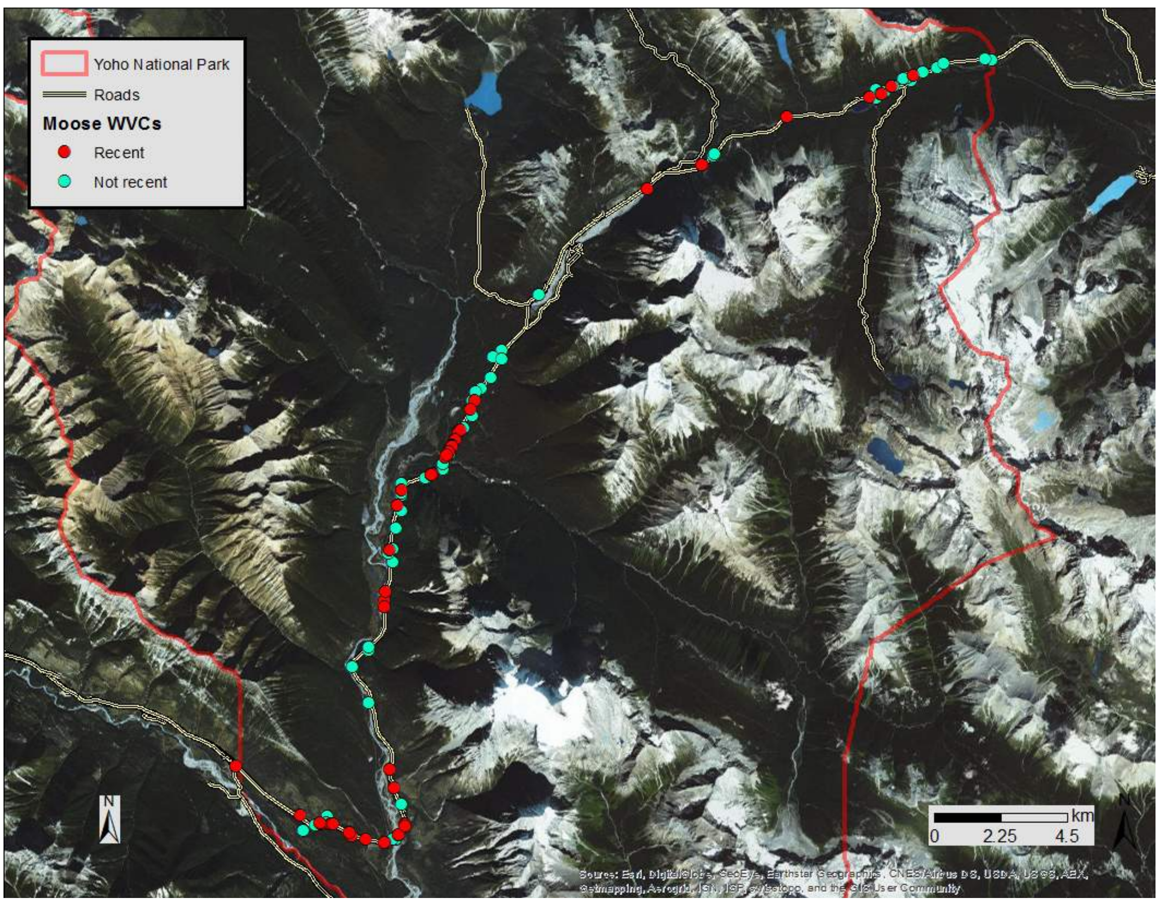


Figure 3.12: Road-caused mortalities and strikes of moose on the Trans-Canada Highway in Yoho National Park, British Columbia.

Mountain Goats

In Parks Canada's mortality database, we found 17 mountain goat vehicle collisions. Mountain goat WVCs occurred between 22 August 1982 and 27 June 2016. Mortalities were concentrated during late summer and early fall (Figure 3.13). The locations of vehicle collisions with mountain goats were highly clustered in the vicinity of two goat licks on the TCH between kilometer marker posts 85 to 86 and 89 to 90 (Figure 3.14).

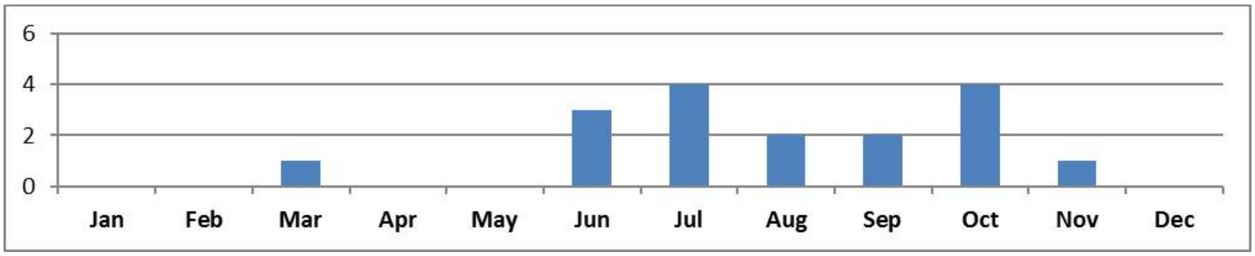


Figure 3.13: Road-caused mountain goat mortalities and strikes by month along the Trans-Canada Highway in Yoho National Park, British Columbia.

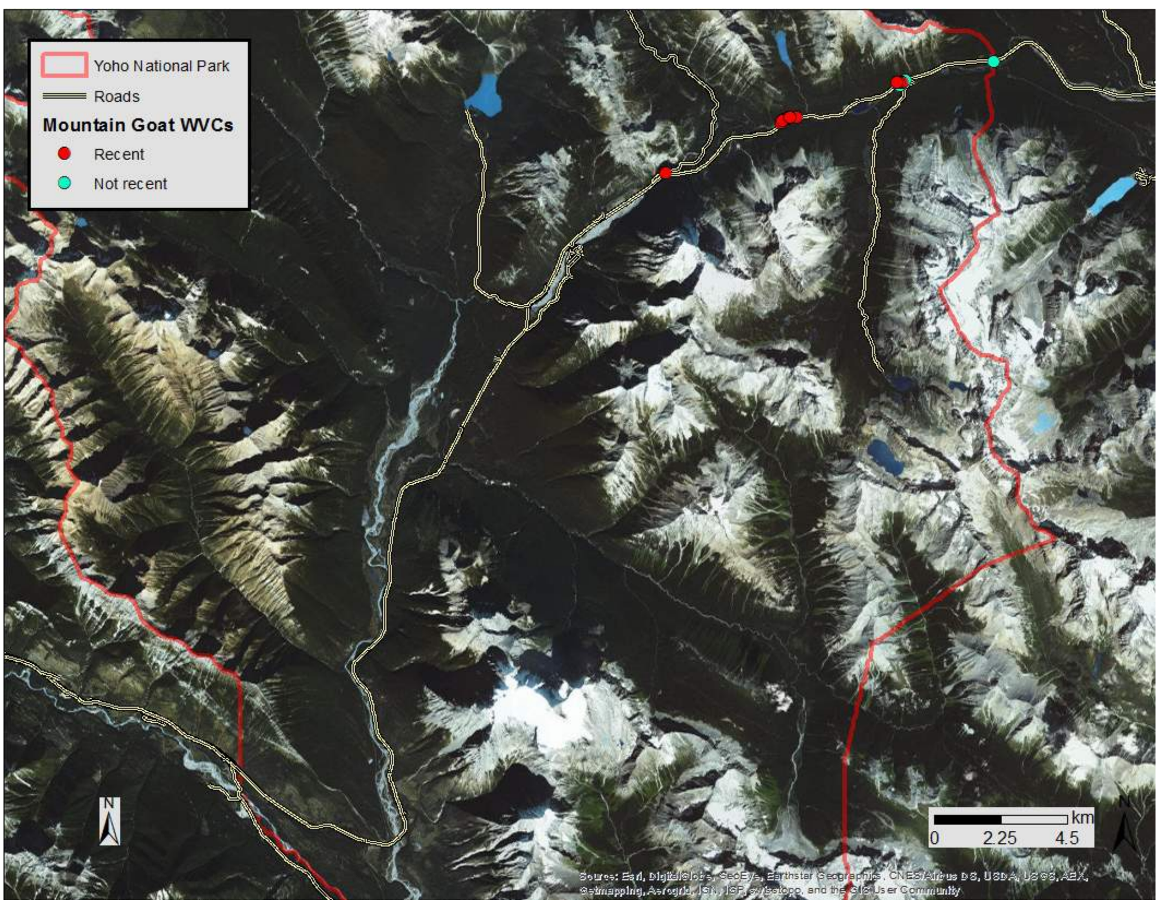


Figure 3.14: Road-caused mountain goat mortalities and strikes on the Trans-Canada Highway in Yoho National Park, British Columbia.

References

Bertch, B., M. Gibeau. 2010. Black bear mortalities in the Mountain National Parks: 1990-2009. Report prepared for Parks Canada Agency, Banff, Alberta.

Clevenger, A.P., Chruszcz, & Gunson, K. 2001. Drainage culverts as habitat linkages and factors affecting passage by mammals. Journal of Applied Ecology 38:1340-1349.

Clevenger, A.P., B. Chruszcz, K. Gunson 2003. Spatial patterns and factors influencing small vertebrate fauna road-kill aggregations. Biological Conservation 109:15-26.

Damas and Smith. 1982. Wildlife mortality in transportation corridors in Canada's National Parks. Report for Parks Canada. Volume 1, Main report, Ottawa, Ontario.

Gunson, K, A. Clevenger, A. Ford, J. Bissonette, A. Hardy. 2009. A comparison of data sets varying in spatial accuracy used to predict the occurrence of wildlife-vehicle collisions. Environmental Management 44:268-277.

4. Connectivity Modeling

Introduction

Connectivity models can be useful for identifying important habitat linkages and areas for highway mitigation. Previously, Geographic Information System (GIS)-generated habitat models have been used to determine the regionally important locations for wildlife crossing structures (Clevenger et al. 2002; Clevenger and Wierzchowski 2006). Recent attention has focused on the use of landscape resistance models to guide highway mitigation efforts (Landguth et al. 2012). These types of connectivity models that test the landscape by resistance hypothesis to gene flow (McRae 2006) may be particularly well-suited for identifying important crossing locations as they model large, landscape scale processes (i.e dispersal patterns).

We used 3 landscape resistance (i.e. connectivity) models, based off published models for black bears (Cushman et al. 2006, Landguth et al. 2012), grizzly bears (Graves et al. 2014, Proctor et al. 2015) and wolverines (Balkenhol 2009, Copeland et al. 2010, McKelvey et al. 2011, Inman 2013) and generalized here, to help identify key areas for highway mitigation in YNP. We did not specifically model ungulate movements, because we had insufficient location data to create reliable ungulate landscape resistance surfaces, but based on past experience we feel that our black bear model may be a good surrogate for ungulates movements. We used black bears to represent *general forest connectivity in low elevations* across the highway (Landguth et al. 2012) and used grizzly bears to represent connectivity at *middle elevations* and wolverines to represent connectivity at *high elevations*.

Our specific objective for least cost path (LCP) analysis was to use the generalized forest connectivity models for the 3 species to identify and prioritize important habitat linkages for wildlife across a range of elevational gradients by examining where LCPs cross the TCH in YNP.

Methods

For our connectivity models, we focused on black bears, grizzly bears, and wolverines, because they have extensive home ranges, need to cross roads frequently to access habitat patches, disperse long distances, and thus are ideal species for landscape resistance models (Cushman et al. 2006). Further, they may be suitable surrogates for other forest dwelling species (e.g., ungulates, lynx, wolves).

Study Area

We delineated a 28,618 km^2 study area for modeling landscape connectivity that encompassed all of Yoho, Kootenay and Banff National Parks (Figure 4.1). This extensive area was chosen so that Yoho would be roughly centered in the middle of the extent to allow each least cost path for all 3 carnivore species to gather strength before entering the focal area of interest for highway mitigation; this helps to prevent the issue of biased low strength LCPs on the edges of extent due to fewer possible connections.

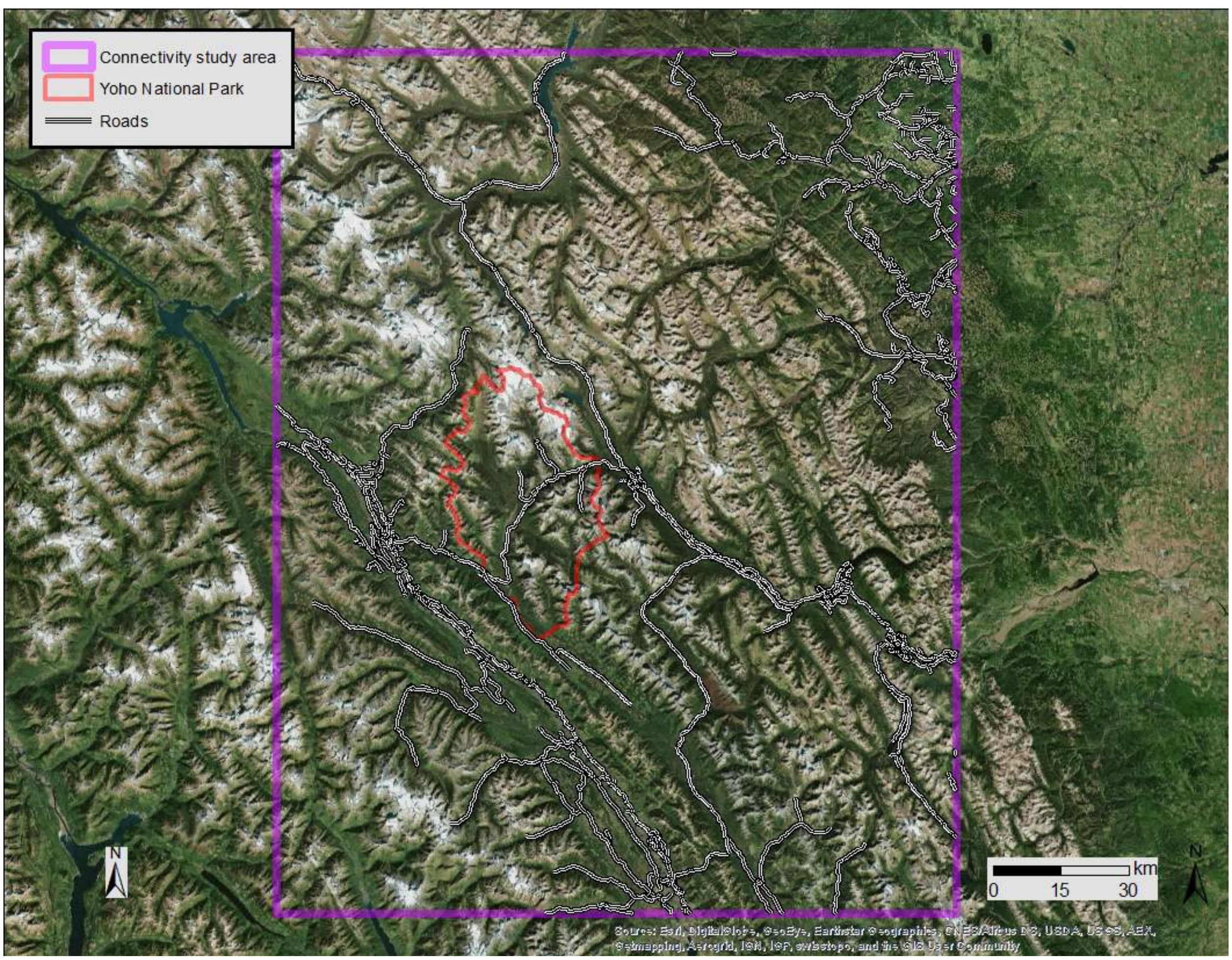


Figure 4.1: Our extensive study area for landscape connectivity modeling in Yoho National Park, British Columbia.

Landscape resistance models

We gathered *GIS data* based on published analyses to model resistance to movement for each of the 3 species. We built resistance models from the following landscape variables: elevation, forest cover, non-habitat (e.g., buildings, large water bodies), ruggedness, persistent snow, and protected status. Additionally, we modeled resistance to roads; however, we did not use the road variable in our final LCP analysis as including it did not change the main paths and limited the number of paths that crossed the TCH. Each of the GIS layers was reclassified to resistance values between 1-10 (1=low resistance, 10=high resistance). Reclassified raster layers were then combined together by summing the resistance values to get final landscape resistance surfaces. Details about GIS data layers, landscape resistance methods and results can be found in Supplemental Material l.

We used the following expert opinion models to build landscape resistance surfaces based on published analyses and generalized for comparability and to emphasize the elevational gradient across species:

Black Bears (low elevation)
Elevation + Forest Cover + Non-habitat + Protected Areas

Grizzly Bears (medium elevation)
Elevation + Forest Cover + Non-habitat + Protected Areas

Wolverines (high elevation)
Elevation + Forest Cover + Non-habitat + Protected Areas + Ruggedness + Persistent Snow

We converted each of the landscape data to a landscape resistance model following Cushman et al. (2006). We randomly placed 500 points in our extensive study area with a minimum distance of 2 km and selecting against non-habitat surfaces for bears and wolverines (Supplemental Material 1). Preliminary runs explored number of points and point placement with relatively little change in path convergence. LCP models identify the shortest path of least resistance from point A to point B. We used UNICOR (Landguth et al. 2012) to run LCPs between the 500 starting points and examined areas where the paths crossed the TCH.

In addition to our generalized models that used landscape variables gleaned from several studies, we wanted to compare our expert opinion based pathways to single published landscape resistance models from other study areas. For black bears, we used the Cushman et al. (2006) black bear resistance model in northern Idaho, which included minimum resistance to medium elevation, high resistance to non-forested areas and roads. For grizzly bears, we used the Graves et al. (2014) resistance model that included habitat type and road density. For wolverines, we used the Balkenhol (2009) resistance model (e. g., Dilkina et al. 2016). These models were highly congruent with our more generalized models; therefore we do not report the results here.

Results

Our landscape connectivity models were run over an area much larger than the TCH corridor in YNP as the real extents encompassed all of Yoho, Kootenay and Banff National Parks (Figures 4.2, 4.3, 4.4). As mentioned in Methods above, the large area was chosen so the TCH corridor study area would be centered, allowing the LCP for each carnivore species to gather strength before entering our area of interest for highway mitigation.

We identified several important cross-highway linkages and corridors using LCPs from UNICOR and these are shown in more detail in the following section (*Synthesis of WVCs and Connectivity Models*). As expected, many of the LCPs follow low-mid elevation gradients and contour with major watersheds. There was little difference between the LCPs under different hypotheses so we used the elevation and forest cover resistance removing road resistance to identify habitat linkages.

Four areas of importance to cross-highway movement emerged from this analysis:

1. Eastern edge of Yoho National Park and Kicking Horse Pass area
2. Confluence of Amiskwi River and Kicking Horse River.
3. Confluence of Ottertail River and Kicking Horse River.
4. Southern bend of the TCH that crosses the Kicking Horse River.

Our analysis highlighted Kicking Horse Pass and the Continental Divide area as a regionally important corridor for north-south movement for all three carnivore species.

Black bears

High strength LCPs for black bears were concentrated along the entire length of the valley bottom from Kicking Horse Pass to the confluence of the Kicking Horse and Beaverfoot Rivers. This pattern reflects the low elevation preference that we modeled for this species. Our analysis highlighted the Kicking Horse River and the confluences with its major tributaries as regionally important corridors for north-south movement for black bears.

The following areas of importance to cross-highway movement emerged for black bears:

1. Eastern edge of Yoho National Park and Kicking Horse Pass area
2. Confluence of Amiskwi River and Kicking Horse River.
3. Confluence of Ottertail River and Kicking Horse River.
4. Southern bend of the TCH that crosses the Kicking Horse River.

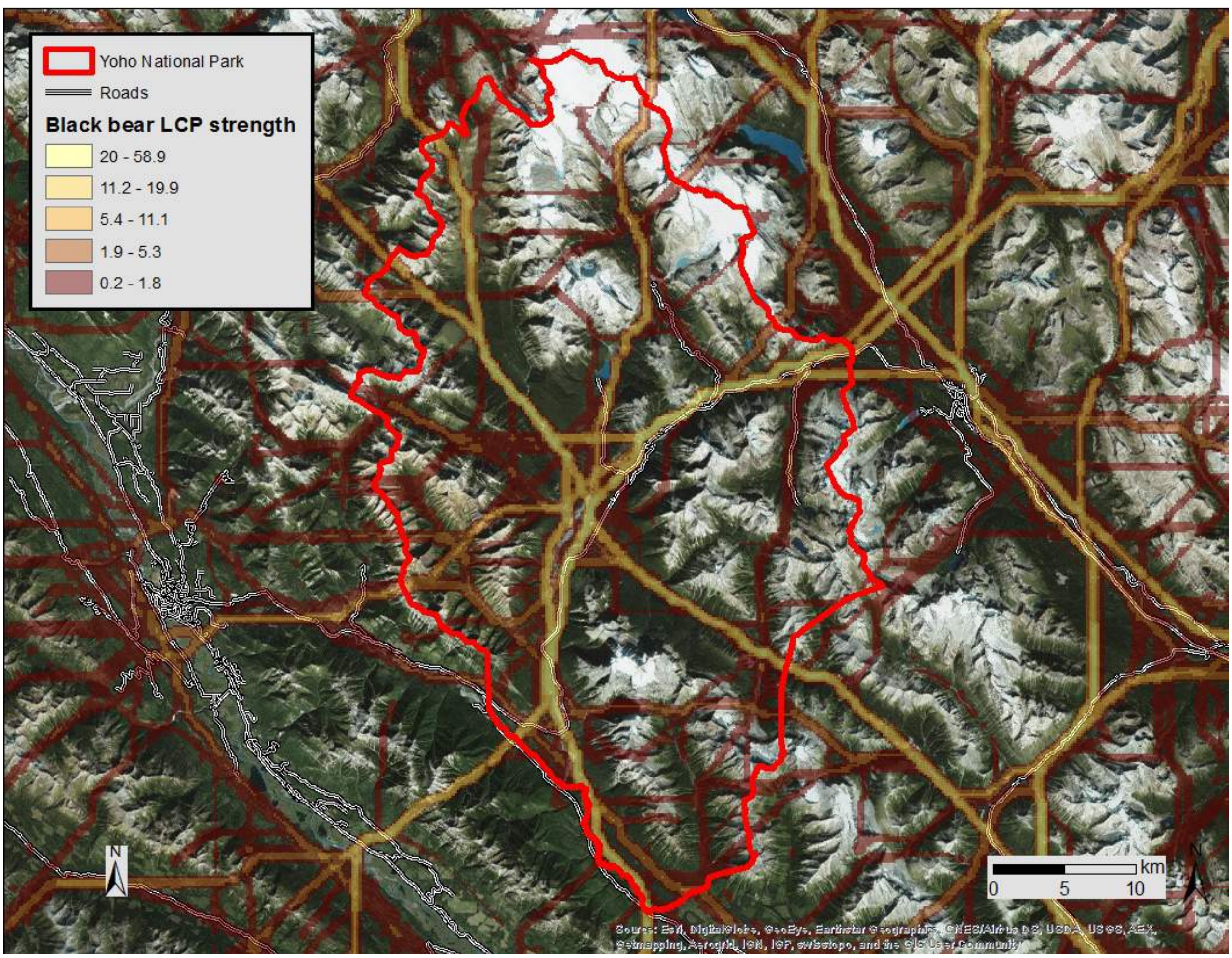


Figure 4.2: Least cost paths (LCP) for black bears in Yoho National Park, British Columbia.

Grizzly bears

High strength LCPs for grizzly bears were more restricted to upper elevations than black bears. This pattern reflects the mid elevation preference that we modeled for this species to reflect their tendency to avoid low elevations which are dominated by humans (Proctor et al. 2015). Our analysis highlighted the Kicking Horse Pass and the confluences of the Kicking Horse River with its major tributaries as regionally important corridors for north-south movement for grizzlies.

The following areas of importance to cross-highway movement emerged for grizzly bears:

1. Eastern edge of Yoho National Park and Kicking Horse Pass area
2. Confluence of Emerald River, Amiskwi River, and Kicking Horse River.
3. Area to the east of confluence of Ottertail River and Kicking Horse River.
4. Area to the west of confluence of Ottertail River and Kicking Horse River.

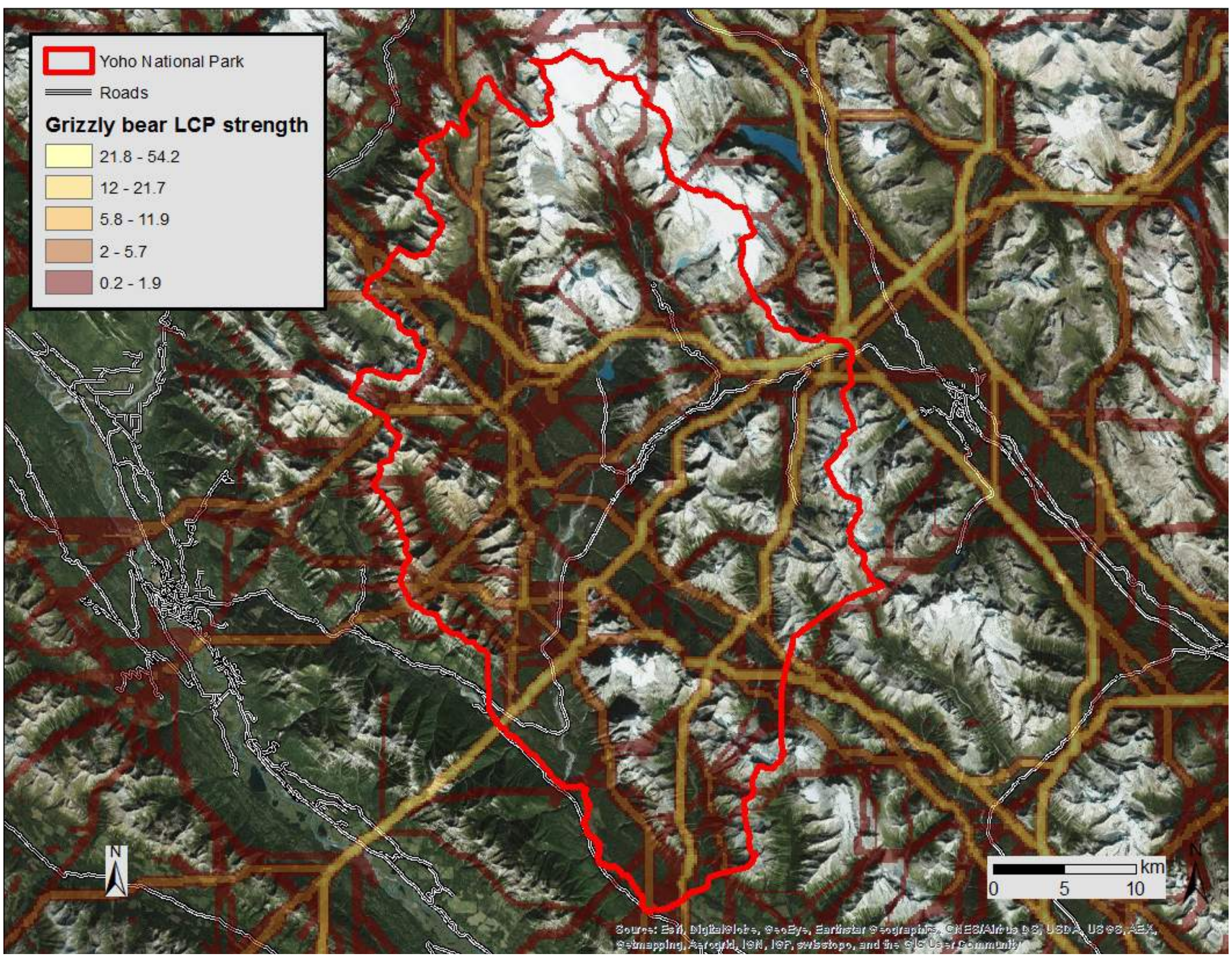


Figure 4.3: Least cost paths (LCP) for grizzly bears in Yoho National Park, British Columbia.

Wolverines

High strength wolverine LCPs were concentrated along valley bottoms and ridges. This pattern reflects the high elevation, snow, and ruggedness preferences that we modeled for this species. Our analysis highlighted the confluences of the Kicking Horse River with the Ottertail and Beaverfoot Rivers as regionally important corridors for north-south movement for wolverines.

The following areas of importance to cross-highway movement emerged for wolverines:

1. Eastern edge of Yoho National Park and Kicking Horse Pass area
2. Confluence of Amiskwi River and Kicking Horse River.
3. Confluence of Ottertail River and Kicking Horse River.
4. Southern bend of the TCH that crosses the Kicking Horse River.
5. Western edge of Yoho National Park.

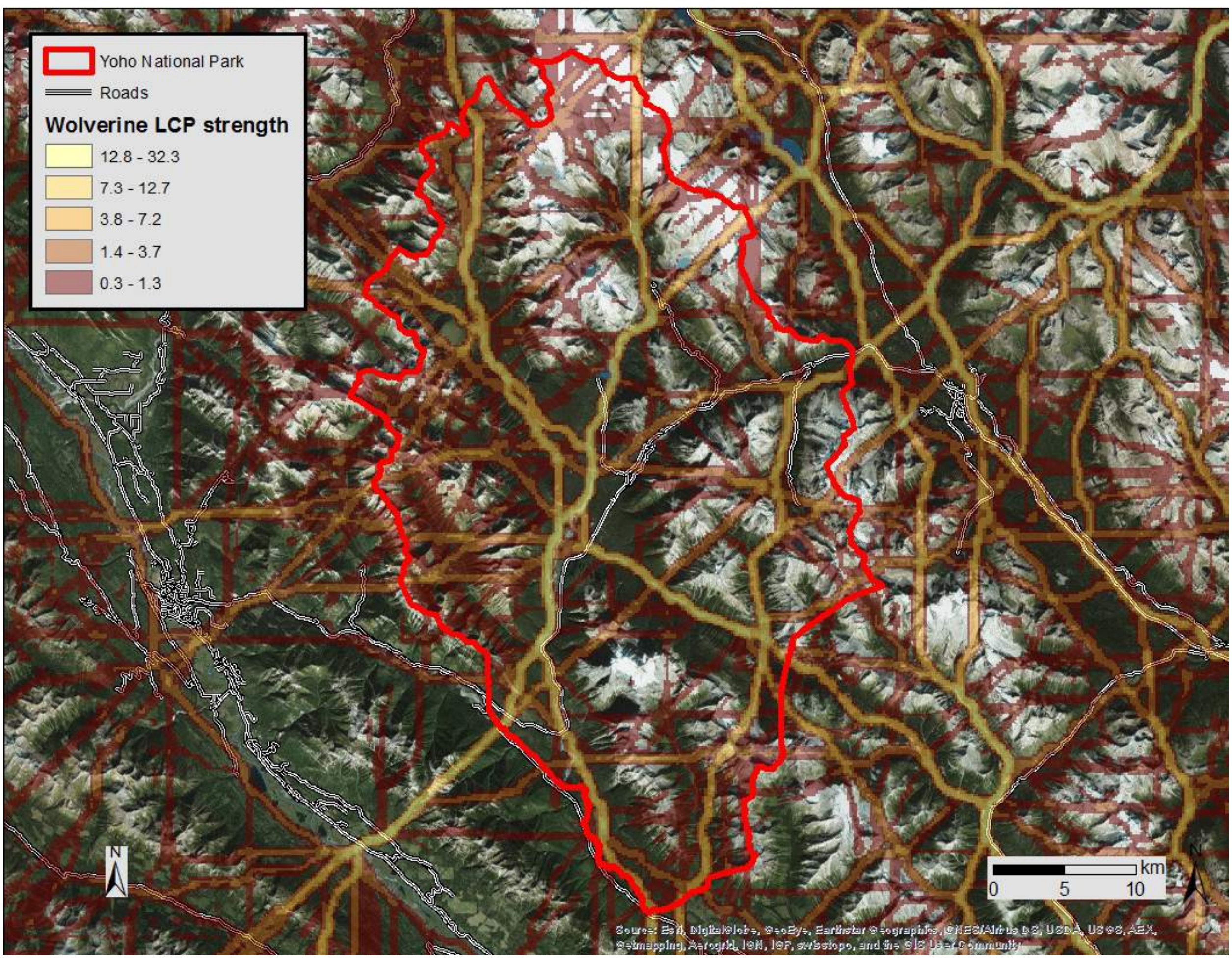


Figure 4.4: Least cost paths (LCP) for wolverines in Yoho National Park, British Columbia.

References

Balkenhol, N. 2009. Evaluating and improving analytical approaches in landscape genetics through simulations and wildlife case studies. Doctoral Thesis. University of Idaho, Moscow, ID

Clevenger, A.P, J. Wierzchowski. 2006. Maintaining and restoring connectivity in landscapes fragmented by roads. Pages 502-535. In *Connectivity Conservation* (Eds. K. Crooks, M. Sanjayan). Cambridge University Press.

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

Copeland, J.P., K.S. McKelvey, K.B. Aubry, A. Landa, J. Persson, R.M. Inman, J. Krebs, E. Lofroth, H. Golden, J.R. Squires, A. Magoun, M.K. Schwartz, J. Wilmot, C.L. Copeland, R.E. Yates, I. Kojola, and R. May. 2010. The bioclimatic envelope of the wolverine: do climatic constraints limit its geographic distribution? Canadian Journal of Zoology 88:233–246.

Cushman, S.A., K.S. McKelvey, J. Hayden, M.K. Schwartz. 2006. Gene flow in complex landscapes: testing multiple hypotheses with casual modeling. The American Naturalist, 168:486-499.

Dilkina, B., R. Houtman, C. Gomes, C. Montgomery K. McKelvey, K. Kendall, T. Graves, R. Bernstein, M. Schwartz. 2016. Trade-offs and efficiencies in optimal budget-constrained multispecies corridor networks. Conservation Biology doi:10.1111/cobi.12814.

Graves, T., R. Chandler, J.A. Royle, P. Beier, K. Kendall. 2014. Estimating landscape resistance to dispersal. Landscape Ecology 29:1201-1211.

Hansen, M. C., P. V. Potapov, R. Moore, M. Hancher, S. A. Turubanova, A. Tyukavina, D. Thau, S. V. Stehman, S. J. Goetz, T. R. Loveland, A. Kommareddy, A. Egorov, L. Chini, C. O. Justice, and J. R. G. Townshend. 2013. "High-Resolution Global Maps of 21st-Century Forest Cover Change." Science 342 (15 November): 850–53. Data available on-line from: http://earthenginepartners.appspot.com/science-2013-global-forest.

Inman, R.M. 2013. Wolverine ecology and conservation in the Western United States. Doctoral Thesis. Uppsala University, Uppsala, Sweden

Landguth, E.L., B.K. Hand, J. Glassy, S.A. Cushman, M.A. Sawaya. 2012. UNICOR: a species connectivity and corridor network simulator. Ecography 35: 9-14.

McKelvey, K.S., J.P. Copeland, M.K. Schwartz, J.S. Littell, K.B. Aubry, J.R. Squires, S.A. Parks, M.M. Elsner, and G.S. Mauger. 2011. Climate change predicted to shift wolverine distributions, connectivity, and dispersal corridors. Ecological Applications 21:2882-2897.

McRae, B.H. 2006. Isolation by resistance. Evolution 60:1551-1561.

Proctor, M.F., S.E. Nielsen, W.F. Kasworm, C. Servheen, T.G. Radandt, A. G. Machutchon, and M.S. Boyce. 2015. Grizzly bear connectivity mapping in the Canada-United States Trans-Border Region. Journal of Wildlife Management 79: 544-558.

Short Bull, R.A., S.A. Cushman, R. Mace, T. Chilton, K.C. Kendall, E.L. Landguth, M.K. Schwartz, K. McKelvey, F.A. Allendorf. 2011. Why replication is important in landscape genetics: American black bear in the Rocky Mountains. Molecular Ecology 20:1092-1107.

5. Synthesis of Wildlife-Vehicle Collisions (WVC) and Connectivity Models

Introduction

Connectivity models can be useful for identifying important wildlife corridors; however, like all models, they are gross oversimplifications of biological reality. Assigning values to landscape variables and ranking their relative importance to landscape scale movement is a somewhat subjective process. Thus, the most powerful inference from connectivity models based on expert opinion can be drawn when the results are congruent with different model types and with disparate data sources. Our objective was to compare landscape resistance-based, least cost paths to observational data and to WVC data to help identify and prioritize suitable locations for mitigating TCH impacts on connectivity.

Methods

We compared least cost paths for 3 species (i.e. black bears, grizzly bears, wolverines) from UNICOR with wildlife observations and WVC locations to determine areas of congruence for identifying areas for highway mitigation emphasis along the TCH in YNP. Least cost path analysis with UNICOR (Landguth et al. 2012, Clevenger et al. 2014) and WVC data collection and results were described previously (Sections 3 and 4, respectively). We queried the Parks Canada observations database to find all recorded observations for each species of interest (Figure 5.1). Lastly, we compared the overlap between our least cost paths, observations, and WVC data.

Results

We found a high degree of congruence between our three methods to determine crossing structure placement: landscape resistance-based least cost paths, Parks Canada's wildlife observations, and WVC data. As expected, our least cost paths overlapped with mortality hotspots, particularly in the Kicking Horse Pass region, which had a high density of cross-highway linkages and a large number of observations. Although we used very different UNICOR models on 3 species with different habitat preferences (black bears, grizzly bears, wolverines), our least cost paths with relatively high corridor strength were congruent with habitat linkages identified by the observational and road-kill data. Perhaps this is not so striking when the amount of rock and ice in the study area are considered as these areas are generally avoided by least cost paths, because they have little habitat value (i.e., high resistance) and connectivity models generally perform better when excluding habitat rather than predicting high quality habitat so congruence becomes more likely as there is less habitat available.

We found 11,783 wildlife observations in Parks Canada's observations database of which 10,270 had useable spatial location data (Figure 5.1). Observations were compiled for 154 wildlife species, including birds, reptiles, amphibians, small mammals, ungulates, and carnivores. Like the wildlife mortality data in the previous section the database is rich in terms of the taxonomic diversity and spatial representation in the TCH corridor and greater park area. Not surprising, however, the observations were primarily large mammals. Most ungulate observations found in the database were elk (N=3462), followed by mountain goats (N=1175) and then moose (N=605). The oldest wildlife observation in the database was recorded on 12 January 1981 and the most recent was on 24 November 2014.

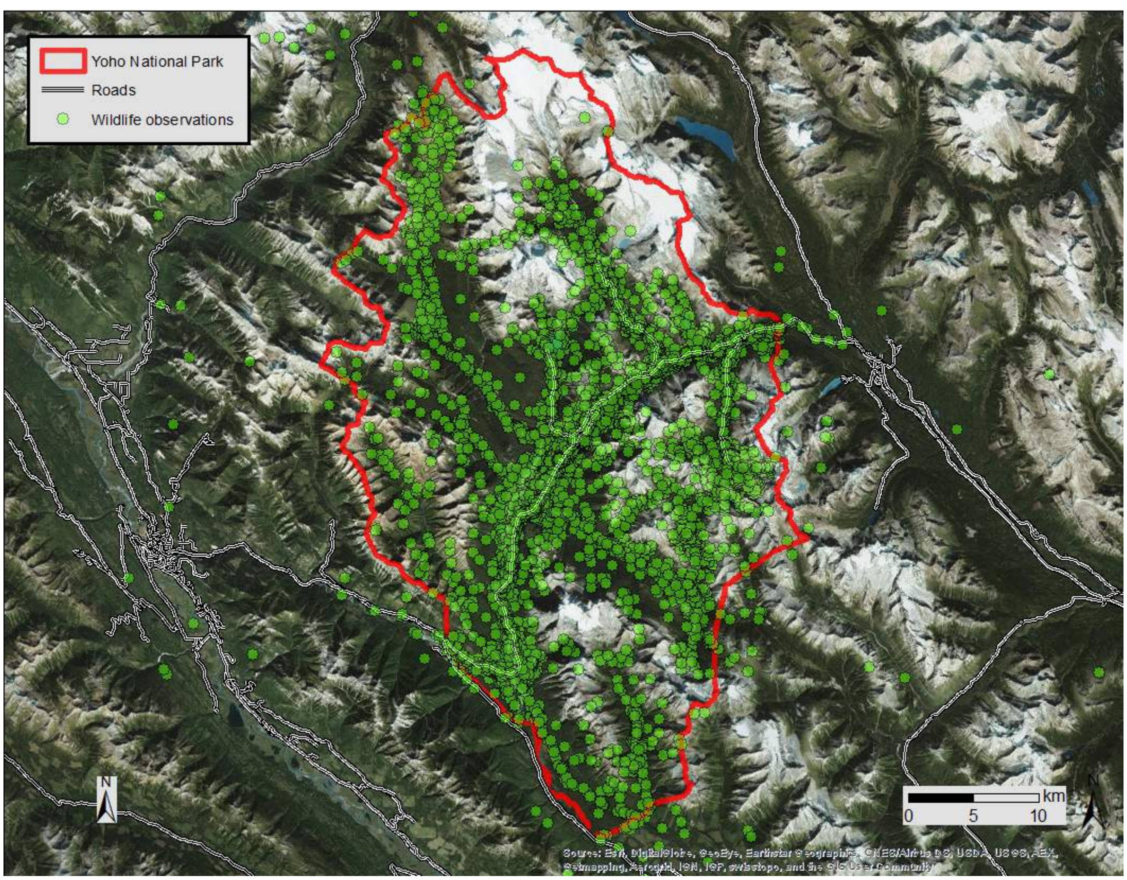


Figure 5.1: Locations of wildlife observations from Parks Canada's observations database in Banff and Yoho National Parks.

Black Bears

The stronger least cost paths for black bears, and Parks Canada's observational and road-kill data (Figure 5.2), affirm the importance of lower elevation valley bottoms and help to validate our model for regional black bear population connectivity. We found 1515 black bear locations in Parks Canada's observations database, ranging from 21 May 1981 to 7 August 2014. The highest strength least cost paths, WVCs, and the observations were all highly concentrated on the floor of the Kicking Horse Valley and well distributed along the entire TCH through YNP. Strong paths crossed the TCH near the confluence of the **Ottertail River and the Kicking Horse River and at the south bend of the TCH under the Kicking Horse River Bridge**. Most black bear observations that were recorded at low and high elevations were on or near a least cost path. Road mortality hot spots for black bears were also congruent with least cost path crossing locations of the TCH, lending further validation to our black bear population connectivity model.

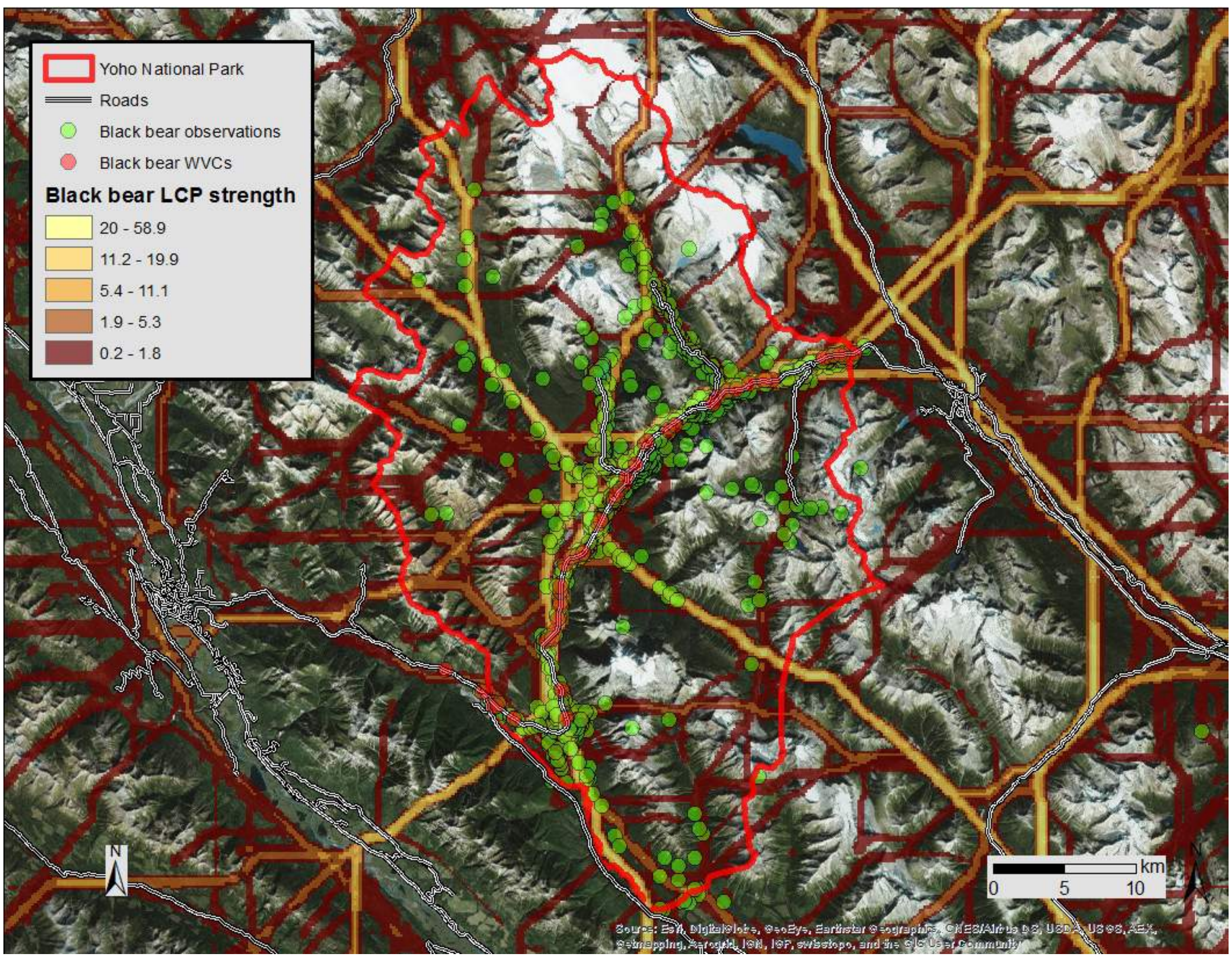


Figure 5.2: Comparison of UNICOR's least cost paths, observations, and wildlife-vehicle collision data for black bears in Yoho National Park, British Columbia.

Grizzly Bears

The stronger least cost paths for grizzly bears were consistent with Parks Canada's observational and WVC data (Figure 5.3), showing greater grizzly presence at higher elevations than black bears and helping to validate our model for regional grizzly population connectivity. We found 1408 grizzly bear locations in Parks Canada's observations database, ranging from 23 May 1981 to 21 September 2014. The highest strength paths and the observations were concentrated at mid elevations in the Kicking Horse Valley and near the west edge of Kicking Horse Pass. Strong paths crossed the TCH near the confluence of the **Ottertail River and the Kicking Horse River, near the confluence of the Amiskwi River, and at the south bend of the TCH under the Kicking Horse River Bridge**. One of the two grizzly mortalities occurred just west of the pass in an area with strong least cost paths, the other mortality occurred directly on a medium strength path, lending some validation, along with the observation data, to our grizzly connectivity model

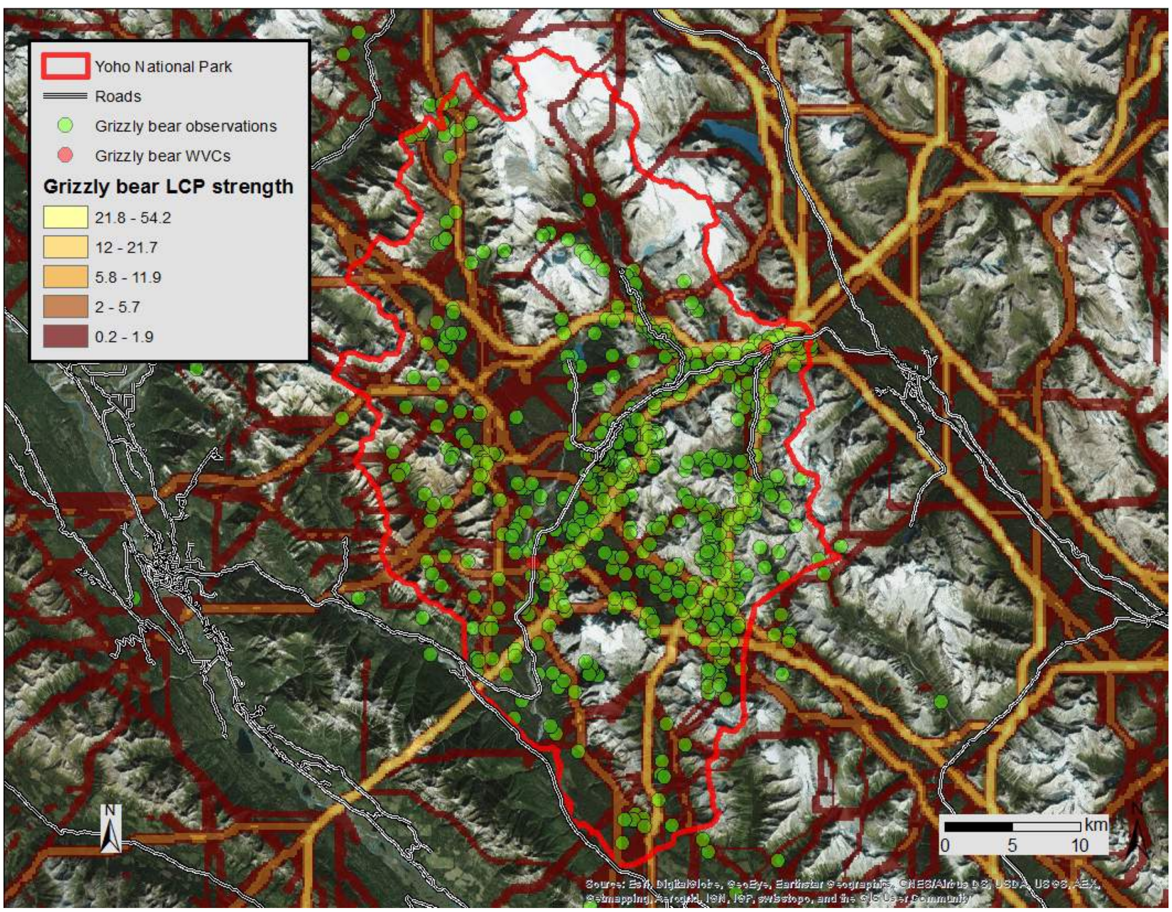


Figure 5.3: Comparison of UNICOR's least cost paths, observations, and wildlife-vehicle collision data for grizzly bears in Yoho National Park, British Columbia.

We examined 39,796 grizzly bear Global Positioning System (GPS) collar locations (Table 5.1) to identify key crossing areas for grizzlies and to further test our grizzly connectivity model. The GPS collar data spanned two time periods (2001-2004, 2012-2015) and included location data for 13 females (N=20,142) and 11 males (N=19,654).

Many of the female locations were clustered to the east, near Kicking Horse Pass and the Lake O’Hara road (Figure 5.4), further highlighting the importance of this area to local and regional grizzly bear movements. This area was also identified as important with our connectivity model and observational data, providing further evidence for the area’s importance to connectivity and additional validation of our grizzly bear connectivity model (Figure 5.3).

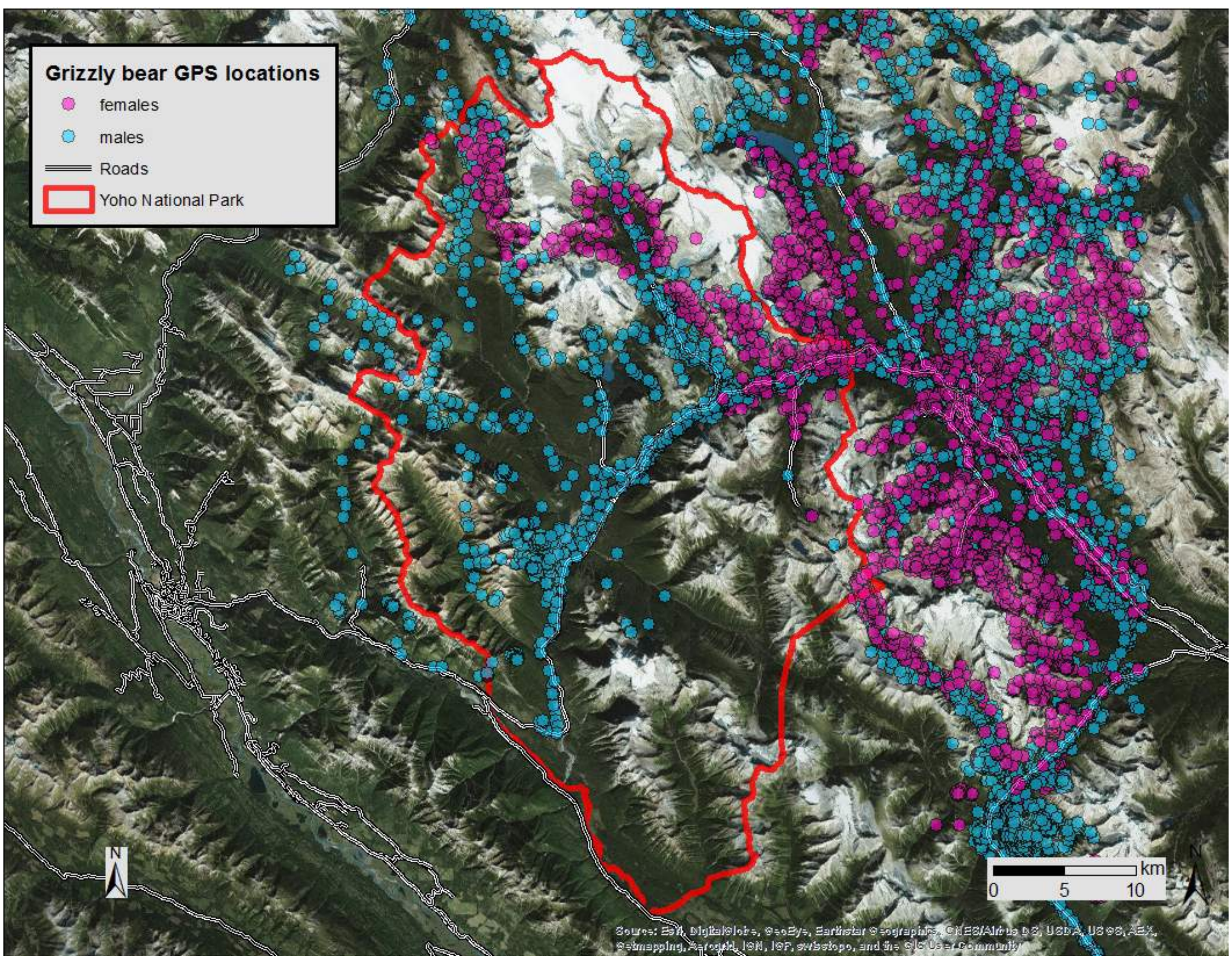


Figure 5.4: Grizzly bear Global Positioning System (GPS) collar locations from 2001 to 2015 near Kicking Horse Pass, British Columbia.

Wolverines

The stronger least cost paths for wolverines were consistent with Parks Canada's observational data (Figure 5.5), showing the importance of higher elevations (Kicking Horse Pass) and helping to validate our model for regional population connectivity. We found 149 wolverine locations in Parks Canada's database, ranging from 12 November 1981 to 7 October 2014. Most observations were clustered near Field town site and Lake O'Hara, areas with relatively large aggregations of high strength pathways. The strongest paths and lower elevation observations were **highly concentrated near the confluence of the Kicking Horse River and the Otterhead/Amiskwi Rivers. Moderately strong paths crossed the TCH at multiple sites west of the confluence of the Beaverfoot and Kicking Horse River.** Road mortality data for wolverines was nonexistent, but observations match up well with high strength paths, lending further validation to our wolverine population connectivity model.

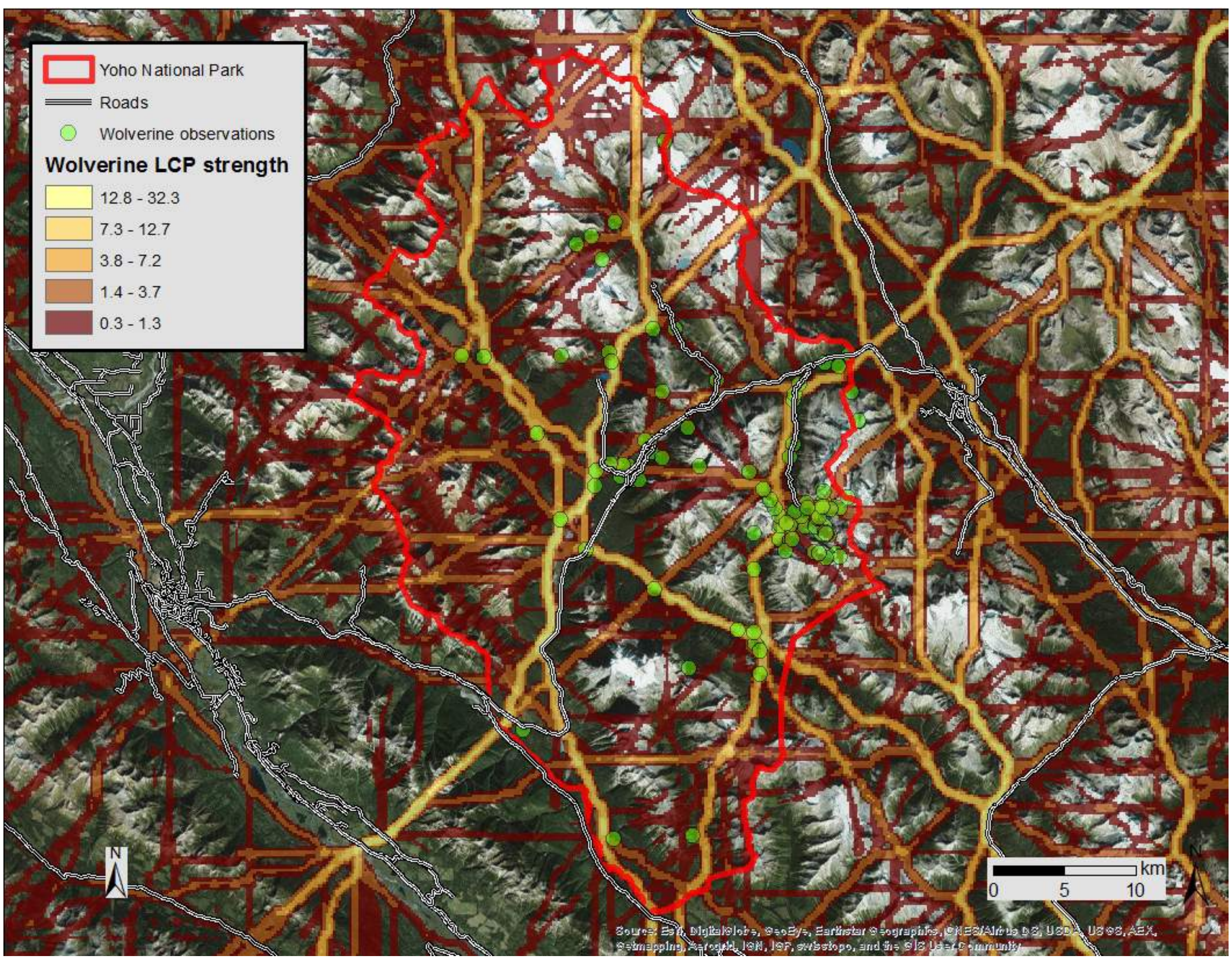


Figure 5.5: Comparison of UNICOR's least cost paths and observation data for wolverines in Yoho National Park, British Columbia.

References

Clevenger, A.P., M.A. Sawaya, E.L. Landguth, and B.P. Dorsey. 2014. Mitigating multi-species mortality and fragmentation on the Trans-Canada Highway through Mount Revelstoke and Glacier National Parks, British Columbia. Final report to Parks Canada Agency, Revelstoke, British Columbia.

Landguth, E.L., B.K. Hand, J. Glassy, S.A. Cushman, M.A. Sawaya. 2012. UNICOR: a species connectivity and corridor network simulator. Ecography 35:9-14.

McRae, B.H. 2006. Isolation by resistance. Evolution 60:1551-1561.

McRae, B.H., B.G. Dickson, T.H. Keitt, and V.B. Shaw. 2008. Using circuit theory to model connectivity in ecology, evolution, and conservation. Ecology 89:2712-2724.

6. Mountain Goat Connectivity

Background

The expansion of Trans-Canada Highway (TCH) in Yoho National Park (YNP) enters subalpine habitats at the spine of the Continental Divide. This cosystem is important for a variety of high-elevation, localized species (HELS; Clevenger et al. 2009). Recent research in Banff and YNP has underscored the importance of the Continental Divide for wolverine movements, gene flow and population connectivity (Sawaya and Clevenger 2014). The Divide is also recognized as an important juncture of major drainages and ridge systems (Bath, Yoho, Cataract, Bow, Kicking Horse) that promote regional-scale movements of grizzly bears, lynx, wolverine and mountain goats.

The TCH has been in place since the 1950s and the CP railway since the late 1800s. It plausible that these two transportation corridors have had some effect on movement and gene flow of HELS, including mountain goats. Observation data for mountain goats in Banff, Kootenay and Yoho National Parks from 1978 to 2016 revealed three clusters with elevated numbers of observations (Figure 6.1). In YNP and along the TCH corridor there was a relatively high cluster centered around km 85-86, within Phase 4A. In Phase 4B, a moderately large cluster occurred around km 89-90, with a localized cluster nearby at km 91, and a small cluster occurred at km 94.

The proposed twinning and fenced TCH could potentially limit movements and interchange of mountain goats north and south of the highway. If the TCH were a barrier to movements it would fragment population into peripheral subpopulations, which might disproportionately lose genetic diversity (Shafer et al. 2011). For these reasons it will be of paramount importance to ensure the best data, science and methods are used to identify areas for mitigating the TCH throughout YNP.

Mountain goats have been documented crossing major highways (see Poole 2012), which are also a source of mortality (Singer 1978, Clevenger et al. 2015). Along the TCH in Banff National Park over 40 crossing structures have been constructed. More than 150,000 crossing of large mammals were detected between 1996 and 2014 (Clevenger and Barrueto 2014). However, during the 17 years there were no mountain goats detected using the crossings, despite populations at high elevations on opposite sides of the TCH (Clevenger and Barrueto 2014). Camera monitoring of the structures was not used at all the sites since they were established, so detections of mountain goat passage by track monitoring may have been confounded by deer or sheep tracks. Mountain goats were not detected during three years of camera monitoring using two wildlife overpasses built on the TCH in the Kicking Horse Canyon, British Columbia (Sharpe 2013).

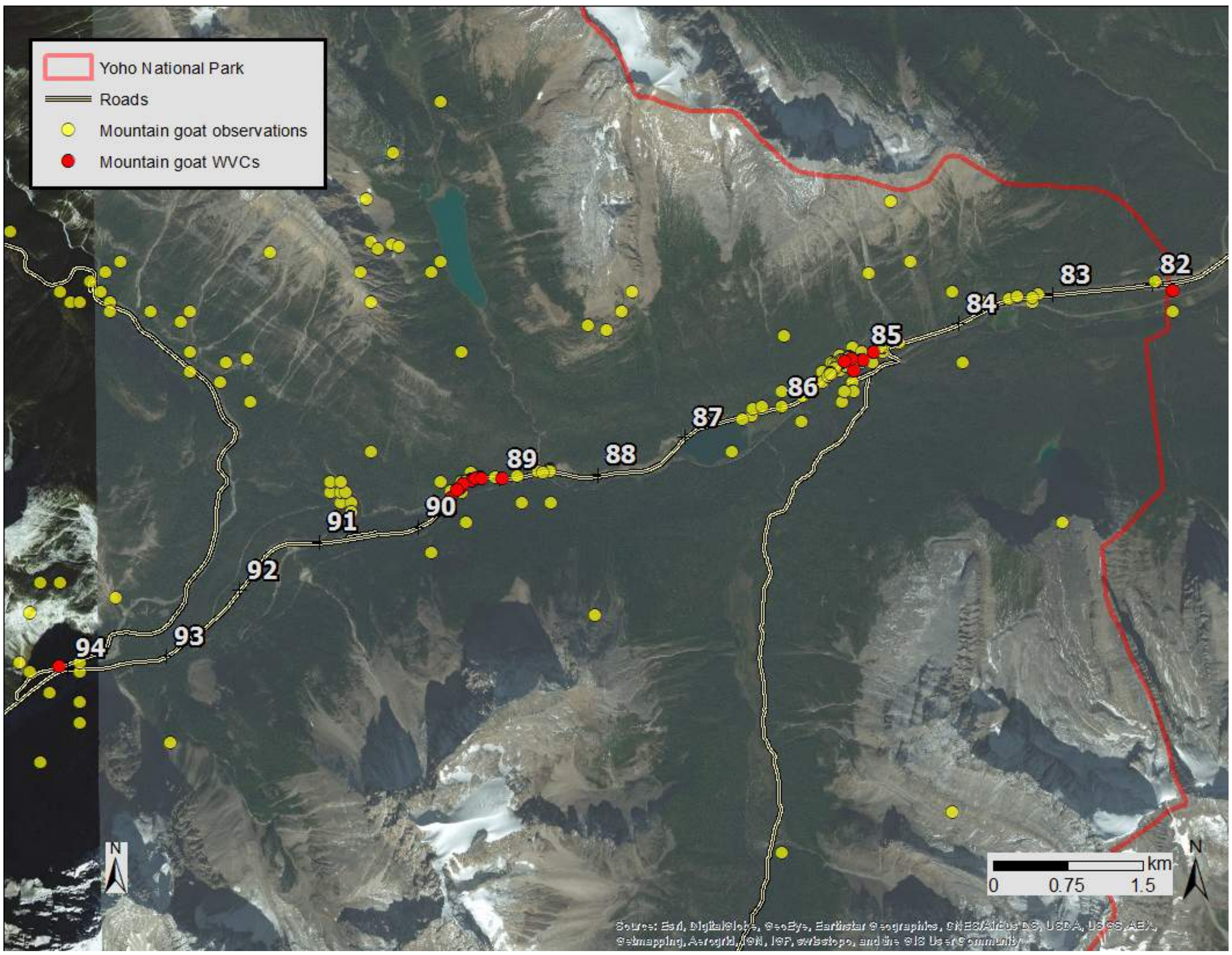


Figure 6.1: Mountain goat observations and road-related mortality on the Trans-Canada Highway in the eastern section of Yoho National Park, British Columbia. Phase 4B begins at km 88.0

The only documented passage by mountain goats at wildlife crossings was recorded in Glacier National Park, Montana (Singer and Doherty 1985, Pedevillano and Wright 1987).

Objectives

YNP has a large amount of data well suited for analysis and identification of key locations for mitigating mountain goat mortality and improving connectivity among populations across the TCH. In recent years Parks Canada has obtained an independent evaluation of potential crossing structures for mountain goats in YNP (Poole 2012) and begun camera monitoring mountain goat activity at salt licks and game trails near the TCH (Nicholl unpublished report, Flagg 2015). We review the abovementioned studies, discuss their main findings and implications for the YNP twinning project.

Technical Reports

Poole 2012 – Evaluation of potential crossing structures for mountain goats in Yoho National Park

In this report, Poole examined the feasibility of and provided advice for designing wildlife crossing structures for mountain goats across the TCH in eastern YNP. The assessment was restricted to the eastern 12 km of the YNP. He reviewed the literature, contacted other biologists familiar with mountain goat ecology and behaviour, crossing structures, and genetics, and utilized knowledge he has gained from more than 15 years of experience on mountain goats within British Columbia. He also conducted a site visit with Parks Canada staff.

After a literature review of mountain goat movement and genetic linkages, use of wildlife crossing structures, highway crossings, and highway mortality, the conclusions were the following:

1. Encouraging or facilitating at least some movement of mountain goats between north and south sides of the TCH in the eastern portion of YNP is desirable from a conservation biology and genetics point of view (by minimizing loss of genetic diversity and reducing risk of local extinction). This also would help fulfill the objectives of the YNP management plan (Parks Canada 2010).

2. Poole encouraged that field mapping of mountain goat trails, sign and high use areas on both sides of the TCH adjacent to, at that time, the three potential crossing areas should be conducted to help identify the most suitable locations for crossing structures by possibly identifying traditional movement corridors. The following reports summarized below (Nicholls and Flagg) were prepared in response to this recommendation.
3. Regarding which crossing structure type (underpass, overpass) will better facilitate mountain goat movement, Poole was unable to conclude or recommend due to the lack of any information on structures mountain goats have used. Goats are adapted to open terrain and likely rely on sight as one of their first lines of defense from predators, much like other ungulates. They commonly use forested habitats for travel to low elevation licks also. He recommended locating overpasses at the Bosworth and Ogden sites and ensuring that goats can move under the Kicking Horse Bridge at the bottom of the Field Hill.

   a. *Bosworth*: The lick has a high number of sightings each year and evidence of use. It is the most commonly used of the 3 sites listed above.
   b. O*gden*: Evidence of use, but also appears to be associated with more road-related mortality. The only sites that might be capable of underpass construction are Monarch Creek and approximately 200 m east of the old CPR bridge.
   c. *Base of Field Hill*: An existing underpass is present under the highway bridge along slopes between the interior abutments and the base of the highway; larger on the west side of the bridge. Approach to this highway bridge from either direction along the river is fairly open. Mountain goat use at the time of Poole's report was undocumented. The bridge was monitored as part of a report summarized below.

Although Poole was unable to provide any clear recommendations for crossing structure type or design, there are several key lessons learned from the only experience with mountain goat use of wildlife underpasses, Glacier National Park, Montana. **This information should be taken into consideration during mitigation planning in YNP:**

1. Use of the two underpasses in GNP was equal despite one having less cover and being

one-half the dimension of the other.

2. Steeper, open access routes to the underpasses were preferred.
3. Crossing structures should be located on traditional crossing routes, where possible.
4. Learning (of use of crossing structures) and tolerance (of human disturbance) will occur if interactions are not negative.

Nicholl (no date). – LLYK Highway Mitigation Monitoring Project

The objective of this work was to establish remote cameras at key locations to gain information regarding monthly and daily species distributions and possibly highway crossing locations. Cameras were placed in Yoho and Kootenay National Park. We will on review results from sites in YNP that were within or close proximity to the TCH corridor.

1. The *Kicking Horse crossing bridge* site is located at the base of Field Hill in YNP on the TCH approximately 4.5 km east of Field at an elevation of 1270 m. The bridge has enough space on either bank for animals to cross the road beneath the bridge and game trails have been found in the area. This site was chosen because mountain goats have been seen on both mountains and it is uncertain whether these two populations are genetically isolated (A. Dibb, LLYK Field Unit, personal communication). In addition, understanding whether various wildlife species use the bridge to cross the road or not would be important in determining whether the bridge is already an adequate crossing structure.
2. The *Amiskwi lick* site is located in YNP approximately 2 km from the TCH and 800 m on the Kicking Horse fire road. The site was chosen because it is a known and commonly used animal lick and is located in a major wildlife corridor where the Beaverfoot, Amiskwi and Ottertail valleys converge. Looking at the animals that use the lick may be indicative of the distribution of animals in the region and informative of which types of crossing structures would provide adequate mitigation.
3. The *Leanchoil site* is located in YNP approximately 650 m from the TCH and 1.25 km on the Ice River fire road from its starting point at the Hoodoos campground. The site was chosen because it is the southern extent in YNP of the same wildlife corridor as in site 2. Animals moving from YNP into the Beaverfoot Valley must cross the TCH at some point

in this area due to its trajectory.

Results

No mountain goats were captured on any of the cameras. Mountain goats are known to remain in a fairly small horizontal range but migrate vertically between seasons.

1. *Kicking Horse River (base of Field Hill) bridge*. No large animals were recorded on the camera although there was evidence of ungulate activity on the southeast side of the highway. A substantial game trail and many tracks were seen in the vicinity as well as some old, unidentified ungulate scat.
2. The *Amiskwi Lick site* was dominated by white-tailed deer, followed by black bears, moose and mule deer.
3. The *Leanchoil site* was visited by diverse wildlife species and is also a well-used hiking trail. The majority of wildlife photographs were wolves, red foxes and elk, followed by cougars, grizzly bear, black bear and white-tailed deer.

Flagg 2015 – Seasonal and diurnal use of mineral licks by mountain goats on Mount Bosworth in Yoho National Park and Mount Wardle in Kootenay National Park

Remote cameras were stationed on game trails leading to mineral licks used by mountain goats. The mineral licks are located at the base of Mt. Bosworth in YNP. The purpose of this work was to provide information that can help Parks Canada managers mitigate the impacts future infrastructure projects may have on the mountain goat populations that use Mt. Bosworth mineral lick. Results from this work were believed to help inform Parks Canada-specific management decisions regarding mitigating risks to the mountain goat populations in YNP.

The south aspect of Mt. Bosworth overlooks the TCH. Two remote cameras referred to as 'Bosworth Bluff East' and 'Bosworth West Lick2' were set up to collect data. The cameras were located on game trails leading to dry mineral licks known to be used by mountain goats below Mt. Bosworth.

Results

The camera data revealed distinct seasonal use of the mineral licks by mountain goats on Mt. Bosworth. Previous studies suggested the use of mineral licks by mountain goats typically peaks in June and July (Ayotte, Parker & Gillingham, 2008; Hebert & Cowan, 1971; Poole, Bachmann & Teske, 2010; Rice, 2010, Singer, 1978). While the findings of Flagg's report support the general understanding of increased mineral lick use in the summer months, the second seasonal wave of mineral lick use in October and November observed at the Bosworth Bluff East and Bosworth West Lick2 cameras sites has not been documented in mountain goat studies.

Flagg found that all mineral lick usage occurred consistently in the four years of monitoring (2011-2014). This work revealed distinct diurnal use of the mineral licks by mountain goats on Mt. Bosworth. The mountain goats using the Mt. Bosworth mineral licks in YNP used the licks during nighttime hours. The nighttime use by mountain goats might indicate that higher traffic volumes may discourage mountain goats from using the mineral licks during daytime hours. However, Flagg suggested the nighttime use of mineral licks by Mt. Bosworth mountain goats might be influenced by other unknown variables.

Implications for YNP Twinning

Poole provided a thorough literature review on the subject of mitigating highways for mountain goats, however, the review did not provide any solid empirical information on how or where best apply mitigation measures. Nicholls report covered camera sites that were few in number (n=3) and well off the TCH, but within the TCH corridor. Given the rarity of mountain goat movements across valley bottoms and the sample size of 3 it would be difficult to detect goat movements at these sites. She included the Kicking Horse River Bridge (base of Field Hill), an area which we detected elk tracks on the TCH right-of-way during our 12 October 2016, field inspection of the Mitigation Emphasis Sites. Flagg focused exclusively on mineral licks in the Mt. Bosworth area and timing of goat activity (seasonal, daily). This provides little data to inform the location of crossing structures for mountain goats along TCH in YNP, particularly due to fact that Mt Bosworth is within Phase 4A, currently in construction. There is a mineral lick regularly used by mountain goats approximately 2 km up the Ottertail trail (from TCH), which has only recently been monitored by cameras.

Summary

1. Little is known, if anything, regarding how to determine placement and design effective crossing structures for mountain goats. Regarding placement, the basic principles of wildlife crossing structure planning and placement should be used, i.e., placement should be in areas of identified corridors, areas with the greatest likelihood of movement and regional connectivity.
2. Mountain goats reside in the TCH corridor within YNP (Clevenger et al. 2009, HELS database, Bow Valley Naturalist, Banff, Alberta). Therefore a mitigation strategy that ensures regional scale connectivity should be used in TCH expansion and mitigation planning. One noteworthy observation of a mountain goat in close proximity to the TCH occurred in 2009, when one was observed above the TCH at the exact location of the soon to be constructed Lake Louise wildlife overpass.
3. Wildlife crossing recommendations should follow that outlined by Poole. Crossing should have the following attributes:
    a. Large in size
    b. Open with good visibility (wide, high clearance)
    c. Located on level ground including approach areas
    d. In areas with minimal human disturbance
4. This is a unique opportunity to learn about crossing design selection of mountain goats. A range of wildlife crossing design types will be constructed in areas in close proximity to mountain goat habitat. Similar to newly constructed crossings for wolverines and lynx on Phase 3B of the TCH in Banff (Clevenger and Barrueto 2014), this presents an excellent opportunity in North America to learn about use and potential crossing structure selection by monitoring in the future.

References

Ayotte, J. B., Parker, K. L., & Gillingham, M. P. 2008. Use of natural licks by four species of ungulates in Northern British Columbia. Journal of Mammalogy. 89:1041–1050.

Clevenger, A.P., M. Barrueto. 2014. Trans-Canada Highway wildlife and monitoring research, final report. Part B: Research. Report to Parks Canada Agency, Radium Hot Springs, British Columbia, Canada.

Clevenger, A.P., A.T. Ford, M.A. Sawaya. 2009. Banff wildlife crossings project : Integrating science and education in restoring population connectivity across transportation corridors. Final report to Parks Canada Agency, Radium Hot Springs, British Columbia, Canada. 165 pp.

Flagg, H. 2015. Seasonal and diurnal use of mineral licks by mountain goats on Mount Bosworth in Yoho National Park and Mount Wardle in Kootenay National Park. Report to Lake Louise, Yoho Kootenay Field Unit.

Hebert, D., I.M. Cowan. 1971. Natural salt licks as a part of the ecology of the mountain goat. Canadian Journal of Zoology, 49 (5), 605-610.

Nicholl, S. (no date). LLYK Highway Mitigation Monitoring Project. Report to Lake Louise, Yoho Kootenay (LLYK) Field Unit.

Parks Canada. 2010. Yoho National Park management plan. Ministry of Canadian Heritage, Ottawa, Ontario.

Pedevillano,C., R.G.Wright. 1987.The influence of visitors on mountain goat activities in Glacier Nation Park. Biological Conservation 39:1-11.

Poole, K.G. 2012. Evaluation of potential crossing structures for mountain goats in Yoho National Park

Poole, K. G., K. Bachmann, I. Teske. 2010. Mineral lick use by GPS radio-collared mountain goats in Southeastern British Columbia. Western North American Naturalist, 70 (2), 208-217.

Poole, K.G., D. Reynolds, G. Mowat, D. Paetkau. 2011. Estimating mountain goat abundance using DNA from fecal pellets. Journal of Wildlife Management 75:1527-1534.

Rice, C. G. 2010. Mineral lick visitation by mountain goats, *Oreamnos americanus*. Canadian Field- Naturalist. 124(3): 225–237.

Shafer ABA, Côté SD, Coltman DW. 2011. Hot spots of genetic diversity descended from multiple Pleistocene refugia in an alpine ungulate. Evolution 65:125–138.

Sharpe S. 2013. Kicking Horse Pass wildlife survey and remote camera interim report 2011-2013 for MoTI. Report to BC Ministry of Transportation, Kamloops BC.

Singer, F.J. 1978. Behavior of mountain goats in relation to US Highway 2, Glacier National Park, Montana. Journal of Wildlife Management 42:591-597.

Singer, F.J. and J.L. Doherty. 1985: Managing mountain goats at a highway crossing. Wildlife Society Bulletin 13:469-477.

7. Recommendations

Identification of Mitigation Emphasis Sites

Our comparison of mortality sites and movement models of large mammals in the Trans-Canada Highway (TCH) corridor identified 26 sites that we deemed suitable for mitigation measures (hereafter, mitigation emphasis sites; Figure 7.1). MES are specific locations within the YNP study area where opportunities for reducing wildlife–vehicle collisions and improving connectivity for all wildlife are highest, including fragmentation-sensitive species (Figure 7.1). Focusing highway mitigation efforts on these 26 MES should improve motorist safety, reduce wildlife mortalities and improve habitat linkages and animal movement through transitional habitat along these highway segments.

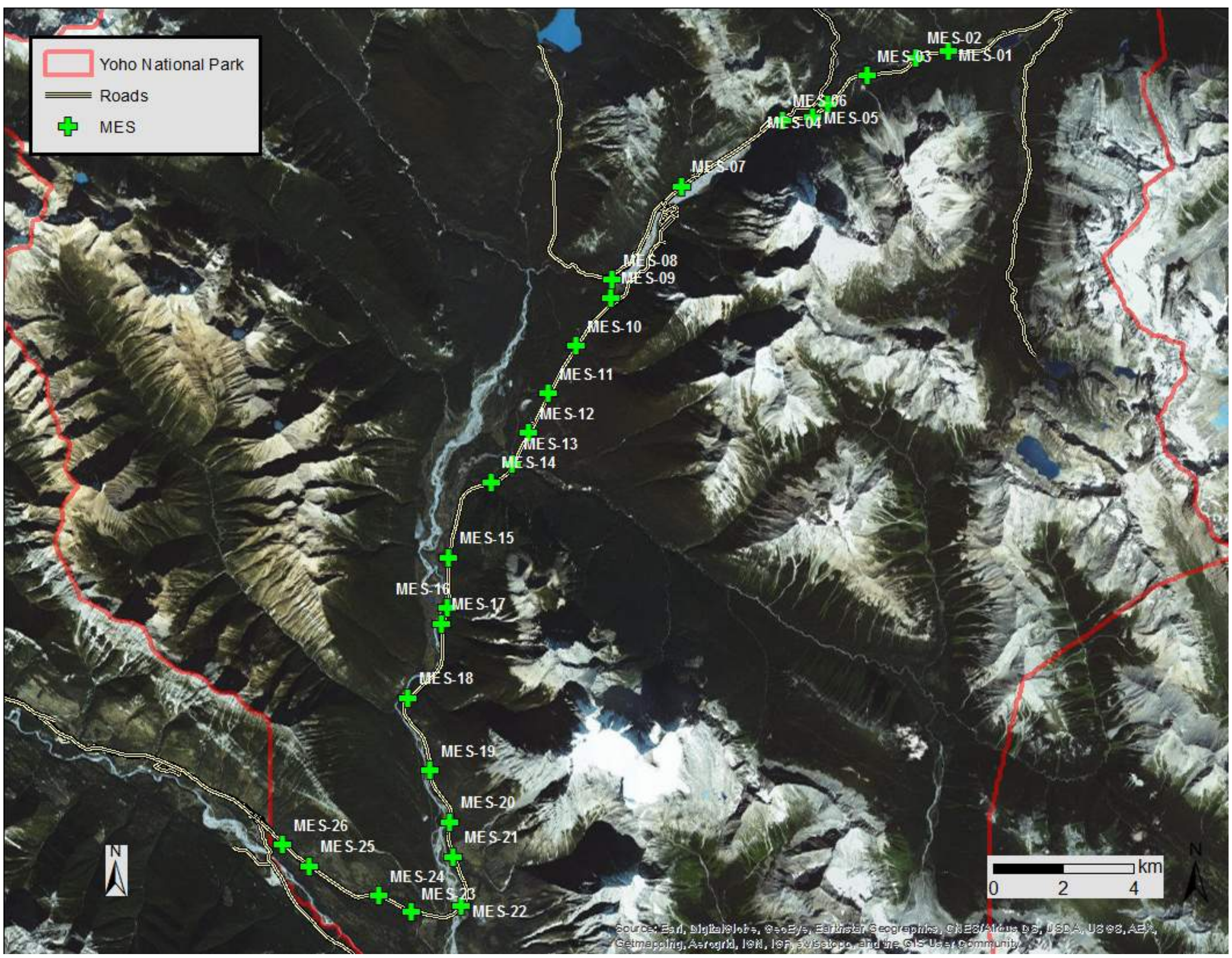


Figure 7.1: Recommended mitigation emphasis sites along the Trans-Canada Highway in Yoho National Park, British Columbia.

The sites were divided into four zones based on biogeographic conditions along the highway in Yoho National Park (YNP). The zones follow an east-to-west gradient through Phase 4B project area (approximately km 88 to 127), i.e., Sherbrooke Creek in Kicking Horse Pass to west boundary of YNP (Figure 7.1).

- **6 sites in Zone A** (Sherbrooke Creek to base of Field Hill)
- **2 sites in Zone B** (Base of Field Hill to Kicking Horse River/Canadian Pacific (CP) railway bridge near Natural Bridge)
- **10 sites in Zone C** (Kicking Horse River/CP Bridge to Finn Creek
- **8 sites in Zone D** (Finn Creek to west boundary of YNP)

Valuation Matrix

We created a valuation matrix of the MES by using information provided by wildlife-vehicle collision (WVC) data, spatially explicit, regional-scale connectivity models, highway data, expert opinion, available anecdotal reports, and opportunities and constraints with respect to adjacent terrain and land use. We conducted a site visit at each MES on October 18, 2016 and evaluated each for mitigation constructability potential, local connectivity, and developed the recommended mitigation design type.

The matrix assisted in ranking sites for mitigation priority, we assigned each site a subjective score from 1 (low) to 5 (high) on the basis of the following four criteria:

- *Mortality Risk* – relative rate of WVCs where wildlife are killed on roadways is often times a useful indicator where important habitat linkages are located and where animal movement corridors intersect highways.
- *Local Connectivity Value* – the value of the highway mitigation to local wildlife conservation regardless of regional significance. This was associated with high quality local habitats, i.e., meadows, creeks, rivers.
- *Regional Connectivity Value* - the potential significance of highway mitigation to address regional connectivity concerns for the *combined* three species (averaged values), we

modeled connectivity (black bear, grizzly bear, wolverine). These three species were used as surrogates to represent landscape connectivity in low (black bear), middle (grizzly bear) and high (wolverine) elevations across the highway (Landguth et al. 2011).

- *Transportation Mitigation Constructability* – the degree or relative ease to which mitigation can be constructed at the site. This is primarily based on site factors such as: local topography, proximity to: rivers, lakes, railway lines; assumed water table levels etc.

Table 7.1 displays the scores for each criteria and the average for all four criteria for each MES. We recorded scores and comments on Information or Hot Sheets (**Appendix A**) and averaged scores to help prioritize the MES.

We developed recommendations for mitigation measures at each MES. A variety of measures are recommended, from simple to complex. Some require only replacing existing under-sized culverts with larger culverts, while others necessitate major structural work, e.g., widening bridge supports while upgrading existing bridge structures. The recommendations for improving motorist safety and wildlife connectivity for the TCH in YNP include a total of five different proven or promising mitigation measures (Huijser et al. 2007). Table 7.2 includes a list of the measures, their effectiveness in reducing WVCs, the target of the measure (type) and the ranking category as presented in the Huijser et al. (2007) report.

Categories of Wildlife Crossing Structure Design

We devised three categories of recommended wildlife crossing structures with the following design criteria (Table 7.3). **Primary** wildlife crossing structures consist of 40-50 m wide wildlife overpasses or open span bridge underpass measuring 3.5-4.0 m high x 22 m wide. **Secondary** wildlife crossing structures consist of open span bridge underpass approximately 3 m high and 11 m wide. **Tertiary** wildlife crossing structures consist of elliptical steel multi-plate culverts 4 m high x 7 m wide or concrete box culverts measuring 2.4 high x 3.6 m wide.

The rationale for the three categories of crossing structure and specific design type and dimensions stems from previous research and recommendations for wildlife crossing mitigation in Banff National Park (Clevenger et al. 2002, Clevenger and Waltho 2000, 2005; Clevenger and

Barrueto 2014). The TCH corridor has been identified as a source of mortality and fragmentation for wildlife populations in the Canadian Rockies: wolverines (Clevenger 2013), grizzly bears (Chruszcz et al. 2003, Bertch and Gibeau 2010), wolves (Parks Canada, unpublished data), moose (Parks Canada, unpublished data), lynx (Apps 2000) and mountain goats (Parks Canada, unpublished data).

The location of the tertiary crossing structures is more flexible than that of the primary and secondary crossing structures. It is important that the primary and secondary crossing structures are built at the recommended locations. However, one or possibly two of the tertiary crossing structures could eventually be eliminated, or a secondary structure moved, if engineering constraints prove their constructability unfeasible at the recommended site.

As described above, the MES are specific locations within the YNP study area where our connectivity models and empirical data show the best opportunities for improving connectivity throughout the project area (Figure 7.1). Models and validation data have identified these key linkage areas. The next step and level of detail will consist of conducting site visits with transportation engineers at each MES to ascertain the feasibility of construction, most likely making simple locational adjustments to our initial recommendations within this report.

These types of finer-scale site inspections with engineers are part of the highway mitigation design process prior to starting preliminary design work and have been a part of numerous highway mitigation projects in North America (A.P. Clevenger, personal observation). Such projects include TCH Phase 3B, Banff National Park; Montana US93, Interstate-90 Snoqualmie Pass East, Washington; SR 260 Arizona; US 101 Liberty Canyon, California.

Table 7.1. Trans-Canada Highway mitigation emphasis sites prioritization matrix in Yoho National Park, British Columbia. Sites with scores above average are highlighted in **black bold** print and yellow shading.

MES Number_Name (km#)	Mortality	Local Connectivity	Regional Connectivity	Construct-ability	Average	Rank
1 Sherbrooke Creek (88.5)	**3.0**	**4.0**	**4.7**	**3.0**	**3.7**	**7**
2 Double culverts (89.5)	3.0	3.0	4.0	3.0	3.3	15
3 Spiral tunnels (91.0)	1.0	3.0	2.7	4.0	2.7	24
4 CP Bridge West (92.5)	2.0	3.0	3.0	4.0	3.0	18
5 Monarch Creek (93.0)	1.0	3.0	1.3	3.0	2.1	26
6 KHR_Field Hill (93.8)	2.0	4.0	2.0	5.0	3.3	14
7 East of Field (97.3)	2.0	3.0	3.0	3.0	2.8	23
8 KHR_Natural Bridge (100.8)	**1.0**	**5.0**	**3.7**	**5.0**	**3.7**	**9**
9 Cabin (101.3)	1.0	4.0	3.0	4.0	3.0	17
10 Boulder Creek (103.0)	1.0	5.0	1.7	5.0	3.2	16
11 West of Boulder Creek (104.5)	**5.0**	**3.0**	**3.0**	**4.0**	**3.8**	**6**
12 East of Ottertail (105.8)	**5.0**	**4.0**	**2.7**	**4.0**	**3.9**	**3**
13 Ottertail River (106.7)	**5.0**	**5.0**	**2.3**	**5.0**	**4.3**	**2**
14 West of Ottertail (107.5)	**4.0**	**4.0**	**3.0**	**4.0**	**3.8**	**5**
15 Unnamed (110.3)	2.0	3.0	4.0	4.0	3.3	13
16 East of 3 Culverts (111.7)	2.0	3.0	2.0	3.0	2.5	25
17 3 Culverts (112.2)	2.0	3.0	2.7	4.0	2.9	20
18 Finn Creek (114.7)	2.0	3.0	3.3	3.0	2.8	21
19 Rock Cut (117.0)	2.0	3.0	4.3	4.0	3.3	12
20 West of Rock Cut (118.6)	4.0	4.0	1.3	4.0	3.3	11
21 Hoodoos (119.7)	**4.0**	**4.0**	**3.0**	**4.0**	**3.8**	**4**
22 KHR Bridge_Beaverfoot (121.3)	**5.0**	**5.0**	**4.0**	**5.0**	**4.8**	**1**
23 Wapta Falls (122.7)	**5.0**	**3.0**	**2.7**	**4.0**	**3.7**	**8**
24 West of CP Bridge (123.7)	**5.0**	**3.0**	**2.0**	**4.0**	**3.5**	**10**
25 East of Kiosk (126.0)	3.0	2.0	2.7	4.0	2.9	19
26 West Entrance (126.9)	4.0	2.0	1.0	4.0	2.8	22

Table 7.2: Wildlife mitigation measures, their focus and effectiveness.

Mitigation measure	**Effectiveness**	**Type**[1]	**Category**[2]
Animal detection system	87%	Driver	Promising
Fencing	86%	Separate	Proven
Underpass with waterflow	86%	Animal	Proven
Underpass – wildlife	86%	Animal	Proven
Overpass – wildlife	86%	Animal	Proven

[1] *Driver*: Measures that attempt to influence driver behaviour; *Animal*: Measures that attempt to influence animal behaviour; *Separate*: Measures that physically separate animals from the roadway. From Huijser et al. 2007.
[2] *Proven*: Measures that should be implemented (where appropriate); *Promising*: Measures that appear promising, but require further investigation. From Huijser et al. 2007.

Table. 7.3. Design type and structural guidelines for three categories of recommended wildlife crossing structures on Trans-Canada Highway in Yoho National Park.

Category	Design type	Approximate dimensions (m) Height x width
Primary	Wildlife overpass Open span underpass	40-50 (width) 3.5-4.0 x 22
Secondary	Open span underpass Elliptical CSP[1] culvert (including bottomless arch)	3 x 11 3 x 11
Tertiary	Elliptical CSP[1] culvert Concrete box culvert	4 x 7 2.4 x 3.6

[1]: CSP: corrugated steel plate

Mitigation Recommendations

A large amount of information has been amassed specific to each MES. Information or "Hot Sheets" (**Appendix A**) were prepared for each site and describe all site-specific information with regard to mitigation importance, target species, wildlife objectives, and recommendations for mitigation measures. The Hot Sheets are a quick and easy reference that summarizes mitigation opportunities at each site.

There are a large number of MES throughout the TCH corridor and recommendations for each site. Instead of reviewing each of the 26 sites in detail in this report, we highlight the most relevant sites primarily with regard to regional conservation and connectivity and to a lesser extent wildlife–vehicle collision reduction. To do this, we averaged the values for the 26 sites within YNP. The average score for the matrix valuation of the 26 sites was 3.3. Ten of the 26 sites had scores above the average score. Those sites are listed below from east to west. The 3 highest-ranking sites ($\geq 90^{th}$ percentile) are shown in **bold type** and valuation matrix scores are in parentheses.

- Sherbrooke Creek: Site 1 (3.7)
- KHR_Natural Bridge - Site 8 (3.7)
- West of Boulder Creek- Site 11 (3.8)
- **East of Ottertail – Site 12 (3.9)**
- **Ottertail River – Site 13 (4.3)**
- West of Ottertail – Site 14 (3.8)
- Hoodoos – Site 21 (3.8)
- **KHR Bridge_Beaverfoot – Site 22 (4.8)**
- Wapta Falls – Site 23 (3.7)
- West of CP Bridge – Site 24 (3.5)

We discuss each of these sites and their mitigation recommendations in light of their respective attributes associated with local and regional conservation values and the safety of motorists traveling the TCH. Specific mitigation measures are italicized; general descriptions of the five mitigation measures are found in **Appendix B**. We also briefly describe 3 sites that did not rank within the top 10 but nonetheless are of particular interest and importance for regional scale connectivity.

Sherbrooke Creek - Site 1

This site had the seventh highest matrix score (75th percentile) among all the TCH sites in the study area (avg. = 3.7). The Sherbrooke Creek site is important in terms of regional and local connectivity (scores >4.0), particularly fragmentation-sensitive species such as grizzly bears, wolverines and lynx and high elevation localized species such as mountain goats.

The site has moderate constructability for highway mitigation measures (= 3.0). There is an existing culvert (1.2 m diameter) at the site. A new bridge structure for new lanes to span Sherbrooke Creek will need to be installed during TCH expansion. This construction opportunity can serve to design and install an underpass (possibly bottomless arch) structure that accommodates the need for expanded lanes of traffic and safe passage of wildlife in this critical wildlife corridor.

Recommended mitigation at the Sherbrook Creek site consists of a **secondary** *wildlife underpass* with *fencing*. The recommended dimension of the underpass option is ≥3m high and minimum 9-11 m wide (see *wildlife underpass,* **Appendix B, Sheet B**). Given high water levels and Class 3 rapids on the Kicking Horse River during much of summer, we recommend exploring the possibility of installing a 7-10 m wide wildlife footbridge (overpass) to span the river.

Given the severely constrained conditions at this particular site we recommended a site visit be made with engineers to discuss possible options for construction of the proposed crossing structure types and designs at Sherbrooke Creek.

The recommended structures are based on the high probability of key fragmentation-sensitive species (wolverines, lynx, grizzly bear) and mountain goat movement in this area and need for regional scale connectivity (see Section 4 & 5 above). One of the two grizzly bear road mortalities occurred just east of this site. This Sherbrooke site is part of the critically important Kicking Horse Pass linkage zone across the TCH. Three new wildlife underpasses and one wildlife overpass are currently being constructed on the 6 km between the British Columbia (BC) – Alberta border and Wapta Lake to mitigate TCH impacts on regional scale connectivity in this important high elevation linkage zone (Olyslager 2011, Golder Associates 2004).

Continuous fencing from newly constructed crossing structures on the first 6 km from the Alberta-BC border should be used to guide wildlife to the underpass. Snow levels at this location may cause problems with fencing, primarily snow creep, however it would be advisable to test the integrity of the fence in an adaptive management process. The technical specifications for wildlife fencing in an area of high snow are provided in **Appendix C** and should be considered for fence design at this site.

Kicking Horse River (KHR)_Natural Bridge - Site 8

This site had an averaged matrix score within the 75th percentile (=3.7) of all the TCH sites. Situated in the extreme west end of the Field Flats, the site is important in terms of local (=5.0) and regional (=3.7) connectivity. Species of interest in this area consist of deer, moose, wolves and both grizzly and black bears. Regional connectivity models showed high connectivity scores here for black bear movements (=5) and grizzly bear (=4).

The site has high constructability for highway mitigation measures (= 5.0), given the existing bridge structure that accommodates the Kicking Horse River (KHR) and the CP railway mainline.

Wildlife crossing structure: A new bridge, or partial for new lanes of traffic, will need to be installed during TCH expansion. During reconstruction efforts should be made here to construct a wildlife path ($\geq$6 m wide) to allow for greater wildlife movement and travel through this area. The most suitable location for path is on the east side of the bridge.

Continuous fencing from crossing structures at neighbouring MES will be used to guide wildlife to the underpass. Snow levels at this location should not cause problems with fencing.

West of Boulder Creek - Site 11

Similar to Sherbrooke Creek and KHR_Natural Bridge, Site 11 ranked 6th with an averaged matrix score within the 80th percentile (=3.8) among the TCH sites. Situated in the east end of Zone C, it is an area of high rates of WVC (= 5), primarily with deer, elk, moose, wolves and bears. There is an existing 2.0 m-diameter steel culvert at the site.

The site is moderately important in terms of local (=3.0) and regional (=3.0) connectivity. Modeling of regional connectivity for wolverine movement indicated this location was highly important (=5). Species of interest in this area consist of deer, moose, wolverines, wolves, lynx, and both grizzly and black bears.

The site has moderately high constructability for highway mitigation measures (= 4.0).

Recommended mitigation at the Boulder Creek site consists of a **primary** *wildlife underpass* and *fencing*. A wildlife underpass structure is the most suitable design given the terrain at the site. The recommended dimension for the underpass is $\geq$3.5-4.0 m high and minimum 22 m wide (see *wildlife underpass,* **Appendix B, Sheet B**) and is based on the high probability of key fragmentation-sensitive species (wolverines, lynx, grizzly bear) movement through this area.

Continuous fencing from crossing structures at neighbouring MES will be used to guide wildlife to the underpass. Snow levels at this location should not cause problems with fencing.

East of Ottertail – Site 12

This site had the third highest matrix score among all the TCH sites in the study area (avg. = 3.9). East of Ottertail is an area of very high rates of WVC (= 5), primarily with deer, elk, moose, and bears.

The site is important in terms of local (=4.0) connectivity and less so for maintaining regional connectivity (=2.7). Modeling of regional connectivity for black bear movement indicated this location was important (=4). Species of interest in this area consist of deer, moose, wolverines, wolves, lynx, and both grizzly and black bears.

The site has moderately high constructability for highway mitigation measures (= 4.0). There is a 1.6 m diameter culvert at the site.

Recommended mitigation at the East of Ottertail site consists of a **secondary** *wildlife underpass* and *fencing*. A wildlife underpass structure is the most suitable design at the site. The recommended dimension for the underpass is $\geq$3 m high and minimum 11 m wide (see *wildlife underpass,* **Appendix B, Sheet B**) and is based on the high probability of key fragmentation-sensitive species (wolverines, lynx, grizzly bear) movement in this area.

Continuous fencing from crossing structures at neighbouring MES will be used to guide wildlife to the underpass. Snow levels at this location should not cause problems with fencing.

Ottertail River – Site 13

This site had the second highest matrix score among all the TCH sites in the study area (avg. = 4.3). Ottertail River is an area of very high rates of WVC (=5) and highly important in terms of local connectivity (=5.0). The area is moderately important for regional (=2.3) connectivity. Species of interest in this area consist of deer, moose, wolverines, wolves, lynx, and both grizzly and black bears. Regional connectivity models showed moderate connectivity scores here for black bear (=3) and wolverine (=3) movements.

The site has high constructability for highway mitigation measures (= 5.0), since there is the existing bridge structure over the Ottertail River. However, given the narrow and steep-walled terrain below the bridge, any structural work will not significantly improve wildlife passage below the bridge. Further, the Ottertail River site has the lowest regional connectivity score compared to neighbouring sites (MES 11, 12, 14).

Wildlife movement along the Ottertail River proper is likely minimal given the rugged and steep terrain. A large part of the regional movement in and out of the Ottertail drainage most likely occurs above the river and within the adjacent area. Wildlife and their tracks are often seen on the Ottertail fire road from the trailhead near the TCH and up valley 14-15 km towards McArthur Creek and Ottertail Falls. Wolverine tracks were regularly found traveling up and down the fire road during three winters (Clevenger and Barrueto 2014) and a regularly visited lick for mountain goats approximately 3 km from trailhead is located adjacent to the fire road.

Wildlife crossing structure: A new bridge for new lanes of traffic will need to be installed during TCH expansion. The Ottertail drainage under the bridge is steep-walled, although some wildlife movement may occur here. We do not recommend any mitigation work be done here. The greatest benefit of ensuring local and regional connectivity through the broader Ottertail area will be from mitigations at neighbouring MES No. 11 (West Boulder Creek), 12 (East of Ottertail) and 14 (West of Ottertail).

Continuous fencing from crossing structures at neighbouring MES will be used to guide wildlife to the underpass. Snow levels at this location should not cause problems with fencing.

West of Ottertail – Site 14

This site west of Ottertail River ranked 5th with an average matrix score within the 90th percentile (avg.=3.8) among the TCH sites. Situated in the middle of Zone C, it is an area of high rates of WVC (= 4), primarily with deer, elk, moose bears and wolves. There is a 1.6 m diameter culvert at the site.

The site is important in terms of local connectivity (=4.0) but less so for regional connectivity (=3.0). Species of interest in this area consist of deer, moose, wolverines, wolves, lynx, and both grizzly and black bears. Regional connectivity models suggest this is an important area for maintaining wolverine movements throughout the area (=4).

The site has moderately high constructability for highway mitigation measures (= 4.0).

Recommended mitigation at this site consists of a **secondary** *wildlife underpass* and *fencing*. A wildlife underpass structure is the most suitable design given the terrain at the site. The recommended dimension for the underpass is $\geq$3 m high and minimum 11 m wide (see *wildlife underpass,* **Appendix B, Sheet B**) and is based on the high probability of key fragmentation-sensitive species (wolverines, lynx, grizzly bear) movement through this area.

Continuous fencing from crossing structures at neighbouring MES will be used to guide wildlife to the underpass. Snow levels at this location should not cause problems with fencing.

Hoodoos – Site 21

The Hoodoo site had the 4th highest matrix score among all the TCH sites in the study area (avg. = 3.8). It is an area of high rates of WVC (= 4), primarily with deer, elk, moose, bears and wolves.

The Hoodoo site is important in terms of local (=4.0) connectivity and also for maintaining regional connectivity (=3.0). Modeling of regional connectivity for black bear movement indicated this location was important (=4). Given the location near the confluence of the Kicking Horse and Beaverfoot Rivers, it is an area rich in wildlife species year-round and junction of several key regional travel corridors. Species of interest in this area consist of deer, moose, elk, wolverines, wolves, lynx, and grizzly and black bears. The site has moderately high constructability for highway mitigation measures (= 4.0). There is no existing infrastructure at the site.

Recommended mitigation at the Hoodoo site consists of a **primary** *wildlife underpass or overpass* and associated *fencing*. The recommended dimension for the underpass is $\geq$3.5-4 m high and minimum 22 m wide (see *wildlife underpass,* **Appendix B, Sheet B**). The minimum dimension of the wildlife overpass option is minimum 40-50 m wide. Both passage structures are based on the high probability of key fragmentation-sensitive species (wolverines, lynx, grizzly bear, wolves) movement through this area and need for regional scale connectivity (see Section 4 & 5 above). Either overpass or underpass should be suitable for the target species in the area. Final determination of what structure type to build will depend largely on the engineering of a relatively large underpass in this location given the high water table.

Continuous fencing from crossing structures at neighbouring MES will be used to guide wildlife to the underpass. Snow levels at this location should not cause problems with fencing.

KHR Bridge_Beaverfoot – Site 22

This site had the highest matrix score among all the TCH sites in the study area (avg. = 4.8). Given the location near the confluence of two major watersheds in YNP (Kicking Horse joins the Beaverfoot River), the area is rich in wildlife year-round and is the junction of key regional wildlife corridors. Species of interest in this area consist of deer, moose, elk, wolverines, wolves, lynx, and grizzly and black bears.

The area of the Kicking Horse Bridge is known for its very high rates of WVC (=5) and to be highly important for local (=5.0) and regional connectivity (=4.0) of wildlife. The area is moderately important for regional (=2.3) connectivity. Species of interest in this area consist of deer, moose, wolverines, wolves, lynx, and both grizzly and black bears. Regional connectivity models showed important connectivity scores here for black and grizzly bears (=4) and wolverine (=4) movements (the Graves et al. 2014 model showed a strong LCP here and significantly differed from our expert opinion model at this site; therefore, we adjusted the grizzly bear regional connectivity value upwards to reflect this particular discrepancy). The site has high constructability (for highway mitigation measures (= 5.0), given the existing bridge structure that accommodates the Kicking Horse River. During our October 2016 site visit we found several wolf tracks passing under the bridge.

Wildlife crossing structure: A new bridge, or partial for new lanes of traffic, will need to be installed during TCH expansion. There is currently travel space for wildlife below the bridge, particularly during low water levels. However, during reconstruction efforts should be made here to ensure that the bridge spans allow for greater wildlife movement and travel (and hydrologic activity) below the bridge and through this area. Two large culverts, one near each end of the bridge, are located adjacent to vegetative cover will allow for movements of more forest- or cover-associated wildlife. Next to the Kicking Horse Pass linkage area, this is one of the most important travel corridors on Phase 4B.

Continuous fencing from crossing structures at neighbouring MES will be used to guide wildlife to the underpass. Snow levels at this location should not cause problems with fencing.

Wapta Falls – Site 23

This site had an averaged matrix score of 3.7**.** Situated at the west end of Zone D, it is an area with very high rates of WVC (= 5) and moderately important local and regional connectivity. Modeling indicated that the area was of importance for maintaining regional connectivity for black bears (=4) and lesser so for wolverines (=3). The site has moderately high constructability for highway mitigation measures (= 4.0). There does exist infrastructure at the site in the form of a 2 m diameter culvert.

Recommended mitigation at the site consists of a **secondary** *wildlife underpass* and *fencing*. A wildlife underpass structure is the most suitable design at the site. The recommended dimension for the underpass is $\geq$3m high and minimum 11 m wide (see *wildlife underpass,* **Appendix B, Sheet B**) and is based on the high probability of common species (deer, elk, moose, cougars, bears) movement in this area.

Continuous fencing from crossing structures at neighbouring MES will be used to guide wildlife to the underpass. Snow levels at this location should not cause problems with fencing.

West of CP Bridge – Site 24

This site had an averaged matrix score of 3.5. It is an area with very high rates of WVC (= 5) and moderately important local and regional connectivity. Modeling indicated that the area was of importance for maintaining regional connectivity for black bears (=4). The site has moderately high constructability for highway mitigation measures (= 4.0). There is a CP rail bridge within a few hundred meters to the east. Therefore there are two mitigation options: Using the site indicated at MES 24 or the CP Bridge a few hundred meters to the east.

Recommended mitigation at the MES would consist of a **tertiary** *wildlife underpass* and *fencing*. A wildlife underpass structure is the most suitable design. The recommended dimension for the underpass is 4 x 7 m elliptical multi-plate culvert (see *wildlife underpass,* **Appendix B, Sheet B**) and is based on the high probability of common species (deer, elk, moose, cougars, bears) movement in this area. Recommended mitigation at the CP Bridge to the east would consist of reconstruction of the existing bridge, by widening span underneath to allow for wildlife passage (≥6 m wide paths on both sides) - similar to work recommended at other CP bridges at MES 3, 4, and 8.

Continuous fencing from crossing structures at neighbouring MES will be used to guide wildlife to the underpass. Snow levels at this location should not cause problems with fencing.

References

Apps, C. D. 2000. Space use, diet, demographics, and topographic associations of lynx in the southern Canadian Rocky Mountains. Pages 351-371 *in* L. F. Ruggiero, K. B. Aubry, S. W. Buskirk, G. M. Koehler, C. J. Krebs, K. S. McKelvey, and J. R. Squires, editors. Ecology and conservation of lynx in the United States. University Press of Colorado, Denver, Colorado, USA.

Bertch, B., M. Gibeau. 2010. Black bear mortalities in the Mountain National Parks: 1990-2009. Report prepared for Parks Canada Agency, Banff, Alberta.

Clevenger, A.P., Waltho, N. 2000. Factors influencing the effectiveness of wildlife underpasses in Banff National Park, Alberta, Canada. Conservation Biology 14:47-56.

Clevenger, A.P., N. Waltho. 2005. Performance indices to identify attributes of highway crossing structures facilitating movement of large mammals. Biological Conservation 121:453-464.

Clevenger AP. 2013. Mitigating highways for a ghost: Data collection challenges and implications for managing wolverines and transportation corridors. Northwest Science 87:256-264.

Chruszcz, B., Clevenger, A.P., Gunson, K., Gibeau, M.L. 2003. Relationships among grizzly bears, highways and habitat in the Banff-Bow Valley, Alberta. *Canadian Journal of Zoology 81:1378-1391.*

Golder Associates. 2004. Screening report for the Trans-Canada Highway twinning project phase IIIB, Banff National Park. Report for Parks Canada, Banff National Park, Alberta.

Graves, T., R. Chandler, J.A. Royle, P. Beier, K. Kendall. 2014. Estimating landscape resistance to dispersal. Landscape Ecology 29:1201-1211.

Olyslager, J. 2011. Adjustment to the environmental screening report TCH Twinning phase IIIB. Parks Canada, Lake Louise, Alberta.

Proctor, M. et al. 2012. Population fragmentation and inter-ecosystem movements of grizzly bears in western Canada and the norther United States. Wildlife Monograph 180:1-46.

8. Landscape-Specific Guidelines for Highway Mitigation in Yoho National Park

The application of site-specific mitigations has significantly reduced road-related mortality of wildlife and improved means of habitat connectivity across highways (Dodd et al. 2007, Huijser et al. 2007, Sawaya et al. 2013, Huijser et al. 2016). However, traditional highway mitigations may be confounded in parts of YNP due to the unique landscape they are found. Some of the unique landscape and climatic attributes of eastern YNP consist of:

1. **Extremely high snowfall, prevalence of avalanche activity** (Mount Bosworth, Field Flats), and highly dissected and steep terrain, i.e., limited areas for wildlife movement thus highly defined movement corridors.

2. **Kicking Horse River floodplain at the Field Flats**. This broad, open floodplain is at road grade level and the water table is expected to be high. Further, installing a wildlife fence on both sides of the highway through this vast flood plan has negative effects in terms of visual aesthetics. If an underpass or overpass are not feasible due to high water table (former) or less than desirable because of visual aesthetics (latter) in the Field Flats, an alternative means of reducing collisions with wildlife will be needed, while maintaining movement across the TCH.

In addition to the unique landscape and climatic elements that factor into a highway mitigation strategy in YNP, there are also several bridges that span the CP railway, which could serve as wildlife crossing structures if designs are made to increase their span.

Thus, standard or traditional mitigation measures up until now used elsewhere may not apply to all MES or in YNP be as effective. Mitigation measures designed for YNP will need to be adapted to these conditions of climate, landscape, and shared bridge infrastructure.

There are two issues we have identified during the project that will influence landscape-specific guidelines for highway mitigation:

- Floodplain (Field Flats)
    - Open floodplain of the Kicking Horse River.
- High snowfall - resulting deep snowpack in the eastern sector of YNP corridor.
    - Dissected landscape and steep terrain, which leads to avalanche paths that cross the TCH.

Floodplain (Field Flats)

The Field Flats is situated between MES 7 (East of Field) and MES 6 (Base of Field Hill). The area is characterized by a broad floodplain with high water table and TCH at grade, being in close proximity to the Kicking Horse River, and an open landscape mostly void of vegetation. Because of the stark openness of the landscape, the visual aesthetics of the area are not conducive to having a wildlife fence along the highway. In the area there are four access roads onto the TCH that with wildlife fencing would require animal deterrents at these locations, such as Texas gates or some form of electrified deterrent, both, which have questionable efficacy in areas with regular snow. The barren openness of the floodplain and lack of vegetative cover likely inhibit some wildlife movement across the flats, particularly species that need cover for travel and/or sensitive to human disturbance. There is a large distance between MES in this area, which does not have notable road-kill occurrence (other than elk), therefore the irregular movement we would expect to occur crossing the TCH would best occur at grade.

An ideal strategy would allow wildlife movement across the Field Flats warning motorists of passing wildlife to keep the highway permeable to movements. Providing safe passage of wildlife across the TCH safely now and in the future will be a challenge given increasing traffic volumes, however, they are far below 20,000 vehicles per day (AADT), which is when ADS become undesirable (Huijser et al. 2015). An effective strategy to reduce WVCs in this unique landscape is to warn motorists and have them slow down when wildlife are on or near highways. By reducing speeds stopping distances are shortened and there is less likelihood of accidents occurring (Anderson et al. 1997).

Animal-Detection Systems (ADS)

Radar-based ADS are gaining popularity among transportation agencies in North America due to relatively low cost and increasing reliability at reducing collisions with elk, deer and moose (Huijser et al. 2015; M. Huijser, Western Transportation Institute, personal communication, 2016). The infrared radar-based system "tracks" animals while they are inside the road corridor and continues to activate warning road signage until animals are well outside the predetermined area of concern. ADS are most effective on relatively straight sections of highway that have localized, site-specific problems with ungulate-vehicle collisions, commonly occurring ungulate aggregations due to road salt or other attractants, or movement across roads at fence terminations or defined movement corridors (Huijser et al. 2015). Our recommendation is that ADS be placed at MES with greatest likelihood of animals reaching the end of the fence and crossing the highway (MES 6 & 7) or along stretches of highway without fencing, such as the area between both MES on Field Flats.

Recently, ADS were installed in two locations along Highway 3 in British Columbia (Sparwood and Elko). Both were approximately 2.0 km sections. The systems designed by FLUOR were installed in January 2016 and are currently being evaluated (Ed Miska, BC Ministry of Transportation, personal communication).

The Field Flats is a suitable location for an ADS given that it meets many of the requirements and characteristics for installation (Huijser et al. 2015). The focal section of highway is level and mostly straight with few curves. There are some limitations to ADS. Installation of some systems takes considerable effort and some experience technological problems related to power, system function, and false positive events (detection with no animal in area) and false negative events (no detection with animal in area). These system defects can lead to animals gaining access inside the fenced sections – thus reason for jump-outs and escape ramps (see below) near fence terminations. New ADS are wireless with long range detectors that communicate up to 1 km. Remote monitoring with a cellular gateway is able to show infrared detection events by location, the time and date stamp. To fine-tune or test the system video cameras can be incorporated to film infrared detection events and address the problem of false negatives and false positives.

On the other hand, other ADS for the most part have proven reliable and substantially reduce collisions with large mammals, up to 80% and greater (Huijser et al. 2015). Nevertheless, ADS should still be considered experimental; combining them with wildlife fencing and crossing structures is considered the most effective mitigation (Huijser et al. 2015).

Alternatively, an adaptive management approach could be taken with regard to mitigating fence terminations by monitoring wildlife activity and mortality at fence terminations. If rates of WVCs become problematic, then an ADS can be installed. Monitoring of ADS will be important to evaluate their effectiveness at reducing accidents. Current costs for radar-based ADS are roughly $200,000/km (Blake Dickson, Rotalec, personal communication, 2013). This cost covers the ADS; all its components required for operation and full installation costs.

Jump-outs/Escape Ramps

Because there are fence ends east of MES 7 (East of Field) and at MES 7 (Base of Field Hill) *jump-outs or escape ramps* (see **Appendix B, Sheet B**) will be needed to allow animals that gain access inside the fenced area to exit quickly. Jump-outs should be placed on each side of the highway in close proximity to fence ends (MES 7) or fence ends at a crossing structure (MES 6). If warranted additional jump-outs can be placed as a back-up measure in case animals do not find the first jump-out. Jump-outs are relatively inexpensive measures (approximately $CD 5000-10,000; Highway Engineering Service, Parks Canada, personal communication) being built of interlocking precast concrete blocks.

Avalanches and Deep Snowpack

There are few places in the world where highway mitigation for wildlife is centered in areas of high snowfall (northern Norway, Washington State Cascades). High snowfall can wreak havoc on fencing and affect usage of underpasses and culverts that might become blocked or partially blocked by snow.

Fencing and avalanches

Fences may be damaged in areas of high snowfall. First, deep snowpacks shift over the course of winter (snow creep) and severely damage fence material and posts. There are few places where fencing has been used in high snowfall areas. In Appendix C we provide technical specifications for fencing that has been used in high snowfall areas of Norway. Research has taken place in Washington State's Cascade Mountains to devise the best fence materials to minimize snow creep damage. The Washington State Department of Transportation office in Yakima, Washington conducted that research and will be a valuable contact for designing fencing in YNP where snow creep may be a problem. The Highway Engineering Service in Banff National Park at one point discussed experimenting with a "knock-down" or removable wildlife fence at the Bosworth Slide Path in YNP (P. Chambefort, Highway Engineering Services, Banff National Park, personal communication, 2014). If the fence is installed it will serve as a good trial project for future deployment in areas prone to avalanche activity, such as Mt Revelstoke and Glacier National Parks.

Wildlife underpass obstruction by snow

Finally, deep snow packs are capable of blocking partially or entirely culverts and wildlife underpasses. For the most part, we have recommended large span crossing structures at sites that may receive high snowfall. Animal movements and activity generally slows down and movements are restricted during winter, particularly in areas of high snowfall. Therefore we do not expect this to be a significant problem or management concern.

References

Anderson, R.W.G., A. McLean, M. Farmer, B. Lee, C. Brooks. 1997. Vehicle travel speeds and the incidence of fatal pedestrian crashes. Accident Analysis and Prevention 29 :667-672.

Dodd, N., J. Gagnon, S. Boe, A. Manzo, R. Schweinsburg. 2007. Evaluation of measures to minimize wildlife-vehicle collisions and maintain permeability across highways: Arizona Route 260. Final report 540. FHWA-AZ-07-540. Arizona Department of Transportation, Phoenix, Arizona, USA.

Huijser, M.P., P. McGowen, J. Fuller, A. Hardy, A. Kociolek, A.P. Clevenger, D. Smith, R.

Ament. 2007. Wildlife-vehicle collision reduction study. Report to US Congress. U.S. Department of Transportation, Federal Highway Administration, Washington D.C.

Huijser, M.P. C. Mosler-Berger, M. Olsson, M. Strein. 2015. Wildlife warning signs and animal detection systems aimed at reducing wildlife-vehicle collisions. Pp. 198-212, in Van der Ree, R., Grilo, C., Smith, D (Eds.). Handbook of road ecology. John Wiley & Sons, Ltd., New York, NY.

Huijser, M., E. W. Camel-Means, Fairbank, J. Purdum, T. Allen, A. Hardy, J. Graham, J. Begley, P. Basting, D. Becker. 2016. US93 Post-construction wildlife-vehicle collision and wildlife crossing monitoring and research on the Flathead Indian Reservation between Evaro and Polson, Montana. Final Report. Report prepared for Montana Department of Transportation, Helena, Montana.

Sawaya, M, AP Clevenger, S Kalinowski. 2013. Wildlife crossing structures connect Ursid populations in Banff National Park. *Conservation Biology 27:721-730.*

9. Convergence of Parks Canada Report and Mitigation Emphasis Sites

Introduction

Parks Canada previously assessed the potential and made recommendations for highway mitigation in Yoho National Park (YNP), British Columbia (Kinley 2013). Kinley evaluated fine-scale mitigation potential along the entire stretch of TCH through YNP, considering known patterns of wildlife movement through the park (Figure 9.1). Our approach of assigning values to landscape variables and ranking their relative importance to landscape scale movement is a somewhat subjective process. Thus, the most powerful recommendations for highway mitigation can be made when the results of two different approaches are congruent with different experts evaluating the same mitigation conditions. Our objective was to compare our Mitigation Emphasis Sites (MES) with the highest priority sites for highway mitigation proposed by Kinley (2013).

Methods

We plotted the locations of the 21 highest priority Kinley (2013) sites and compared them to our 26 proposed MES to see how they converge. We examined the density of sites, locations of sites, and compared recommended crossing structure designs. We also assessed congruence between the areas Parks Canada identified as important for wildlife movement and our connectivity models.

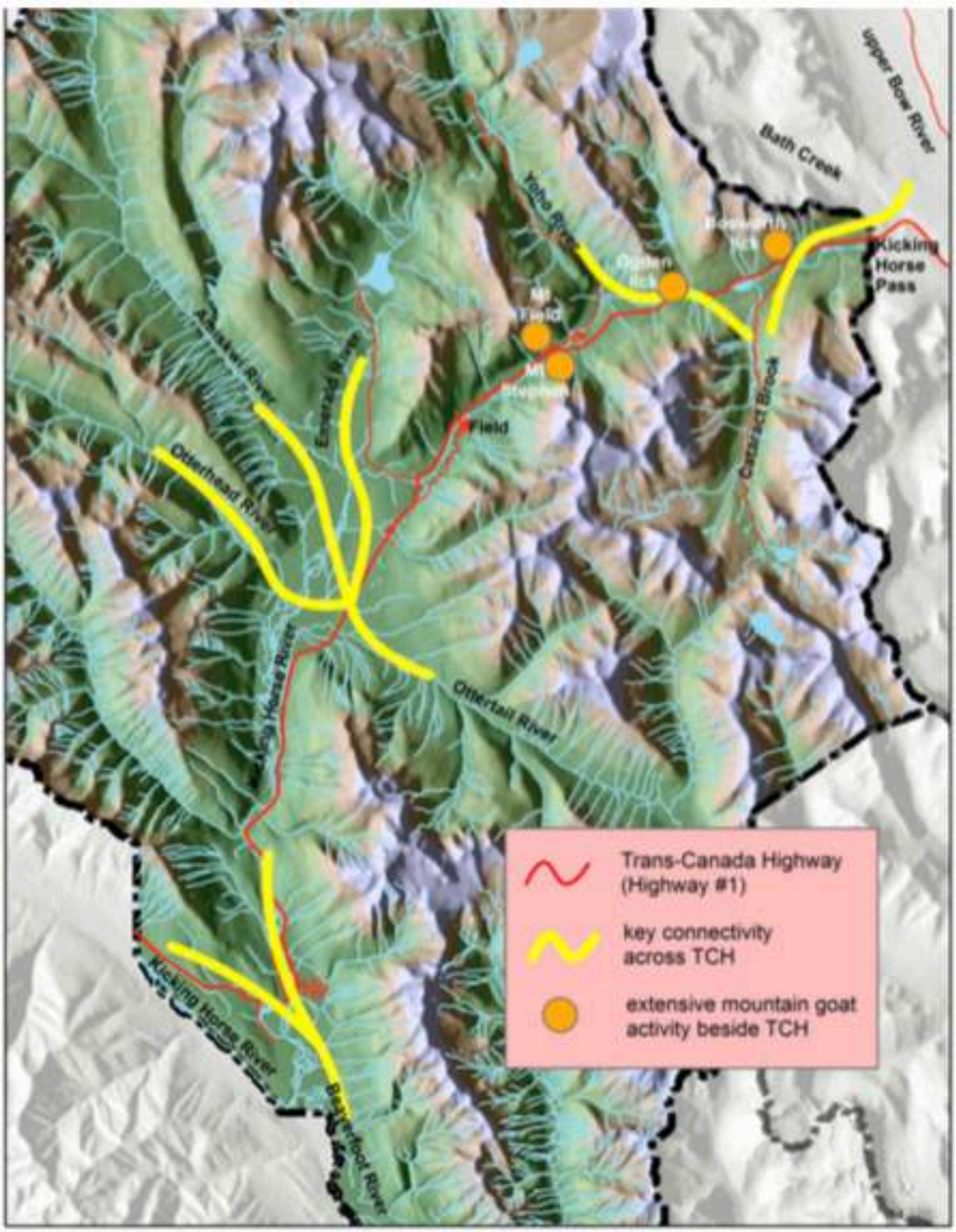


Figure 9.1: Key wildlife connectivity areas across the Trans-Canada Highway identified by Parks Canada in Yoho National Park, British Columbia (from Kinley 2013).

Results

Our results converged well with those of Kinley (2013) and we found congruence between the areas Parks Canada identified as important for wildlife movement and our connectivity models (Figure 9.2. We found comparable density of sites, locations of sites, and recommended crossing structure designs for all 4 zones of TCH mitigation (Figures 9.3, 9.4, 9.5, 9.6).

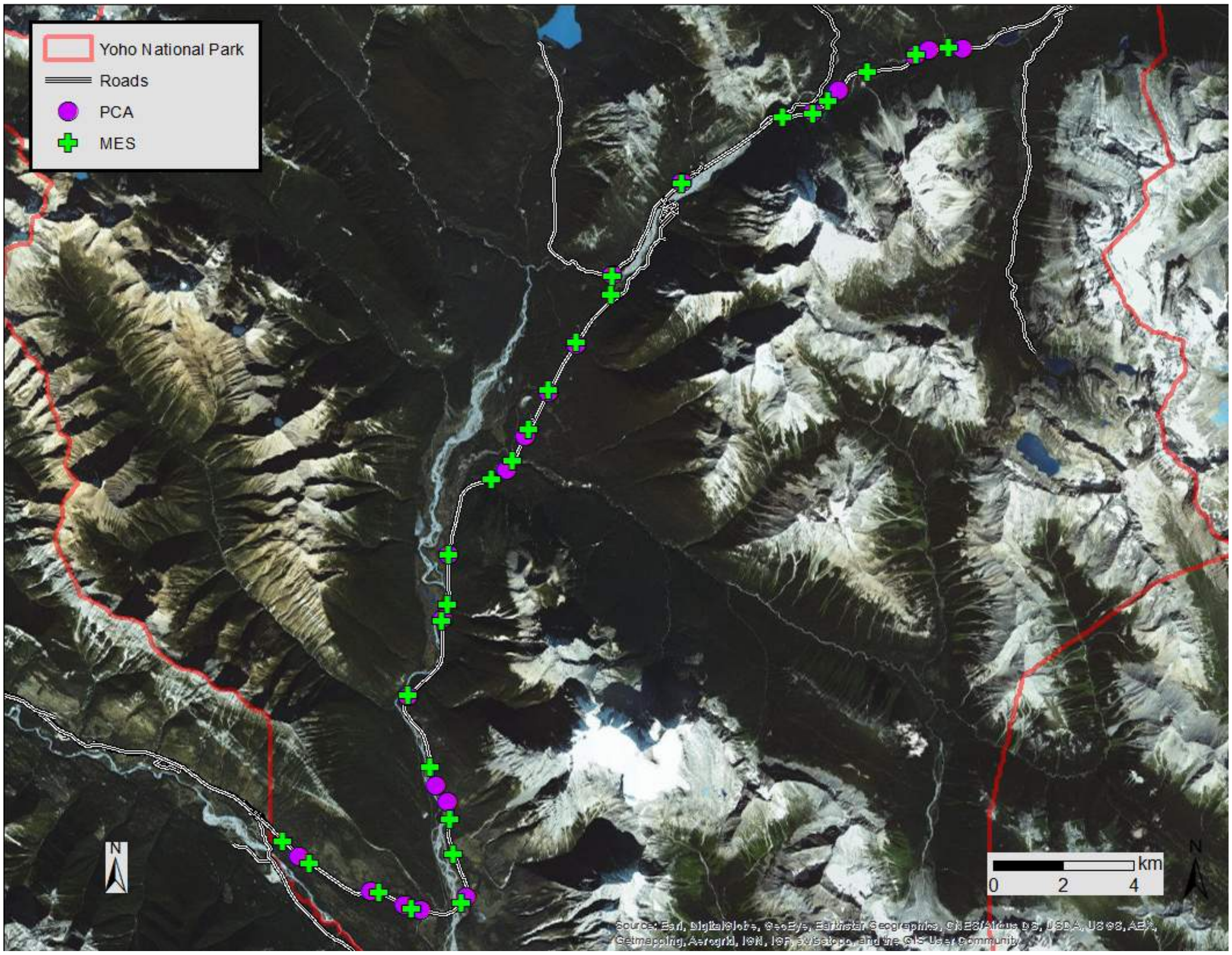


Figure 9.2: Convergence between proposed Mitigation Emphasis Sites (MES) and Parks Canada's (PCA) recommended mitigation sites along the TCH in Yoho National Park, British Columbia.

Zone A

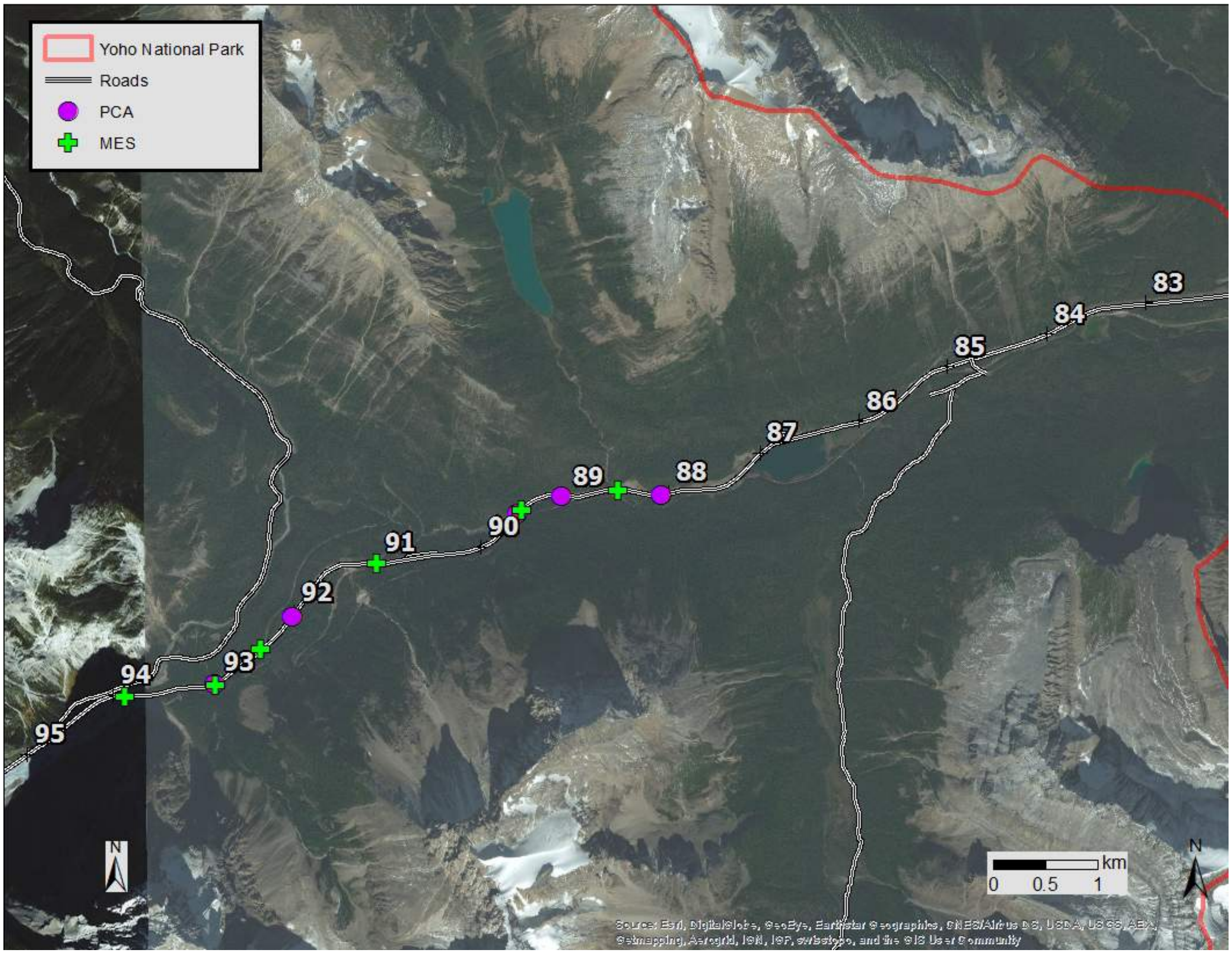


Figure 9.3: Convergence between proposed Zone A Mitigation Emphasis Sites (MES) and Parks Canada's (PCA) recommended mitigation sites on the TCH in Yoho National Park, British Columbia. MES for Phase 4B begins west of km 88.0.

Zone B

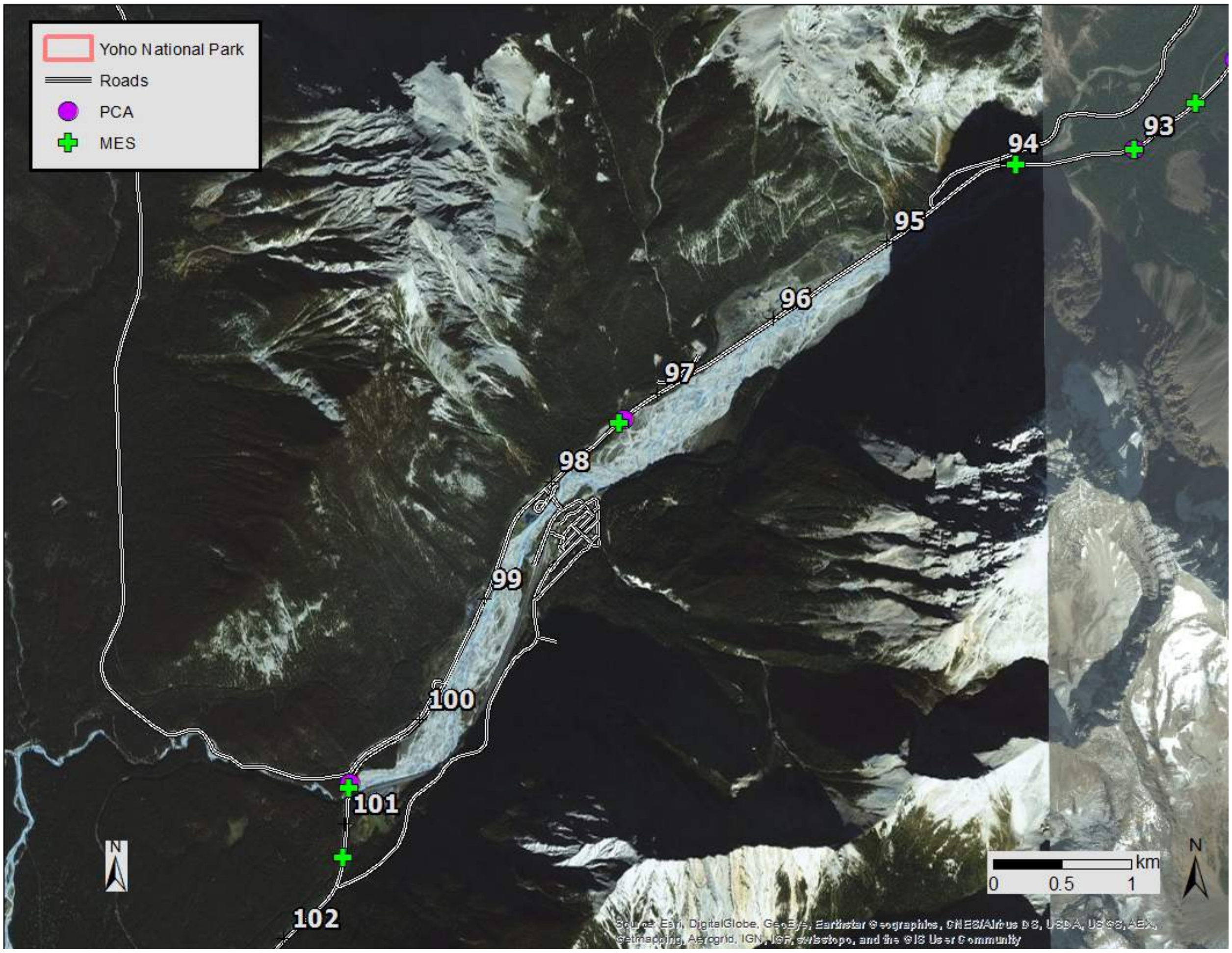


Figure 9.4: Convergence between proposed Zone B Mitigation Emphasis Sites (MES) and Parks Canada's (PCA) recommended mitigation sites on the TCH in Yoho National Park, British Columbia.

Zone C

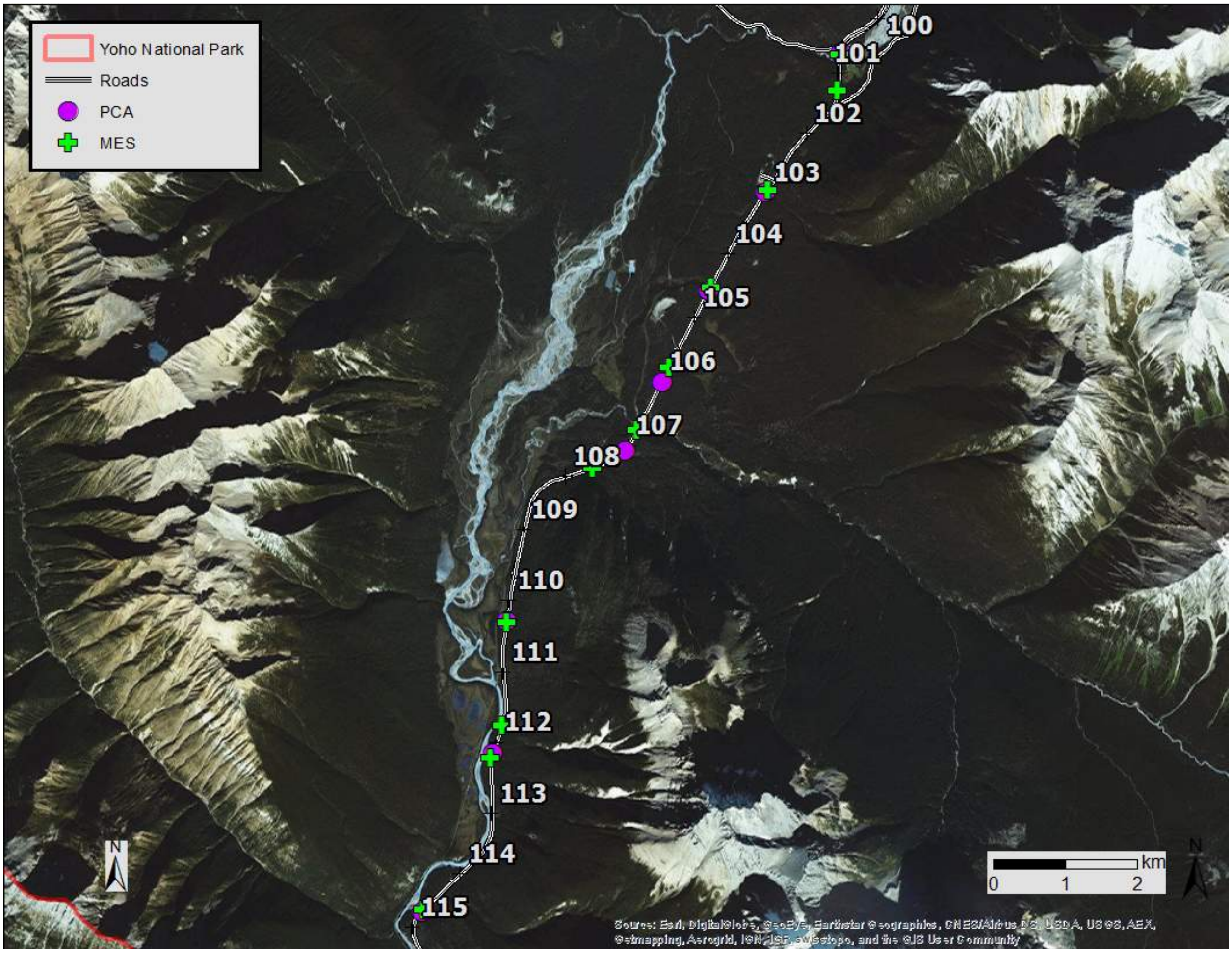


Figure 9.5: Convergence between proposed Zone C Mitigation Emphasis Sites (MES) and Parks Canada's (PCA) recommended mitigation sites on the TCH in Yoho National Park, British Columbia.

Zone D

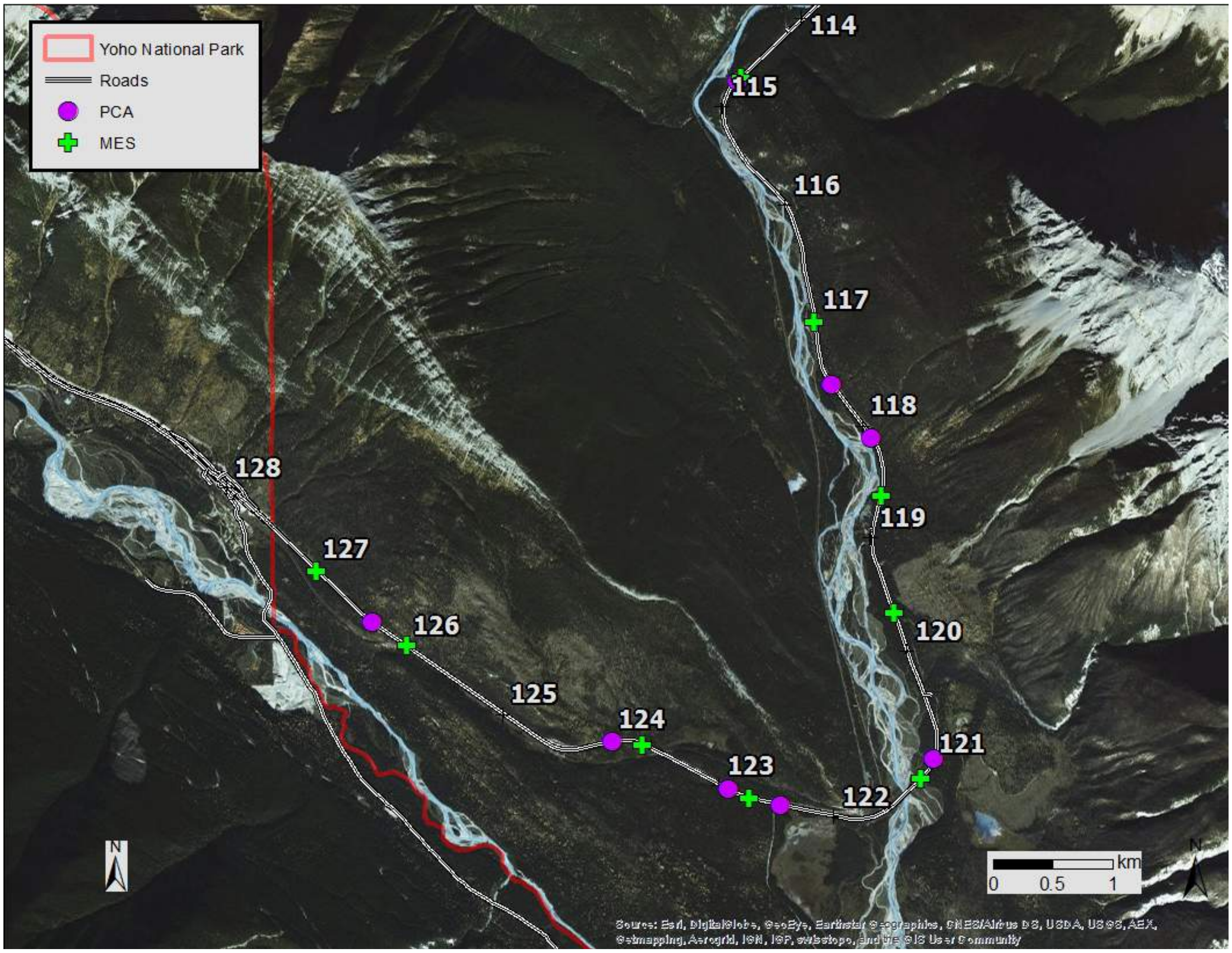


Figure 9.6: Convergence between proposed Zone D Mitigation Emphasis Sites (MES) and Parks Canada's (PCA) recommended mitigation sites on the TCH in Yoho National Park, British Columbia.

Appendix

Appendix A: Mitigation Emphasis Site Summaries (1–26)

Informational summary sheets were prepared for each mitigation emphasis site (MES) and describe all site-specific information with regard to mitigation importance, target species, wildlife objectives, and transportation mitigation recommendations. The Summary Information Sheets are a quick and easy reference that summarizes mitigation opportunities at each MES. Red shading highlights the 12 priority mitigation sites. Italicized text is mitigation measures that are explained in detail in Appendix B.

ZONE A

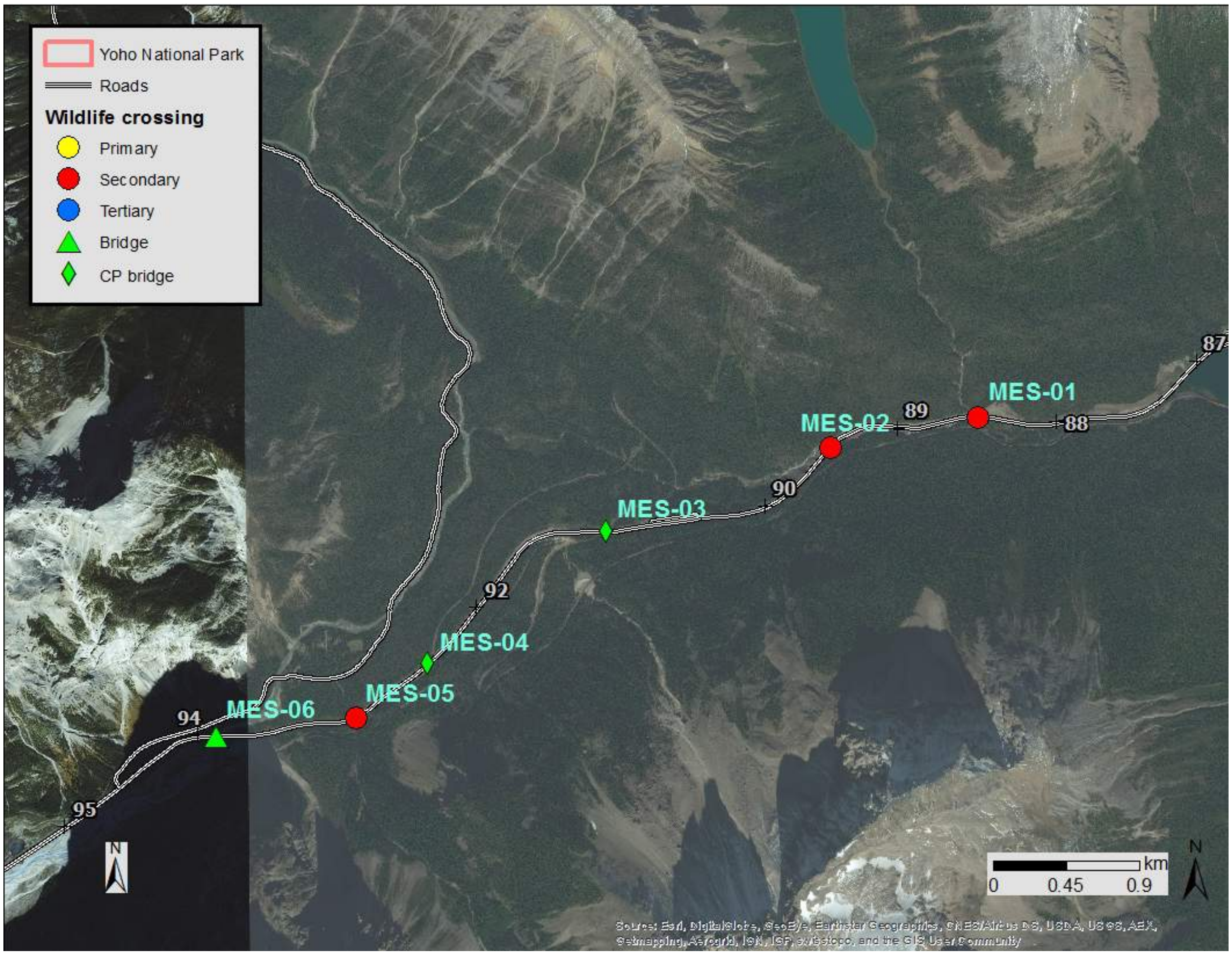


Figure A: Map showing Highway Mitigation Emphasis Zone A in Yoho National Park, British Columbia. Mitigation Emphasis Sites are indicated by category of recommended wildlife crossing structure (primary, secondary, tertiary), span bridge or CP bridge over railway tracks.

Site 1 Summary – Sherbrooke Creek	
Description	
Km number (approximate): 88.5	
Location UTM coordinates: 543479, 5698599	
Species: Multi-species: Mountain goat, grizzly bear, lynx, wolverine,	
Mortality risk: 3	
Local connectivity value: 4	
Regional connectivity_Black bear: 4	
Regional connectivity_Grizzly bear: 5	
Regional connectivity_Wolverine: 5	
Regional connectivity_Combined: 4.7	
Transportation mitigation constructability: 3	
Wildlife objectives	
• Reduce current levels of wildlife–vehicle collisions in this section of highway, primarily mountain goats, lynx, wolverine, grizzly bears and wolves. • Provide safe movement for all wildlife species across highway, primarily mountain goats, lynx, wolverine, grizzly bears.	
Existing infrastructure	
• 2 m diameter metal culvert	
Target species for mitigation planning	
WVC reduction: Mountain goats and common species. **Regional conservation and connectivity**: High elevation localized species (mountain goats) and fragmentation-sensitive species (lynx, wolverine, grizzly bears and wolves).	
Transportation mitigation opportunities	
Score: 3	
To ensure movement of wildlife through the area and reduce wildlife-vehicle collisions, fencing and construction of wildlife *underpass* is recommended. Selection of design type is dependent on terrain and engineering constraints; arched underpass structure is the preferred design. The underpass would need to be extended more to east than west for suitable entry/exit for wildlife. Minimum dimension for **secondary** underpass is 3 m high x 9-11 m wide high due to topographical constraints and high likelihood of movement by fragmentation-sensitive species (lynx, wolverine, grizzly bear) and mountain goats through this area. Given high water levels and Class 3 rapids on the Kicking Horse River during much of summer a 7-10 m wide wildlife footbridge (overpass) could be constructed to span the river. *This location will require a site visit with engineers to discuss possible options for construction of different crossing structure types and designs given the characteristics at this challenging site. F*encing* is recommended to funnel movements to the crossing structure. Fencing should be continuous with the new mitigation structures and fencing installed on Phase 4A (km 0-6), from the AB-BC border to ca. Wapta Lake. Fencing notes: Snow may be a concern at this location due to high annual snowfall.	

Figure A1: Map showing Highway Mitigation Emphasis Site 1 in Yoho National Park, British Columbia.

Site 2 Summary – Double Culverts	
Description	
Km number (approximate): 89.5	
Location UTM coordinates: 542569, 5698411	
Species: Multi-species: Mountain goat, grizzly bear, lynx, wolverine,	
Mortality risk: 3	
Local connectivity value: 3	
Regional connectivity_Black bear: 4	
Regional connectivity_Grizzly bear: 4	
Regional connectivity_Wolverine: 4	
Regional connectivity_Combined: 4.0	
Transportation mitigation constructability: 3	
Wildlife objectives	
• Reduce current levels of wildlife–vehicle collisions in this section of highway, primarily mountain goats, lynx, wolverine, grizzly bears and wolves. • Provide safe movement for all wildlife species across highway, primarily mountain goats, lynx, wolverine, grizzly bears.	
Existing infrastructure	
• 2 large diameter culverts	
Target species for mitigation planning	
WVC reduction: Mountain goats and common species. **Regional conservation and connectivity**: High elevation localized species (mountain goats) and fragmentation-sensitive species (lynx, wolverine, grizzly bears and wolves).	
Transportation mitigation opportunities	
Score: 3	
To ensure movement of wildlife through the area and reduce wildlife-vehicle collisions, fencing and construction of wildlife *underpass* is recommended. Selection of design type is dependent on terrain and engineering constraints; open-span preferred design. Minimum dimension for a **secondary** underpass is 3 m high x 11 m wide due to high likelihood of movement by fragmentation-sensitive species (lynx, wolverine, grizzly bear) and mountain goats through this area. F*encing* is recommended to funnel movements to the crossing structure. Fencing should be continuous with adjacent mitigation structures at MES 1 and 3. Fencing notes: Snow may be a concern at this location due to high annual snowfall.	

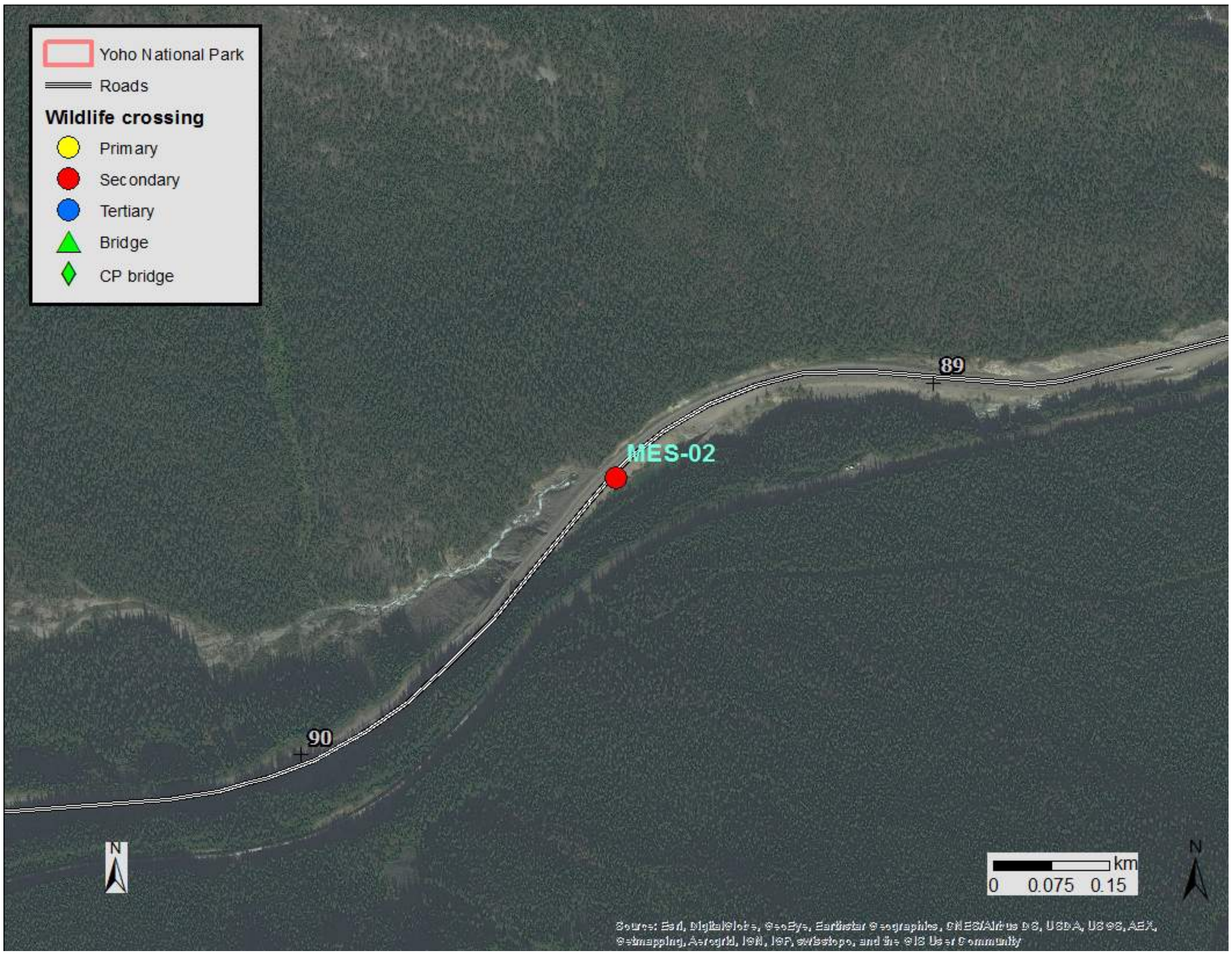


Figure A2: Map showing Highway Mitigation Emphasis Site 2 in Yoho National Park, British Columbia.

Site 3 Summary – Spiral Tunnels	
Description	
Km number (approximate): 91.0	
Location UTM coordinates: 541181, 5697896	
Species: Multi-species. Deer, moose, lynx, wolf, wolverine, bears	
Mortality risk: 1	
Local connectivity value: 3	
Regional connectivity_Black bear: 2	
Regional connectivity_Grizzly bear: 3	
Regional connectivity_Wolverine: 3	
Regional connectivity_Combined: 2.7	
Transportation mitigation constructability: 4	
Wildlife objectives	
• Reduce current levels of wildlife–vehicle collisions in this section of highway, primarily deer, moose, bears and wolves. • Provide safe movement for all wildlife species across highway, primarily deer, moose, bears and wolves.	
Existing infrastructure	
• CP Rail mainline bridge	
Target species for mitigation planning	
WVC reduction: Common species. **Regional conservation and connectivity**: Common species.	
Transportation mitigation opportunities	
Score: 4	
The existing CP Rail bridge structure may be facilitating some wildlife movement under the TCH at this location. Sections of the TCH in Banff National Park have below-grade CPR bridges and pass wildlife. Highway expansion at this site is an opportunity to reconstruct the existing span bridge to allow for a wildlife travel path on both sides (ca. 6 m wide) wider bridge span. The new bridge structure should be constructed with wide support pillars equally wide or wider than the reconstructed span with wildlife travel paths. F*encing* is recommended to funnel movements to the crossing structure. Fencing should be continuous with adjacent mitigation structures at MES 2 and 4.	

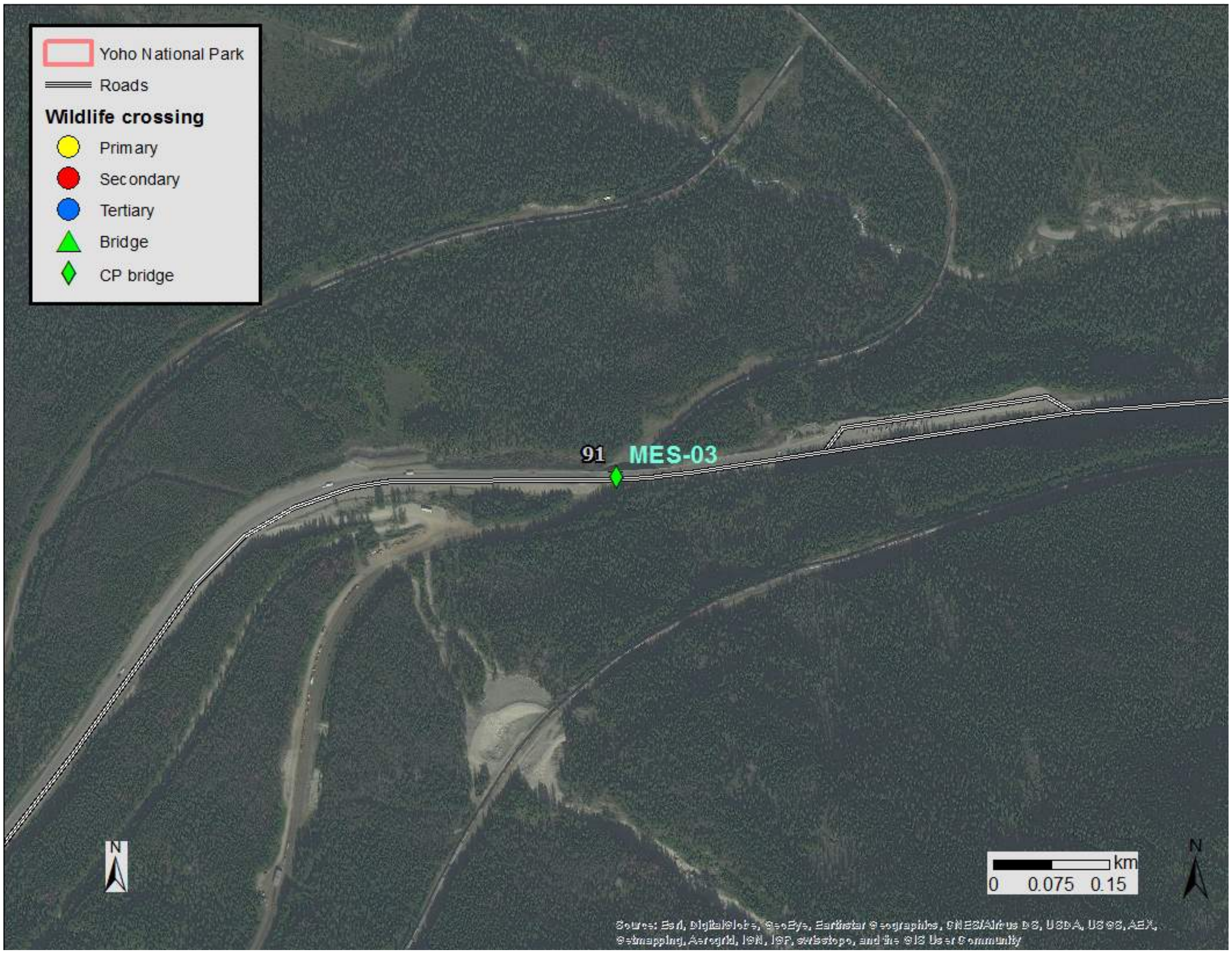


Figure A3: Map showing Highway Mitigation Emphasis Site 3 in Yoho National Park, British Columbia

Site 4 Summary – CP Bridge West	
Description	
Km number (approximate): 92.5	
Location UTM coordinates: 540083, 5697080	
Species: Multi-species. Deer, moose, lynx, wolf, wolverine, bears	
Mortality risk: 2	
Local connectivity value: 3	
Regional connectivity_Black bear:	
Regional connectivity_Grizzly bear:	
Regional connectivity_Wolverine:	
Regional connectivity_Combined: 3.0	
Transportation mitigation constructability: 4	
Wildlife objectives	
• Reduce current levels of wildlife–vehicle collisions in this section of highway, primarily deer, moose, bears and wolves. • Provide safe movement for all wildlife species across highway, primarily deer, moose, bears and wolves.	
Existing infrastructure	
• CP Rail mainline bridge	
Target species for mitigation planning	
WVC reduction: Common species. **Regional conservation and connectivity**: Common species primarily.	
Transportation mitigation opportunities	
Score: 4	
The existing CP Rail bridge structure may be facilitating some wildlife movement under the TCH at this location. Sections of the TCH in Banff National Park have below-grade CPR bridges and pass wildlife. Highway expansion at this site is an opportunity to reconstruct the existing span bridge to allow for a wildlife travel path on both sides (ca. 6 m wide) wider bridge span. The new bridge structure should be constructed with wide support pillars equally wide or wider than the reconstructed span with wildlife travel paths. F*encing* is recommended to funnel movements to the crossing structure. Fencing should be continuous with adjacent mitigation structures at MES 3 and 5.	

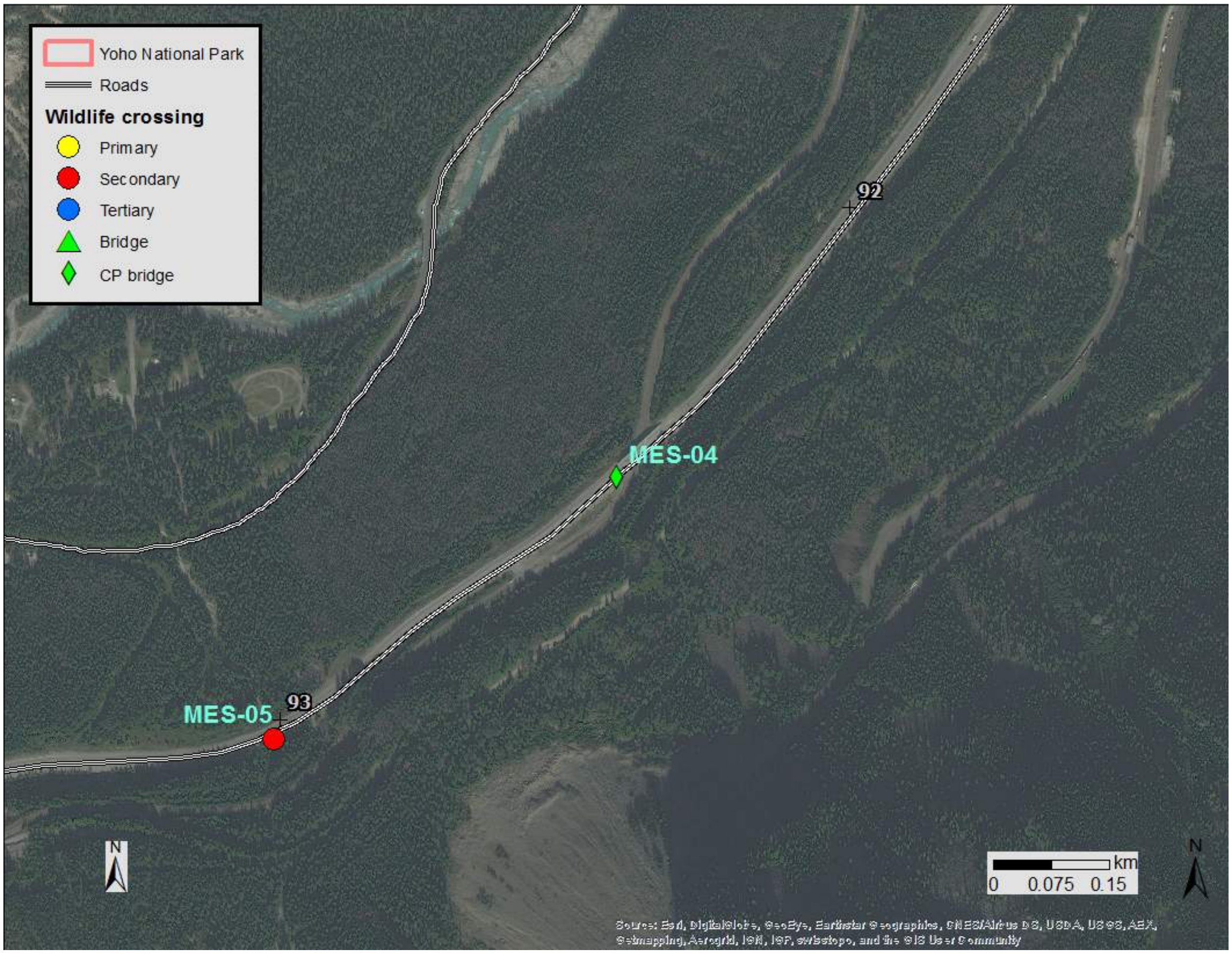


Figure A4: Map showing Highway Mitigation Emphasis Site 4 and 5 in Yoho National Park, British Columbia

Site 5 Summary – Monarch Creek	
Description	
Km number (approximate): 93.0	
Location UTM coordinates: 539642, 5696742	
Species: Multi-species: Deer, moose, lynx, wolf, wolverine, bears	
Mortality risk: 1	
Local connectivity value: 3	
Regional connectivity_Black bear: 1	
Regional connectivity_Grizzly bear: 2	
Regional connectivity_Wolverine: 1	
Regional connectivity_Combined: 1.3	
Transportation mitigation constructability: 3	
Wildlife objectives	
• Reduce current levels of wildlife–vehicle collisions in this section of highway, primarily deer, moose, lynx, wolverines, bears and wolves. • Provide safe movement for all wildlife species across highway, primarily deer, moose, lynx, wolverines, bears and wolves.	
Existing infrastructure	
• Culvert at Monarch Creek	
Target species for mitigation planning	
WVC reduction: Common species and fragmentation-sensitive species. **Regional conservation and connectivity**: Common and fragmentation-sensitive species.	
Transportation mitigation opportunities	
Score: 3	
To ensure movement of wildlife through the area and reduce wildlife-vehicle collisions, fencing and construction of wildlife *underpass* is recommended. Selection of design type is dependent on terrain and engineering constraints; open-span preferred design. Minimum dimension for **secondary** wildlife underpass is 3 m high x 11 m wide due to high likelihood of movement by fragmentation-sensitive species (lynx, wolverine, grizzly bear) and mountain goats through this area. F*encing* is recommended to funnel movements to the crossing structure. Fencing should be continuous with adjacent mitigation structures at MES 4 and 6. Fencing notes: Snow not likely a concern at this location.	

Figure A5: Map showing Highway Mitigation Emphasis Site 5 in Yoho National Park, British Columbia

Site 6 Summary – KHR_Field Hill	
Description	
Km number (approximate): 93.8	
Location UTM coordinates: 538780, 5696632	
Species: Multi-species: Mountain goats, deer, elk, moose, wolves, bears	
Mortality risk: 2	
Local connectivity value: 4	
Regional connectivity_Black bear: 3	
Regional connectivity_Grizzly bear: 2	
Regional connectivity_Wolverine: 1	
Regional connectivity_Combined: 2.0	
Transportation mitigation constructability: 5	
Wildlife objectives	
• Reduce current levels of wildlife–vehicle collisions in this section of highway, primarily mountain goats, deer, moose, and wolves. • Provide safe movement for all wildlife species across highway, primarily mountain goats, deer, moose, and wolves.	
Existing infrastructure	
• Bridge at base of Field Hill	
Target species for mitigation planning	
WVC reduction: Common species, and mountain goats. **Regional conservation and connectivity**: Mountain goats and common species.	
Transportation mitigation opportunities	
Score: 5	
Mountain goat observations are clustered on both sides of TCH at Mt Field and Mt Stephen. The existing bridge structure may be facilitating some wildlife movement under the TCH. Although camera monitoring at this location showed no wildlife use (Flagg 2015), elk have been seen in the right-of-way near this site. Highway expansion at this site will happen and is an opportunity to reconstruct the bridge supports to allow for a wider path for wildlife travel (≥ 6m wide). The new bridge structure should be constructed with wide support pillars equally wide or wider than the reconstructed span with wildlife travel paths. F*encing* is recommended to funnel movements to the crossing structure. Fencing should continue from MES 5 (Monarch Cr) and terminate at the bridge structure at this site. *Animal-detection system (ADS*): At western terminus of fence and bridge structure at base of Field Hill, install animal-detection system (with warning signage) to warn motorists of potential wildlife on or near road. The ADS with warning signage should cover the section of highway without fencing between MES 6 and 7. Fencing notes: Snow not likely a concern at this location due to lower elevation and wind gusts during winter.	

Figure A6: Map showing Highway Mitigation Emphasis Site 6 in Yoho National Park, British Columbia

ZONE B

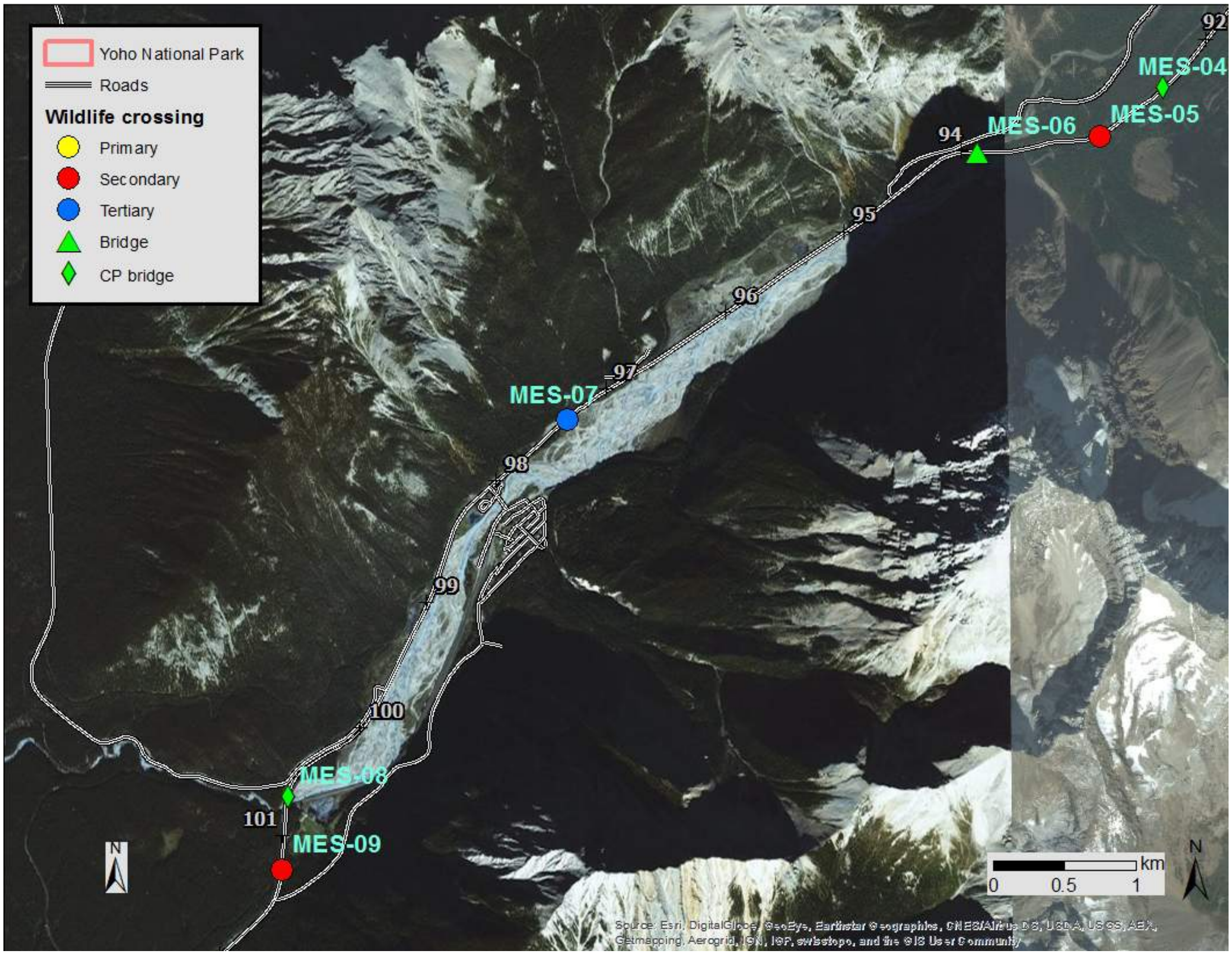


Figure B: Map showing Highway Mitigation Emphasis Zone B in Yoho National Park, British Columbia. Sites are indicated by category of recommended wildlife crossing structure (primary, secondary, tertiary), span bridge or CP bridge over railway tracks.

Site 7 Summary – East of Field	
Description	
Km number (approximate): 97.3	
Location UTM coordinates: 535911, 5694760	
Species: Multi-species: Elk, deer	
Mortality risk: 2	
Local connectivity value: 3	
Regional connectivity_Black bear: 3	
Regional connectivity_Grizzly bear: 3	
Regional connectivity_Wolverine: 3	
Regional connectivity_Combined: 3.0	
Transportation mitigation constructability: 3	
Wildlife objectives	
• Reduce current levels of wildlife–vehicle collisions in this section of highway, primarily elk, deer, moose, and wolves. • Provide safe movement for all wildlife species across highway, primarily elk, deer, moose, and wolves.	
Existing infrastructure	
• None	
Target species for mitigation planning	
WVC reduction: Common species. **Regional conservation and connectivity**: Common species primarily.	
Transportation mitigation opportunities	
Score: 3	
To ensure movement of wildlife through the area and reduce wildlife-vehicle collisions, fencing and construction of **tertiary** wildlife *underpass* is recommended. Selection of design type is dependent on terrain and engineering constraints. Minimum dimension for underpass is 4 m high x 7 m wide, as it will need to be able to pass elk, the most abundant ungulate in the area. *Fencing*: should be used to guide wildlife to the wildlife *underpass* with 1) continuous fencing to MES8 and 6 or 2) wing fencing option with an optional *animal detection system.* If wing *fencing* (200–500 m depending on terrain) is used it should be installed to funnel movements to the underpass structure. South-side fencing should begin near the town of Field and run along the TCH to the underpass and east of the underpass 100-200 m. North-side fencing should begin roughly at same location on south-side (Field entrance) and continue to location where south-side fence terminates. *Animal-detection system (ADS*; *optional*): As part of the wing fencing option at eastern terminus of fence install animal-detection system (with warning signage) to warn motorists of potential wildlife on or near road. The ADS with warning signage should cover the section of highway without fencing east of MES 7 to MES 6 (KHR_Field Hill). Fencing notes: Snow not likely a concern at this location due to lower elevation and wind gusts during winter.	

Figure A7: Map showing Highway Mitigation Emphasis Site 7 in Yoho National Park, British Columbia

Site 8 Summary – KHR _Natural Bridge	
Description	
Km number (approximate): 100.8	
Location UTM coordinates: 533951, 5692114	
Species: Multi-species: Deer, moose, wolves, bears	
Mortality risk: 1	
Local connectivity value: 5	
Regional connectivity_Black bear: 5	
Regional connectivity_Grizzly bear: 4	
Regional connectivity_Wolverine: 2	
Regional connectivity_Combined: 3.7	
Transportation mitigation constructability: 5	
Wildlife objectives	
• Reduce current levels of wildlife–vehicle collisions in this section of highway, primarily deer, moose, bears, and wolves. • Provide safe movement for all wildlife species across highway, primarily deer, moose, bears, and wolves.	
Existing infrastructure	
• Kicking Horse Bridge and CP Rail Bridge	
Target species for mitigation planning	
WVC reduction: Common species. **Regional conservation and connectivity**: Common species primarily, including wolves and bears	
Transportation mitigation opportunities	
Score: 5	
Bridge reconstruction during TCH expansion would allow for wider bridge span and facilitate movement of wildlife, including above high-water mark (see *Underpass with waterflow* Hot sheet). There is space on the east side of the bridge supports to construct a wildlife path (walkway) minimum 6 m wide. *Fencing* should be used to guide wildlife to the bridge with 1) continuous fencing to MES7 or 2) an optional *animal detection system* at eastern fence end where the highway enters the Field Flats. Fencing on the west side of the underpass should be continuous, joining adjacent MES 9. *Animal-detection system (ADS; optional)*: At eastern terminus of fence install animal-detection system (with warning signage) to warn motorists of potential wildlife on or near road. Fencing notes: Snow not likely a concern at this location due to lower elevation.	

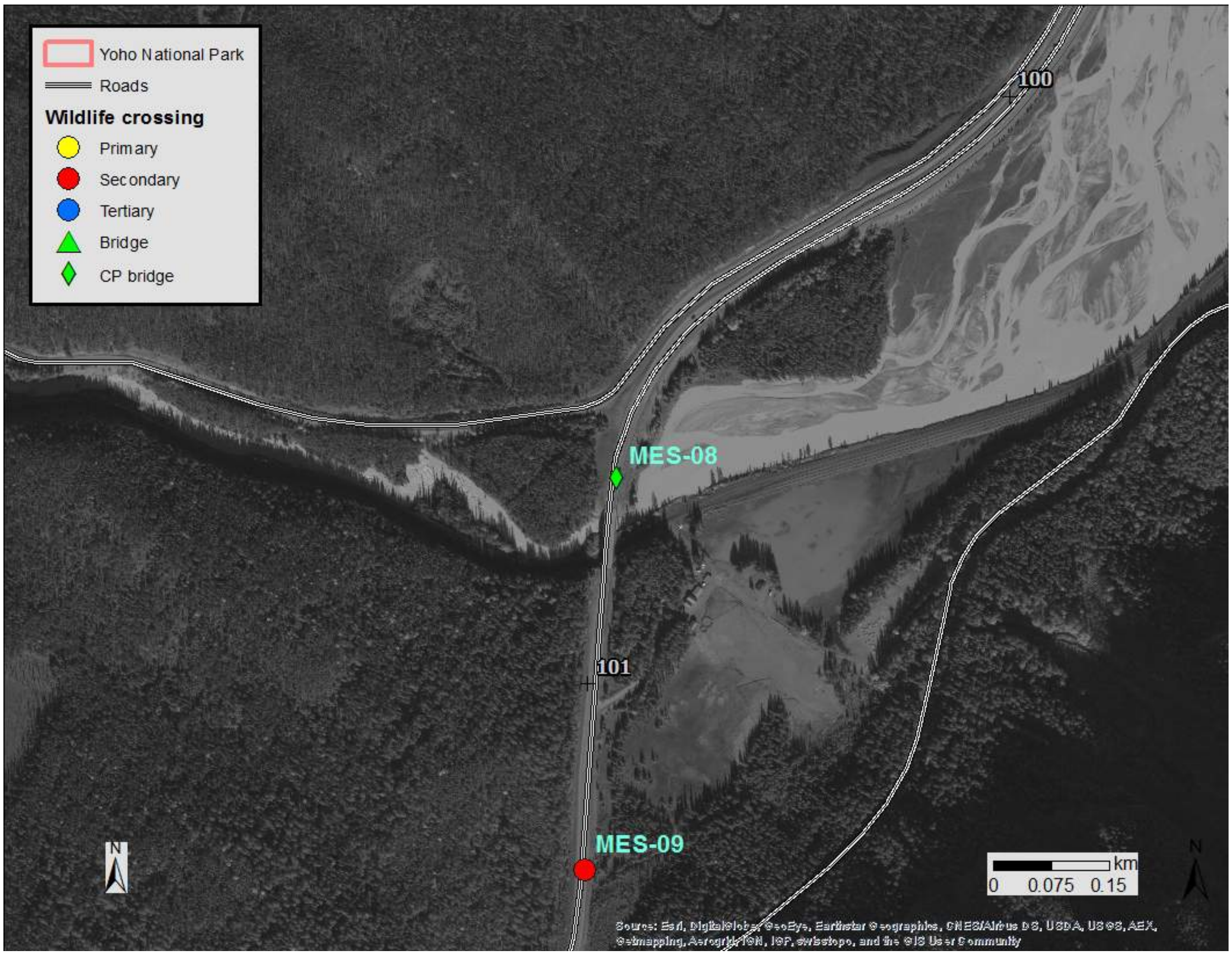


Figure A8: Map showing Highway Mitigation Emphasis Site 8 in Yoho National Park, British Columbia

ZONE C

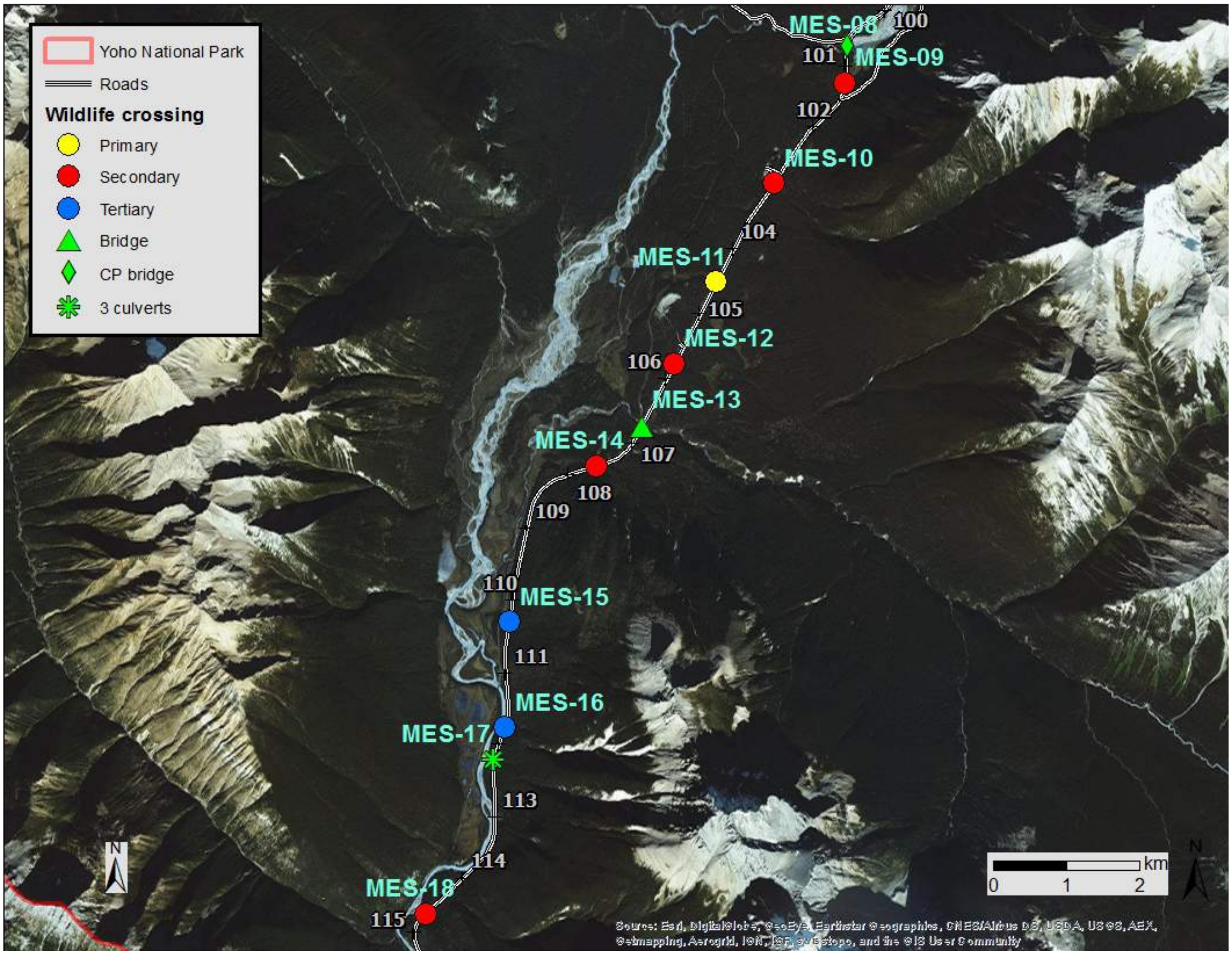


Figure C: Map showing Highway Mitigation Emphasis Zone C in Yoho National Park, British Columbia. Sites are indicated by category of recommended wildlife crossing structure (primary, secondary, tertiary), span bridge or CP bridge over railway tracks. MES 17 is location of 3 constructed culverts.

Site 9 Summary – Cabin	
Description	
Km number (approximate): 101.3	
Location UTM coordinates: 533911, 5691609	
Species: Multi-species: Elk, deer, moose, lynx, wolves, bears	
Mortality risk: 1	
Local connectivity value: 4	
Regional connectivity_Black bear: 3	
Regional connectivity_Grizzly bear: 4	
Regional connectivity_Wolverine: 2	
Regional connectivity_Combined: 3.0	
Transportation mitigation constructability: 4	
Wildlife objectives	
• Reduce current levels of wildlife–vehicle collisions in this section of highway, primarily deer, moose, lynx and wolves. • Provide safe movement for all wildlife species across highway, primarily deer, moose, lynx, and wolves.	
Existing infrastructure	
• None	
Target species for mitigation planning	
WVC reduction: Common species. **Regional conservation and connectivity**: Common species primarily.	
Transportation mitigation opportunities	
Score: 4	
To ensure movement of wildlife through the area and reduce wildlife-vehicle collisions, fencing and construction of **secondary** wildlife *underpass* is recommended. Selection of design type is dependent on terrain and engineering constraints; open-span preferred design. Minimum dimension for underpass is 3 m high x 11 m wide due to high likelihood of some movement by fragmentation-sensitive species (lynx, wolverine, grizzly bear) through this area. F*encing* is recommended to funnel movements to the crossing structure. Fencing should be continuous with adjacent mitigation structures at MES 10 and 8. Fencing notes: Snow not likely a concern at this location.	

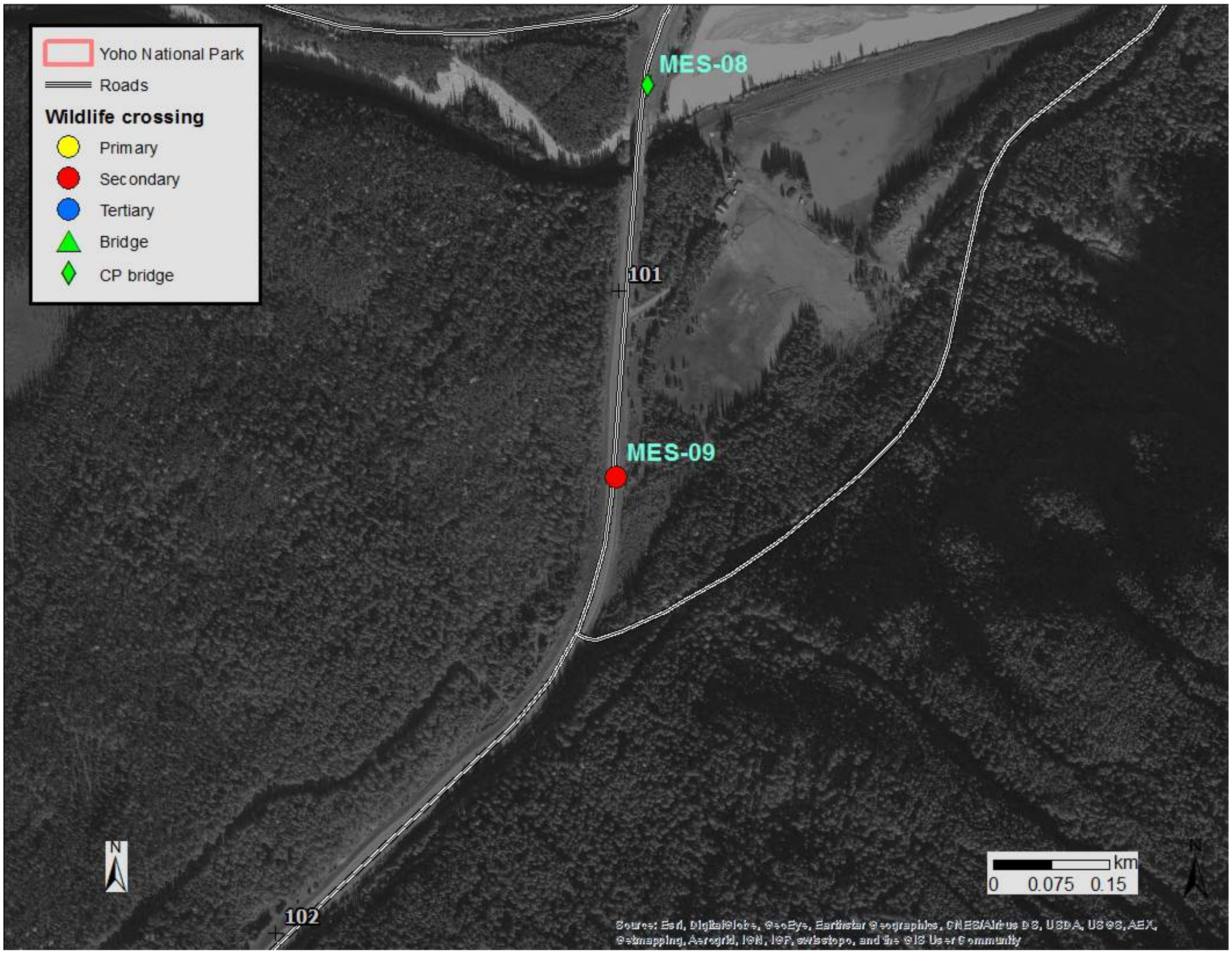


Figure A9: Map showing Highway Mitigation Emphasis Site 9 in Yoho National Park, British Columbia

Site 10 Summary – Boulder Creek	
Description	
Km number (approximate): 103.0	
Location UTM coordinates: 532941, 5690236	
Species: Multi-species: Elk, deer, moose, lynx, wolves, bears	
Mortality risk: 1	
Local connectivity value: 5	
Regional connectivity_Black bear: 2	
Regional connectivity_Grizzly bear: 1	
Regional connectivity_Wolverine: 2	
Regional connectivity_Combined: 1.7	
Transportation mitigation constructability: 5	
Wildlife objectives	
• Reduce current levels of wildlife–vehicle collisions in this section of highway, primarily deer, moose, lynx, bears and wolves. • Provide safe movement for all wildlife species across highway, primarily deer, moose, lynx, bears and wolves.	
Existing infrastructure	
• Concrete box culvert	
Target species for mitigation planning	
WVC reduction: Common species. **Regional conservation and connectivity**: Common species.	
Transportation mitigation opportunities	
Score: 5	
To ensure movement of wildlife through the area and reduce wildlife-vehicle collisions, fencing and construction of wildlife *underpass* is recommended. Selection of design type is dependent on terrain and engineering constraints; open-span preferred design. Minimum dimension for **secondary** underpass is 3 m high x 11 m wide due to high likelihood of some movement by fragmentation-sensitive species (lynx, wolverine, grizzly bear) through this area. The width of underpass should be wide enough to allow for wildlife movement at high water mark. F*encing* is recommended to funnel movements to the crossing structure. Fencing should be continuous with adjacent mitigation structures at MES 11 and 9. Fencing notes: Snow not likely a concern at this location.	

Figure A10: Map showing Highway Mitigation Emphasis Site 10 in Yoho National Park, British Columbia

Site 11 Summary – West of Boulder Creek	
Description	
Km number (approximate): 104.5	
Location UTM coordinates: 532158, 5688887	
Species: Multi-species: Deer, moose, lynx, wolves, bears	
Mortality risk: 5	
Local connectivity value: 3	
Regional connectivity_Black bear: 3	
Regional connectivity_Grizzly bear: 1	
Regional connectivity_Wolverine: 5	
Regional connectivity_Combined: 3.0	
Transportation mitigation constructability: 4	
Wildlife objectives	
• Reduce current levels of wildlife–vehicle collisions in this section of highway, primarily deer, moose, lynx, bears and wolves. • Provide safe movement for all wildlife species across highway, primarily deer, moose, lynx, bears and wolves.	
Existing infrastructure	
• 2.0 m diameter steel culvert.	
Target species for mitigation planning	
WVC reduction: Common species. **Regional conservation and connectivity**: Common species primarily.	
Transportation mitigation opportunities	
Score: 4	
To ensure movement of wildlife through the area and reduce wildlife-vehicle collisions, fencing and construction of wildlife *underpass* is recommended. Selection of design type is dependent on terrain and engineering constraints; open-span preferred design. Minimum dimension for **primary** underpass is 3.5-4.0 m high x 22 m wide due to high likelihood of some movement by fragmentation-sensitive species (lynx, wolverine, grizzly bear) through this area. Modeling indicated that this area was important for regional connectivity of wolverine population. F*encing* is recommended to funnel movements to the crossing structure. Fencing should be continuous with adjacent mitigation structures at MES 12 and 10. Fencing notes: Snow not likely a concern at this location.	

Figure A11: Map showing Highway Mitigation Emphasis Site 11 in Yoho National Park, British Columbia

Site 12 Summary – East of Ottertail	
Description	
Km number (approximate): 105.8	
Location UTM coordinates: 531582, 5687770	
Species: Multi-species: Deer, moose, lynx, wolves, bears	
Mortality risk: 5	
Local connectivity value: 4	
Regional connectivity_Black bear: 4	
Regional connectivity_Grizzly bear: 1	
Regional connectivity_Wolverine: 3	
Regional connectivity_Combined: 2.7	
Transportation mitigation constructability: 4	
Wildlife objectives	
• Reduce current levels of wildlife–vehicle collisions in this section of highway, primarily deer, moose, lynx, wolverine, bears and wolves. • Provide safe movement for all wildlife species across highway, primarily deer, moose, lynx, wolverine, bears and wolves.	
Existing infrastructure	
• 1.6 m diameter culvert	
Target species for mitigation planning	
WVC reduction: Common species. **Regional conservation and connectivity**: Common species primarily.	
Transportation mitigation opportunities	
Score: 4	
To ensure movement of wildlife through the area and reduce wildlife-vehicle collisions, fencing and construction of wildlife *underpass* is recommended. Selection of design type is dependent on terrain and engineering constraints; open-span preferred design. Minimum dimension for **secondary** underpass is 3 m high x 11 m wide due to high likelihood of some movement by fragmentation-sensitive species (lynx, wolverine, grizzly bear) through this area. Modeling indicated that this area was important for regional connectivity of wolverine population. F*encing* is recommended to funnel movements to the crossing structure. Fencing should be continuous with adjacent mitigation structures at MES 13 and 11. Fencing notes: Snow not likely a concern at this location.	

Figure A12: Map showing Highway Mitigation Emphasis Site 12 in Yoho National Park, British Columbia.

Site 13 Summary – Ottertail River	
Description	
Km number (approximate): 106.7	
Location UTM coordinates: 531127, 5686903	
Species: Multi-species: Deer, moose, lynx, wolverines, wolves, bears	
Mortality risk: 5	
Local connectivity value: 5	
Regional connectivity_Black bear: 3	
Regional connectivity_Grizzly bear: 1	
Regional connectivity_Wolverine: 3	
Regional connectivity_Combined: 2.3	
Transportation mitigation constructability: 5	
Wildlife objectives	
• Reduce current levels of wildlife–vehicle collisions in this section of highway, primarily deer, moose, lynx, wolverine, bears and wolves. • Provide safe movement for all wildlife species across highway, primarily deer, moose, lynx, wolverine, bears and wolves.	
Existing infrastructure	
• Ottertail River Bridge	
Target species for mitigation planning	
WVC reduction: Common and fragmentation-sensitive species. **Regional conservation and connectivity**: Common and fragmentation-sensitive species.	
Transportation mitigation opportunities	
Score: 5	
There are topographical constraints at this location that limit the mitigation work that can be done here. The Ottertail drainage under the bridge is steep-walled, although some wildlife movement may occur here. We do not recommend any mitigation work to take place here. The greatest benefit of ensuring local and regional connectivity through the broader Ottertail area will be from mitigations at neighbouring MES No. 11 (West of Boulder Creek), 12 (East of Ottertail) and 14 (West of Ottertail). F*encing* is recommended to funnel movements to the crossing structure. Fencing should be continuous with adjacent mitigation structures at MES 14 and 12. Fencing notes: Snow not likely a concern at this location.	

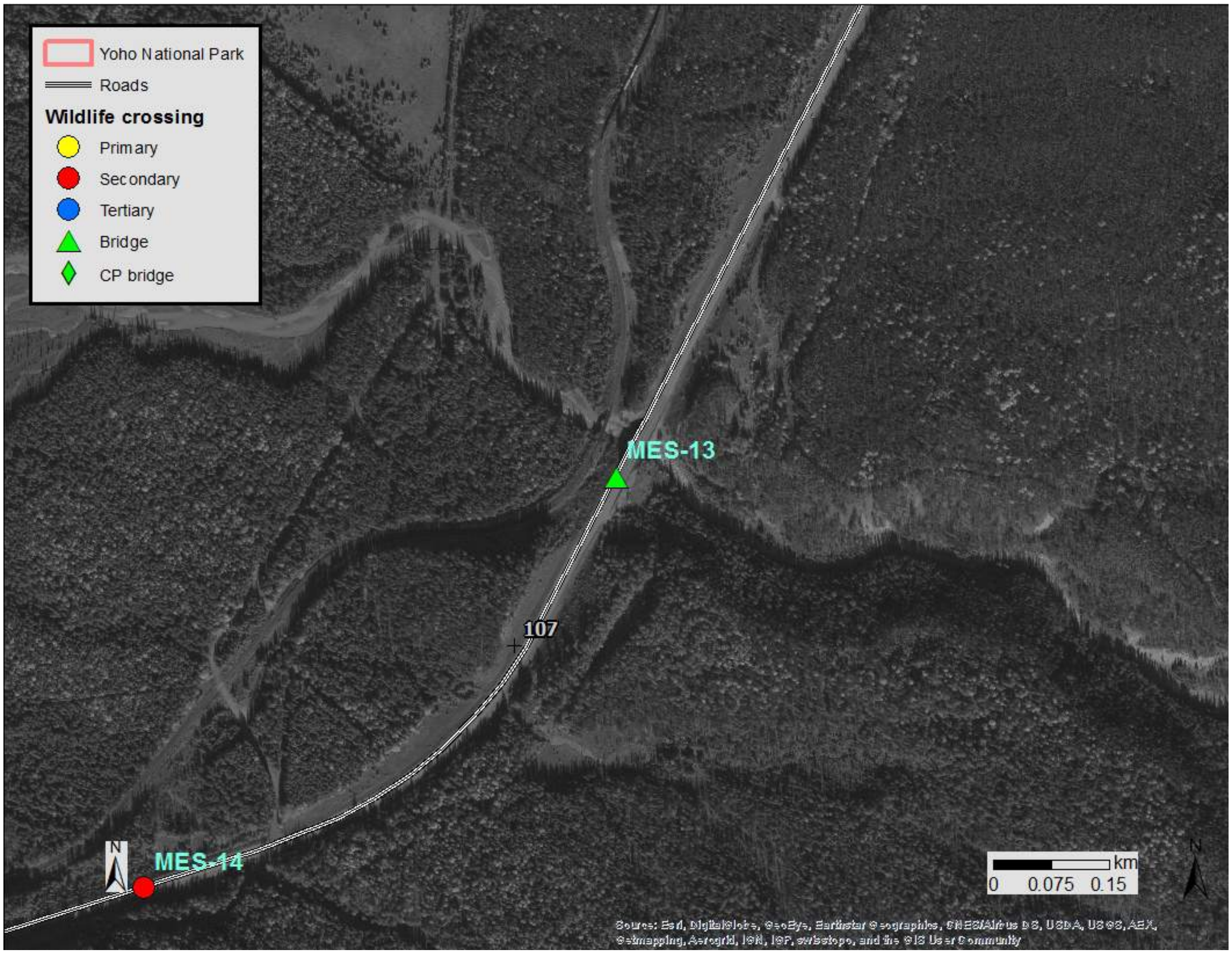


Figure A13: Map showing Highway Mitigation Emphasis Site 13 in Yoho National Park, British Columbia

Site 14 Summary – West of Ottertail	
Description	
Km number (approximate): 107.6	
Location UTM coordinates: 530518, 5686374	
Species: Multi-species: Deer, moose, lynx, wolves, bears	
Mortality risk: 4	
Local connectivity value: 4	
Regional connectivity_Black bear: 3	
Regional connectivity_Grizzly bear: 2	
Regional connectivity_Wolverine: 4	
Regional connectivity_Combined: 3.0	
Transportation mitigation constructability: 4	
Wildlife objectives	
• Reduce current levels of wildlife–vehicle collisions in this section of highway, primarily deer, moose, and wolves. • Provide safe movement for all wildlife species across highway, primarily deer, moose, and wolves.	
Existing infrastructure	
• 1.6 m diameter culvert	
Target species for mitigation planning	
WVC reduction: Common species. **Regional conservation and connectivity**: Common species primarily	
Transportation mitigation opportunities	
Score: 4	
Modeling indicated that this area was important for local and regional connectivity of wildlife populations. Given the neighbouring Ottertail Creek under the bridge is steep-walled, the greatest benefit of ensuring local and regional connectivity through the broader Ottertail area will be from mitigations here and MES No. 12 (East of Ottertail). To ensure movement of wildlife through the area and reduce wildlife-vehicle collisions, fencing and construction of wildlife *underpass* is recommended. Selection of design type is dependent on terrain and engineering constraints; open-span preferred design. Minimum dimension for **secondary** underpass is 3 m high x 11 m wide due to high likelihood of some movement by fragmentation-sensitive species (lynx, wolverine, grizzly bear) through this area. F*encing* is recommended to funnel movements to the crossing structure. Fencing should be continuous with adjacent mitigation structures at MES 15 and 13. Fencing notes: Snow not likely a concern at this location.	

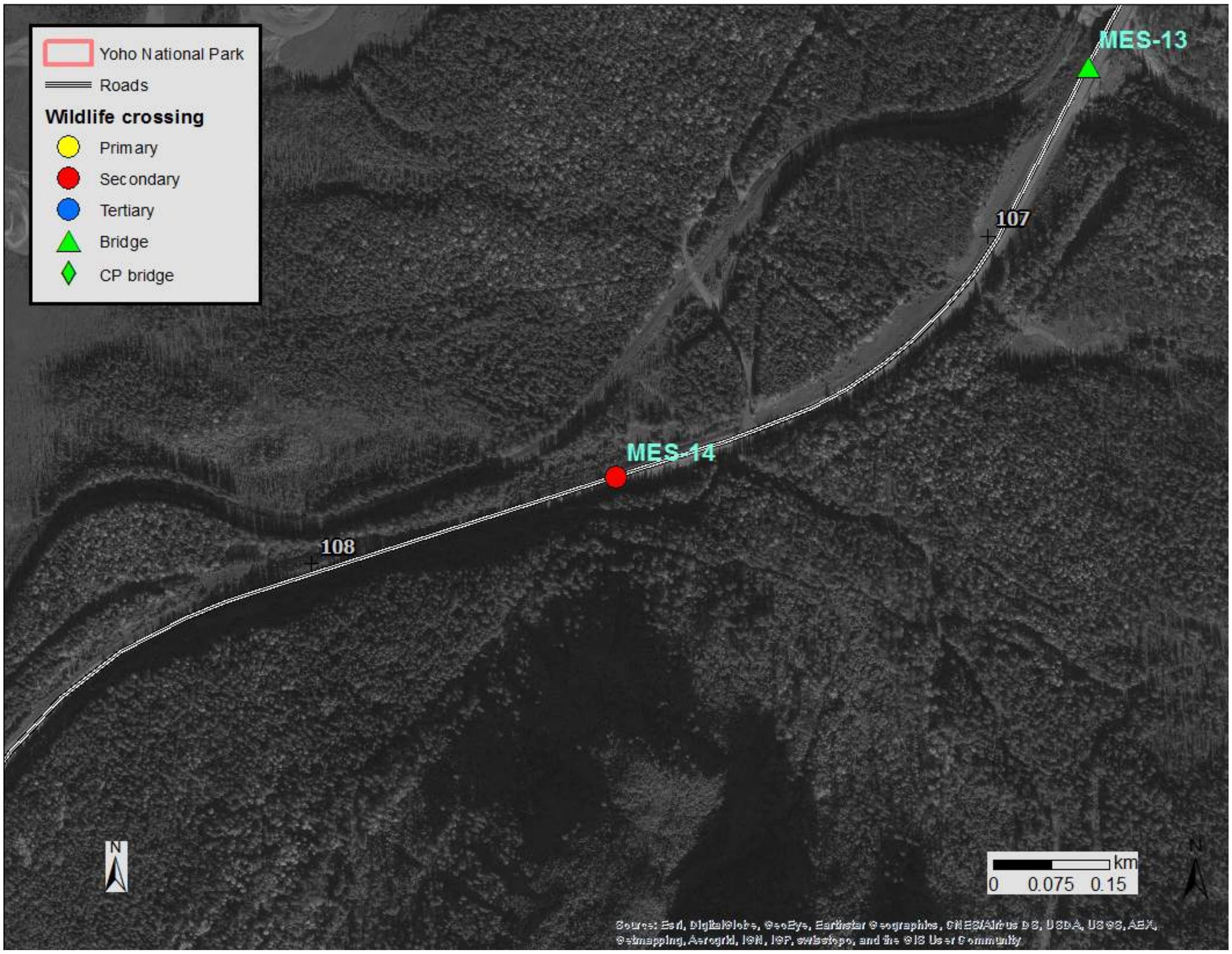


Figure A14: Map showing Highway Mitigation Emphasis Site 14 in Yoho National Park, British Columbia

Site 15 Summary – Unnamed	
Description	
Km number (approximate): 110.3	
Location UTM coordinates: 529326, 5684238	
Species: Multi-species: Deer, moose, lynx, wolves, bears	
Mortality risk: 2	
Local connectivity value: 3	
Regional connectivity_Black bear: 3	
Regional connectivity_Grizzly bear: 4	
Regional connectivity_Wolverine: 5	
Regional connectivity_Combined: 4.0	
Transportation mitigation constructability: 4	
Wildlife objectives	
• Reduce current levels of wildlife–vehicle collisions in this section of highway, primarily deer, moose, and wolves. • Provide safe movement for all wildlife species across highway, primarily deer, moose, and wolves.	
Existing infrastructure	
• None	
Target species for mitigation planning	
WVC reduction: Common species. **Regional conservation and connectivity**: Common species primarily.	
Transportation mitigation opportunities	
Score: 4	
To ensure movement of wildlife through the area and reduce wildlife-vehicle collisions, fencing and construction of a **tertiary** wildlife *underpass* is recommended. Selection of design type is dependent on terrain and engineering constraints. Minimum dimension for underpass is concrete box culvert (2.4 m high x 3.6 m wide) or 4 m high x 7 m wide elliptical multi-plate steel culvert. F*encing* is recommended to funnel movements to the crossing structure. Fencing should be continuous with adjacent mitigation structures at MES 16 and 14. Fencing notes: Snow not likely a concern at this location.	

Figure A15: Map showing Highway Mitigation Emphasis Site 15 in Yoho National Park, British Columbia

Site 16 Summary – East of 3 Culverts	
Description	
Km number (approximate): 111.7	
Location UTM coordinates: 529268, 5682799	
Species: Multi-species: Deer, moose, lynx, wolves, bears	
Mortality risk: 2	
Local connectivity value: 3	
Regional connectivity_Black bear: 3	
Regional connectivity_Grizzly bear: 2	
Regional connectivity_Wolverine: 1	
Regional connectivity_Combined: 2.0	
Transportation mitigation constructability: 3	
Wildlife objectives	
• Reduce current levels of wildlife–vehicle collisions in this section of highway, primarily deer, moose, and wolves. • Provide safe movement for all wildlife species across highway, primarily deer, moose, and wolves.	
Existing infrastructure	
• 0.8 m diameter steel culvert	
Target species for mitigation planning	
WVC reduction: Common species. **Regional conservation and connectivity**: Common species primarily.	
Transportation mitigation opportunities	
Score: 3	
To ensure movement of wildlife through the area and reduce wildlife-vehicle collisions, fencing and construction of a **tertiary** wildlife *underpass* is recommended. Selection of design type is dependent on terrain and engineering constraints. Minimum dimension for underpass is concrete box culvert (2.4 m high x 3.6 m wide) or 4 m high x 7 m wide elliptical multi-plate steel culvert. F*encing* is recommended to funnel movements to the crossing structure. Fencing should be continuous with adjacent mitigation structures at MES 17 and 15. Fencing notes: Snow not likely a concern at this location.	

Figure A16: Map showing Highway Mitigation Emphasis Site 16 in Yoho National Park, British Columbia

Site 17 Summary – 3 Culverts	
Description	
Km number (approximate): 112.2	
Location UTM coordinates: 529106, 5682356	
Species: Multi-species: Deer, moose, lynx, wolves, bears	
Mortality risk: 2	
Local connectivity value: 3	
Regional connectivity_Black bear: 4	
Regional connectivity_Grizzly bear: 2	
Regional connectivity_Wolverine: 2	
Regional connectivity_Combined: 2.7	
Transportation mitigation constructability: Completed	
Wildlife objectives	
• Reduce current levels of wildlife–vehicle collisions in this section of highway, primarily deer, moose, and wolves. • Provide safe movement for all wildlife species across highway, primarily deer, moose, and wolves.	
Existing infrastructure	
• 3 recently installed 4' x 6' concrete box culverts, 100 m apart	
Target species for mitigation planning	
WVC reduction: Common species. **Regional conservation and connectivity**: Common species primarily.	
Transportation mitigation opportunities	
Score: Completed	
We do not categorize conservation value of this location since concrete box culverts were installed in summer 2016 (1 m high x 2.4 m wide). The 3 box culverts are separated by approximately 100 m and are large enough to pass small and medium-sized mammals, and some large mammals such as deer, black bears, lynx, cougars, possibly wolverines. F*encing* is recommended to funnel movements to the crossing structure. Fencing should be continuous with adjacent mitigation structures at MES 18 and 16. Fencing notes: Snow not likely a concern at this location.	

Figure A17: Map showing Highway Mitigation Emphasis Site 17 in Yoho National Park, British Columbia

Site 18 Summary – Finn Creek	
Description	
Km number (approximate): 114.7	
Location UTM coordinates: 528175, 5680251	
Species: Multi-species: Deer, moose, lynx, wolves, bears	
Mortality risk: 2	
Local connectivity value: 3	
Regional connectivity_Black bear: 4	
Regional connectivity_Grizzly bear: 3	
Regional connectivity_Wolverine: 3	
Regional connectivity_Combined: 3.3	
Transportation mitigation constructability: 3	
Wildlife objectives	
• Reduce current levels of wildlife–vehicle collisions in this section of highway, primarily deer, moose, lynx, wolverine, bears, and wolves. • Provide safe movement for all wildlife species across highway, primarily deer, moose, lynx, wolverine, bears, wolves and wolves.	
Existing infrastructure	
• None	
Target species for mitigation planning	
WVC reduction: Common species. **Regional conservation and connectivity**: Common species primarily but also , lynx, wolverine, bears, and wolves.	
Transportation mitigation opportunities	
Score: 3	
To ensure movement of wildlife through the area and reduce wildlife-vehicle collisions, fencing and construction of wildlife *underpass* is recommended. Selection of design type is dependent on terrain and engineering constraints; open-span preferred design. Minimum dimension for **secondary** underpass is 3 m high x 11 m wide due to high likelihood of some movement by fragmentation-sensitive species (lynx, wolverine, grizzly bear, wolves) through this area. F*encing* is recommended to funnel movements to the crossing structure. Fencing should be continuous with adjacent mitigation structures at MES 19 and 17. Fencing notes: Snow not likely a concern at this location.	

Figure A18: Map showing Highway Mitigation Emphasis Site 18 in Yoho National Park, British Columbia.

ZONE D

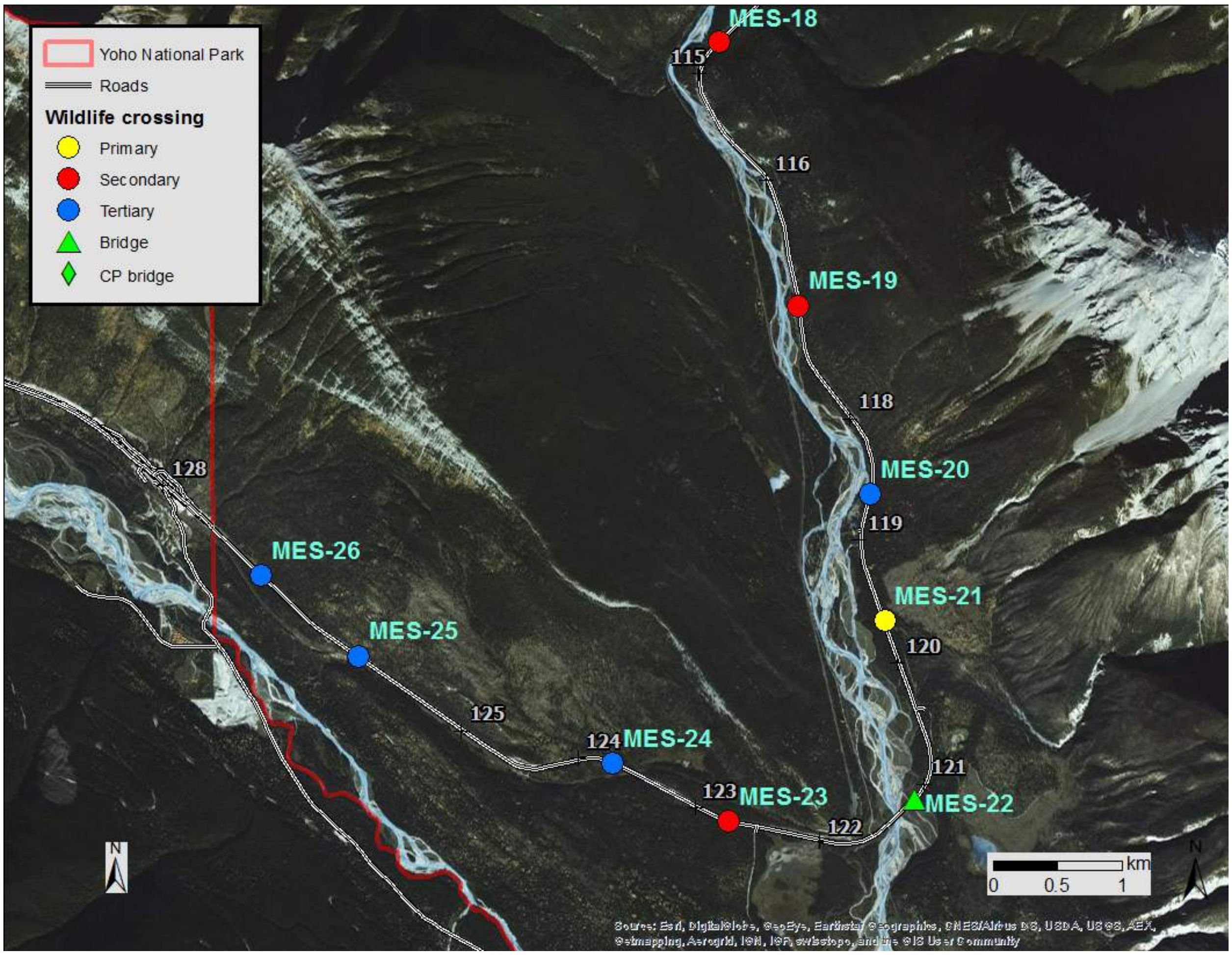


Figure D: Map showing Highway Mitigation Emphasis Zone D in Yoho National Park, British Columbia. Sites are indicated by category of recommended wildlife crossing structure (primary, secondary, tertiary), span bridge or CP bridge over railway tracks.

Site 19 Summary – Rock Cut	
Description	
Km number (approximate): 117.0	
Location UTM coordinates: 528792, 5678199	
Species: Multi-species: Deer, moose, lynx, wolverine, wolves, bears	
Mortality risk: 2	
Local connectivity value: 3	
Regional connectivity_Black bear: 3	
Regional connectivity_Grizzly bear: 5	
Regional connectivity_Wolverine: 5	
Regional connectivity_Combined: 4.3	
Transportation mitigation constructability: 4	
Wildlife objectives	
• Reduce current levels of wildlife–vehicle collisions in this section of highway, primarily deer, moose, and wolves. • Provide safe movement for all wildlife species across highway, primarily fragmentation-sensitive species including lynx, wolverine, grizzly bears and wolves.	
Existing infrastructure	
• None	
Target species for mitigation planning	
WVC reduction: Common species. **Regional conservation and connectivity**: Common and fragmentation-sensitive species.	
Transportation mitigation opportunities	
Score: 4	
Modeling indicated that this area was moderately important for local and regional connectivity of grizzly bear and wolverine populations. To ensure movement of these species and other wildlife through the area and reduce wildlife-vehicle collisions, fencing and construction of wildlife *underpass* or *overpass* is recommended. Selection of design type is dependent on terrain and engineering constraints; open-span preferred design. **Secondary** *underpass* should be open span and 3 x 11 m. Minimum dimension for the *overpass* is 30-40 m wide due to high likelihood of some movement by fragmentation-sensitive species (lynx, wolverine, grizzly bear, wolves) through this area. F*encing* is recommended to funnel movements to the crossing structure. Fencing should be continuous with adjacent mitigation structures at MES 20 and 18. Fencing notes: Snow not likely a concern at this location.	

Figure A19: Map showing Highway Mitigation Emphasis Site 19 in Yoho National Park, British Columbia

Site 20 Summary – West of Rock Cut	
Description	
Km number (approximate): 118.6	
Location UTM coordinates: 529351, 5676734	
Species: Multi-species: Deer, moose, lynx, wolves, bears	
Mortality risk: 4	
Local connectivity value: 4	
Regional connectivity_Black bear significance: 2	
Regional connectivity_Grizzly bear significance: 2	
Regional connectivity_Wolverine significance: 1	
Regional connectivity_Combined: 1.3	
Transportation mitigation constructability: 4	
Wildlife objectives	
• Reduce current levels of wildlife–vehicle collisions in this section of highway, primarily deer, moose, and wolves. • Provide safe movement for all wildlife species across highway, primarily deer, moose, and wolves.	
Existing infrastructure	
• None	
Target species for mitigation planning	
WVC reduction: Common species. **Regional conservation and connectivity**: Common species primarily	
Transportation mitigation opportunities	
Score: 4	
To ensure movement of wildlife through the area and reduce wildlife-vehicle collisions, fencing and construction of **tertiary** wildlife *underpass* is recommended. Selection of design type is dependent on terrain and engineering constraints. Minimum dimension for underpass is 4 m high x 7 m wide elliptical multi-plate steel culvert. F*encing* is recommended to funnel movements to the crossing structure. Fencing should be continuous with adjacent mitigation structures at MES 21 and 19. Fencing notes: Snow not likely a concern at this location.	

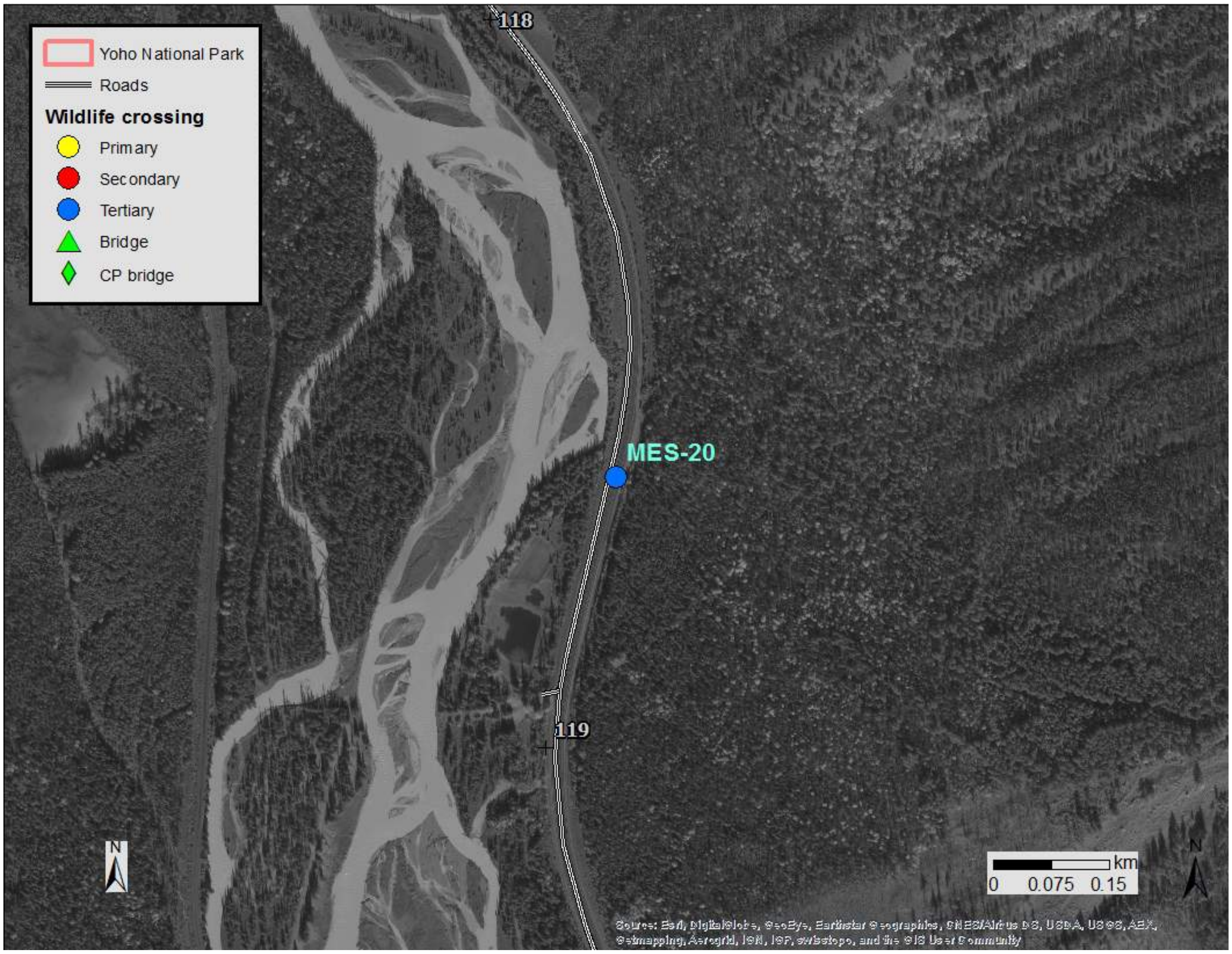


Figure A20: Map showing Highway Mitigation Emphasis Site 20 in Yoho National Park, British Columbia

Site 21 Summary – Hoodoos	
Description	
Km number (approximate): 119.7	
Location UTM coordinates: 529462, 5675754	
Species: Multi-species: Deer, moose, lynx, wolves, bears	
Mortality risk: 4	
Local connectivity value: 4	
Regional connectivity_Black bear significance: 2	
Regional connectivity_Grizzly bear significance: 3	
Regional connectivity_Wolverine significance: 4	
Regional connectivity_Combined: 3.0	
Transportation mitigation constructability: 4	
Wildlife objectives	
• Reduce current levels of wildlife–vehicle collisions in this section of highway, primarily deer, moose, and wolves. • Provide safe movement for all wildlife species across highway, primarily moose, wolverines, cougars, and wolves.	
Existing infrastructure	
• None	
Target species for mitigation planning	
WVC reduction: Common species including wolves. **Regional conservation and connectivity**: Moose, wolves, wolverines and bears.	
Transportation mitigation opportunities	
Score: 4	
Modeling indicated that this area was important for regional connectivity of wolverine population. There is high likelihood of some movement by fragmentation-sensitive species (lynx, wolverine, grizzly bear, wolves) through this area. Fencing and construction of **primary** wildlife *under-* or *overpass* is recommended. Selection of design type is dependent on terrain and engineering constraints, primarily the high water table in area; Minimum dimension for underpass is 3.5-4.0 m high x 22 m wide. Minimum dimensions for overpass is 40 m wide. F*encing* is recommended to funnel movements to the crossing structure. Fencing should be continuous with adjacent mitigation structures at MES 22 and 20. Fencing notes: Snow not likely a concern at this location.	

Figure A21: Map showing Highway Mitigation Emphasis Site 21 in Yoho National Park, British Columbia

Site 22 Summary – KHR Bridge_Beaverfoot	
Description	
Km number (approximate): 121.3	
Location UTM coordinates: 529688, 5674365	
Species: Multi-species: Deer, elk, moose, cougars, lynx, wolves, bears	
Mortality risk: 5	
Local connectivity value: 5	
Regional connectivity_Black bear significance: 4	
Regional connectivity_Grizzly bear significance: 4	
Regional connectivity_Wolverine significance: 4	
Regional connectivity_Combined: 4.0	
Transportation mitigation constructability: 5	
Wildlife objectives	
• Reduce current levels of wildlife–vehicle collisions in this section of highway, primarily deer, moose, elk and wolves. • Provide safe movement for all wildlife species across highway, primarily deer, moose, elk, wolverines, bears and wolves.	
Existing infrastructure	
• Kicking Horse River Bridge	
Target species for mitigation planning	
WVC reduction: Common species. **Regional conservation and connectivity**: Common species and wide-ranging carnivores such as wolverines, bears and wolves.	
Transportation mitigation opportunities	
Score: 5	
This is the highest ranked location for mitigating TCH impacts on wildlife mortality and connectivity at local and regional scales. Unlike Ottertail Creek, there are no topographical constraints at this location that limit the mitigation work that can be done here. Further, modeling indicated that this area was important for regional connectivity of black bear, grizzly bear and wolverine populations. Supporting data indicates it is a key corridor for wolves, moose and elk. Bridge reconstruction during TCH expansion should allow for a wider bridge span to facilitate movement of wildlife through the bridge, including above high-water mark. F*encing* is recommended to funnel movements to the crossing structure. Fencing should be continuous with adjacent mitigation structures at MES 23 and 21. Fencing notes: Snow not likely a concern at this location.	

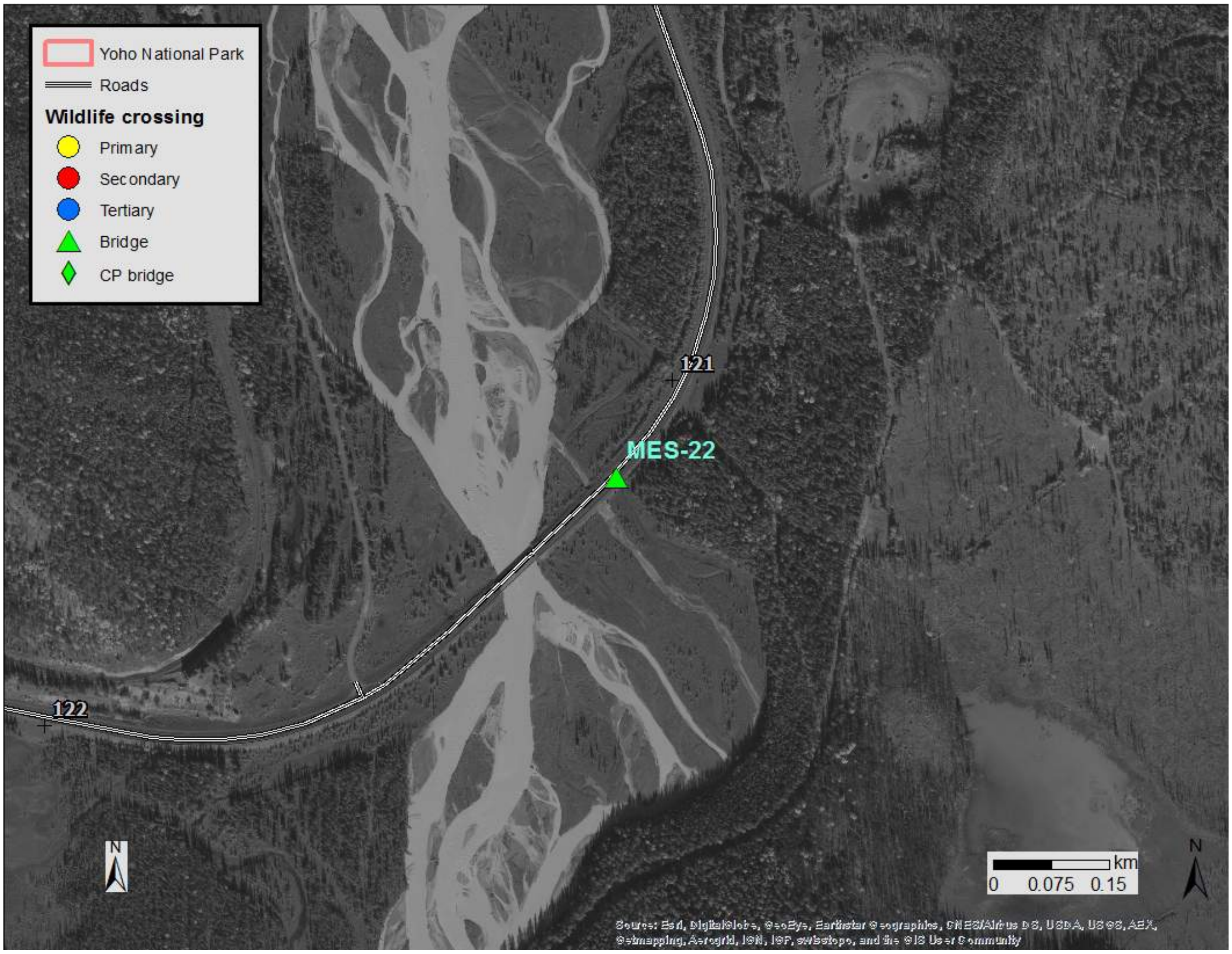


Figure A22: Map showing Highway Mitigation Emphasis Site 22 in Yoho National Park, British Columbia

Site 23 Summary – Wapta Falls	
Description	
Km number (approximate): 122.7	
Location UTM coordinates: 528250, 5674199	
Species: Multi-species: Deer, elk, moose, cougars, lynx, wolves, bears	
Mortality risk: 5	
Local connectivity value: 3	
Regional connectivity_Black bear significance: 4	
Regional connectivity_Grizzly bear significance: 1	
Regional connectivity_Wolverine significance: 3	
Regional connectivity_Combined: 2.7	
Transportation mitigation constructability: 4	
Wildlife objectives	
• Reduce current levels of wildlife–vehicle collisions in this section of highway, primarily deer, moose and elk. • Provide safe movement for all wildlife species across highway, primarily deer, moose, elk, wolves and bears.	
Existing infrastructure	
• 2.0 m diameter steel culvert	
Target species for mitigation planning	
WVC reduction: Common species, primarily deer, elk, moose, wolves. **Regional conservation and connectivity**: Common species primarily.	
Transportation mitigation opportunities	
Score: 4	
The confluence of the Kicking Horse and Beaverfoot Rivers is one of the three important wildlife corridor areas in YNP. This site is part of this key regional connectivity area. To ensure movement of wildlife through the area and reduce wildlife-vehicle collisions, fencing and construction of wildlife *underpass* is recommended. Selection of design type is dependent on terrain and engineering constraints; open-span preferred design. Minimum dimension for **secondary** underpass is 3 m high x 11 m wide due to high likelihood of some movement by fragmentation-sensitive species (lynx, wolverine, grizzly bear, wolves) through this area. F*encing* is recommended to funnel movements to the crossing structure. Fencing should be continuous with adjacent mitigation structures at MES 24 and 22. Fencing notes: Snow not likely a concern at this location.	

Figure A23: Map showing Highway Mitigation Emphasis Site 23 in Yoho National Park, British Columbia

Site 24 Summary – West of CP Bridge

Description

Km number (approximate): 123.7

Location UTM coordinates: 527351, 5674647

Species: Multi-species: Deer, elk, moose, cougars, wolves, bears

Mortality risk: 5

Local connectivity value: 3

Regional connectivity_Black bear significance: 4

Regional connectivity_Grizzly bear significance: 1

Regional connectivity_Wolverine significance: 1

Regional connectivity_Combined: 2.0

Transportation mitigation constructability: 4

Wildlife objectives

- Reduce current levels of wildlife–vehicle collisions in this section of highway, primarily deer, moose and elk.
- Provide safe movement for all wildlife species across highway, primarily deer, moose, elk, wolves and bears.

Existing infrastructure

- None

Target species for mitigation planning

WVC reduction: Common species.
Regional conservation and connectivity: Common species primarily.

Transportation mitigation opportunities

Score: 4

To ensure movement of wildlife through the area and reduce wildlife-vehicle collisions, there are two fencing and construction options:

1) Construction of **tertiary** wildlife *underpass* at the site. Selection of design type is dependent on terrain and engineering constraints. Minimum dimension for underpass is 4 m high x 7 m wide elliptical multi-plate steel culvert.
2) Reconstruction of the existing CP Bridge, by widening span underneath to allow for wildlife passage (≥6 m wide paths on both sides).

F*encing* is recommended to funnel movements to the crossing structure. Fencing should be continuous with adjacent mitigation structures at MES 25 and 23.

Fencing notes: Snow not likely a concern at this location.

Figure A24: Map showing Highway Mitigation Emphasis Site 24 in Yoho National Park, British Columbia

Site 25 Summary – East of Kiosk	
Description	
Km number (approximate): 126.0	
Location UTM coordinates: 524354, 5675478	
Species: Multi-species: Deer, elk, moose, cougars, wolves, bears	
Mortality risk: 3	
Local connectivity value: 2	
Regional connectivity_Black bear significance: 2	
Regional connectivity_Grizzly bear significance: 3	
Regional connectivity_Wolverine significance: 3	
Regional connectivity_Combined: 2.7	
Transportation mitigation constructability: 4	
Wildlife objectives	
• Reduce current levels of wildlife–vehicle collisions in this section of highway, primarily deer, moose and elk. • Provide safe movement for all wildlife species across highway, primarily deer, moose, elk, wolves and bears.	
Existing infrastructure	
• None	
Target species for mitigation planning	
WVC reduction: Common species. **Regional conservation and connectivity**: Common species primarily.	
Transportation mitigation opportunities	
Score: 4	
To ensure movement of wildlife through the area and reduce wildlife-vehicle collisions, fencing and construction of wildlife *underpass* is recommended. Selection of design type is dependent on terrain and engineering constraints. Minimum dimension for **tertiary** underpass is 4 m high x 7 m wide elliptical multi-plate steel culvert. F*encing* is recommended to funnel movements to the crossing structure. Fencing should be continuous with adjacent mitigation structures at MES 26 and 24. Fencing notes: Snow not likely a concern at this location.	

Figure A25: Map showing Highway Mitigation Emphasis Site 25 in Yoho National Park, British Columbia

Site 26 Summary – West entrance	
Description	
Km number (approximate): 126.9	
Location UTM coordinates: 524622, 5676103	
Species: Multi-species: Deer, elk, moose, cougars, wolves, bears	
Mortality risk: 4	
Local connectivity value: 2	
Regional connectivity_Black bear significance: 1	
Regional connectivity_Grizzly bear significance: 1	
Regional connectivity_Wolverine significance: 1	
Regional connectivity_Combined: 1.0	
Transportation mitigation constructability: 4	
Wildlife objectives	
• Reduce current levels of wildlife–vehicle collisions in this section of highway, primarily deer, moose and elk. • Provide safe movement for all wildlife species across highway, primarily deer, moose, elk, wolves and bears.	
Existing infrastructure	
• None	
Target species for mitigation planning	
WVC reduction: Common species. **Regional conservation and connectivity**: Common species primarily.	
Transportation mitigation opportunities	
Score: 4	
To ensure movement of wildlife through the area and reduce wildlife-vehicle collisions, fencing and construction of **tertiary** wildlife *underpass* is recommended. Selection of design type is dependent on terrain and engineering constraints. Minimum dimension for underpass is 4 m high x 7 m wide elliptical multi-plate steel culvert. F*encing* is recommended to funnel movements to the crossing structure. Fencing from the east should be continuous with adjacent mitigation structure at MES 25. Fencing west of the underpass should tie into the existing wildlife exclusion fencing on the BC portion of the TCH. Fencing notes: Snow not likely a concern at this location.	

Figure A26: Map showing Highway Mitigation Emphasis Site 26 in Yoho National Park, British Columbia

Appendix B: Mitigation Measure Information Sheets (A–F)

Mitigation measure information sheets are based on the *Handbook for Design and Evaluation of Wildlife Crossing Structures in North America* (Clevenger and Huijser 2011).

Sheet A: Animal Detection Systems

Sheet B: Fencing

Sheet C: Gates and Ramps

Sheet D: Wildlife Underpasses

Sheet E: Wildlife Underpasses with Water Flow

Sheet F: Wildlife Overpasses

Animal Detection Systems SHEET A

General purpose

Animal detection systems use sensors to detect large animals that approach the road. Once a large animal is detected, warning signals are activated to inform the drivers that a large animal may be on or near the road at that time. The warning signals are time specific—that is, they warn of specific detection events rather than warn of the possibility that animals may be in the area. These systems have been installed in more than 50 locations in North America and Europe.

Animal detection system along Highway 191 in Yellowstone National Park, Montana (Photo: Marcel Huijser, WTI).

System types

There are two broad categories commonly used in animal detection systems: area-cover systems and break-the-beam systems.

Break-the-beam sensors detect large animals when their body blocks or reduces a beam of infrared, laser or microwave radio signals sent by a transmitter to a receiver.

Area-cover systems detect large animals within a certain range of a sensor. Area coverage systems can be passive or active. Passive systems detect animals by only receiving signals. The two most common systems are passive infrared and video detection. These systems require algorithms that distinguish between, e.g., moving vehicles with warm engines and moving pockets of hot air, and movements of large animals. Active systems send a signal over an area and measure its reflection. The primary active area coverage system uses microwave radar.

Area-cover systems are radar-based and contain four key components, solar panel array, the radar, a control enclosure and flashing signage.

The radar is the sensing component that detects and tracks the animals until it leaves the predetermined tracking area. It is pole mounted at various heights and spaced at approximately 350 meters between adjacent radars. The radar will operate in any environment and is not affected by snow, ice, rain, etc.

The radar has a relay output that actuates when an animal is present in the defined tracking area. The relay closure condition is sent wirelessly to the flashing beacons, which house a controller for adjusting the flash conditions.

The radar also has an internal log that can be retrieved via Ethernet on site at the control enclosure of the radar. All of the time-stamped data from system operation can be downloaded via Ethernet or wirelessly. When coupled with video cameras it is possible to analyse system performance, i.e., proportion of false negative and false positives compared to true operation.

The radar is controlled by a small-embedded computer located in the control enclosure. The battery bank is charged by the solar panel array and charge controller and has been designed to provide approximately 3 days of operation without sunlight before the batteries will be depleted beyond 50% of their charge. In areas without sufficient sunlight the system can be tied into existing power typically running alongside the highway, as is the case in MRG.

Effectiveness

The effectiveness of animal detection systems has been investigated with regard to a potential reduction in vehicle speed and a potential reduction in animal–vehicle collisions. Previous studies with earlier models have shown variable results: substantial decreases in vehicle speed, minor decreases in vehicle speed, and no decrease or even an increase in vehicle speed. This variability in the results appeared to be related to various conditions, namely, type of warning signal and signs, whether the warning signs are accompanied with advisory or mandatory speed limit reductions, road and weather conditions, whether the driver is a local resident, and perhaps also cultural differences that may cause drivers to respond differently to warning signals in different regions.

Some work in Switzerland has been done reporting on the number of animal–vehicle collisions before and after seven infrared area cover detection systems were installed. These systems reduced the number of animal–vehicle collisions by 82 percent on average. Similar results in collision reductions were found for radar-based systems installed by the Ministry of Transportation in Ontario to reduce moose-vehicle collisions. The radar-based system is proving more reliable and effective at reducing wildlife-vehicle collisions. This system is recommended for use on the Trans-Canada Highway in MRG to reduce collision rates: 1) with mountain goats at locations where goats lick salt on the highway (snow sheds and areas not associated with snow sheds) and 2) at fence ends.

While the data on the effectiveness of animal detection systems are encouraging, animal detection systems should still be regarded as an experimental mitigation measure rather than a measure that will reduce wildlife–vehicle collisions in the short term with a high degree of certainty (Huijser et al. 2006c).

*Information on testing radar-based animal-detection systems in Canada were published in a New York Times article in 2013 (November 1, 2013; "Canada Tests Animal Detectors").

Case studies and contacts

For a general overview of technology, reliability and effectiveness, contact Marcel Huijser, Western Transportation Institute, PO Box 174250, Bozeman, Montana 59717-4250, (406)543-2377, mhuijser@coe.montana.edu.

For information about a field study on the effectiveness of animal detection systems, contact Christa Mosler-Berger, Wildtier Schweiz, Strickhofstrasse 39, 8057 Zürich, Switzerland, wild@wild.unizh.ch.

For more information about the animal detection system and wildlife fencing along State Route 260 in Arizona, contact Norris Dodd, Wildlife Connectivity Program Coordinator, Arizona Department of Transportation, 1611 W. Jackson Street MD EM04, Phoenix, Arizona 85007, (480) 271-4334, NDodd@azdot.gov.

Manufacturer: Blake Dickson, VP Sales and Marketing, Rotalec, 177 Blossom Avenue East, Unit A, Brantford, Ontario N3T 5L9, (519) 753-5100 ext 427, Blake.Dickson@rotalec.com, http://www.rotalec.com/.

Direct benefits

The available data on the effectiveness of animal detection systems show a reduction in collisions with large animals of 82 percent, which is substantial. This percentage may change as systems improve over time and more data become available from testing systems in place.

Indirect benefits

Animal detection systems do not restrict animal movements when deployed over long distances.

Undesirable effects

Animal detection systems can reduce collisions with large animals, but the presence of poles and equipment in the right-of-way can be a potential hazard to vehicles that run off the road.

Costs

Estimated costs of these systems range from $ 100,000 - $300,000 per km excluding installation costs (unpublished data, Marcel Huijser, Western Transportation Institute – Montana State University). The costs for the equipment will be higher if the road section concerned has curves or slopes, or if the line of sight in the right-of-way is blocked by objects.

Fencing SHEET B

General purpose

Wildlife exclusion fencing keeps animals away from roadways. However, fencing alone can isolate wildlife populations, thus creating a barrier to movement, interchange and limiting access to important resources for individuals and affecting the long-term survival of the population. Fencing is one part of a two-part mitigation strategy—fencing *and* wildlife crossing structures.

Fences keep wildlife away from the roadway and lead animals to wildlife crossings, thus allowing them to travel safely under or above the highway. Fences need to be impermeable to wildlife movement in order to keep traffic-related mortality to a minimum and ensure that wildlife crossings will be used. Defective or permeable fences result in reduced use of the wildlife crossings and increased risk of wildlife–vehicle collisions. Little research and best management practices exist regarding effective fence designs and other innovative solutions to keep wildlife away from roads.

Wildlife exclusion fencing and culvert design wildlife underpass (Photo: Tony Clevenger).

Configurations

Fencing configuration used to mitigate road impacts will depend on several variables associated with the specific location, primarily adjacent land use and traffic volumes. Both sides of the road must be fenced (not only one side) and fence ends across the road need to be symmetric and not offset or staggered.

- *Continuous fencing* – Most often associated with large tracts of public land with little or no interspersed private property or in-holdings. Advantages: Long stretches of continuous fencing have fewer fence ends and generally few problems of managing wildlife movement ("end-runs") around multiple fence ends, as with discontinuous fencing (below). Disadvantages: Access roads with continuous fencing will need cattle guards, electro-mats, or gates to block animal access to roads (see Sheet C).
- *Partial (discontinuous) fencing* – More common with highway mitigation for wildlife in rural areas characterized by mixed land use (public and private land). Generally installed when private lands cannot be fenced. Partial fencing is recommended in locations like MRG where it is not feasible or there is a need to fence long sections of highway. Advantages: Generally accepted by public stakeholders. Few benefits to wildlife and usually the only alternative when there is mixed land use. Disadvantages: Results in multiple segments of fenced and unfenced sections of road, each fenced section having two fence ends. Additional measures need to be installed and carefully monitored to discourage end-runs at fence ends and hasten wildlife use of new crossing structures (see Terminations below). Earthen ramps or "jump-outs" are also needed in close proximity to fence ends in order to allow animals escape the fenced once inside (see Sheet C).

Interceptions

Fences invariably intersect other linear features that allow for movement of people or transport materials. This can include access roads, but also recreational trails (people) and water (creeks, streams). These breaks or interceptions in the fence require special modifications in order to limit the number of wildlife intrusions into the right-of-way.

Roads

Texas Gates – Transportation and land management agencies commonly install Texas Gates (also called cattleguards or cowcatchers) where fences intersect access roads. Many different designs have been used, but few have been tested for their effectiveness with wildlife. Designs of Texas Gates vary in dimension, grate material (flat or cylindrical steel grates), and grate adaptations for safe passage by pedestrians and cyclists. Recently a grate pattern was developed that was 95 percent effective in blocking Key deer movement and was safe for pedestrians and cyclists. Work by Allen et al. (2013) on fenced sections of US-93 in Montana showed that Texas gates were >85% effective in keeping deer from accessing the road and 93.5% of deer used the crossing structure instead of the adjacent wildlife guard when crossing the road. The gates were less effective in keeping black bear and coyotes from accessing the road (33–55%). However, all black bears and 94.7% of coyotes used the crossing structure instead of the adjacent wildlife guard when crossing the road.

-


Cattle guard (Texas gate) in road (Photo: Tony Clevenger).

- *Electro-mats* – These electrified mats act like electric Texas Gates to discourage wildlife from crossing at the gap in the fence. Pedestrians wearing shoes and bicyclists can cross the mats safely, but dogs, horses and people without shoes will receive an electric shock. The electro-mats are generally 2-3 m wide, but can be designed to any width, and built into access roads where they breach fences. Cross-Tek® has been the lead company developing the e-mas and have had great success in high snowfall areas (Anchorage, Alaska) and dry areas (Arizona). They are currently designing and testing e-mats in Banff National Park.
- *Painted crosswalks* – Highway crosswalk structures have been used to negotiate ungulates across highways at grade level. White crosswalk lines are painted across the road to emulate a cattle guard. The painted crosswalk serves as a visual cue to guide ungulates directly across the highway. Painted crosswalks have not been tested, but if effective, they would be an inexpensive alternative to the more costly cattle guards. See Lehert and Bissonette 1997 for more details).

Trails

- *Swing gates (for fishermen, hikers)* – Where fences impede public access to popular recreation areas, swing gates can be used to negotiate fences. Gates must have a spring-activated hinge that ensures that even if the gate is left open it will spring back and close. In areas of high snowfall, gates may be elevated and steps built to keep the bottom of the gate above snow.

Step gate with spring-loaded door situated at trailhead in Banff National Park, Alberta (Photo: Tony Clevenger).

- *Canoe/kayak landings* – There are no known simple gate solutions for transporting canoes/kayaks through fences. The swing gate described above is one solution, although the gate should be slightly wider than normal to allow a wide berth suitable for moving canoes/kayaks. Gates must have a spring-activated hinge that ensures they remain closed after use.

Watercourses

- *Rubber hanging drapes* – Watercourses pose problems for keeping fences impermeable to wildlife movement, as their flow levels tend to fluctuate throughout the year. When water levels are low, gaps may appear under the fence material allowing wildlife to easily pass beneath. Having fencing material well within watercourses will cause flooding problems, as debris being transported will not pass through the fence and can eventually obstruct water flow. A solution to this problem would require having a device on the bottom of the fence that moves up and down with the water levels. This could be done by attaching hinged strips of rubber mat-like material, draping down from the bottom of the fence material into the water. The rubber strips are hinged, so they float on top of the water and move in the direction of flow.

Suggested design details

Mesh type, gauge and size

Fence material may consist of woven-wire (page-wire) or galvanized chain-link fencing. Fence material must be attached to the back (non-highway) side of the posts, so impacts will only take down the fence material and not the fence posts.

- *Woven- or page-wire fencing* – Woven-wire fences consist of smooth horizontal (line) wires held apart by vertical (stay) wires. Spacing between line wires may vary from 8 cm at the bottom for small animals to 15–18 cm at the top for large animals. Wire spacing generally increases with fence height. Mesh wire is made in 11, 12, 12 ½, 14, and 16 gauges and fences are available in different mesh and knot designs. The square-shaped mesh may facilitate climbing by some wildlife, such as bears. If climbing is a concern then use of a smaller mesh is recommended.
  Wildlife fences along the Trans-Canada Highway in Banff National Park consist of 12 ½ gauge line wires with tensile strength of 1390 N/sq. mm. Stay wires have a tensile strength of 850 N/sq. mm. All wires had Class III zinc galvanized coating (see below) at a minimum of 260 gms/sq. m.
- *Chain-link fencing* – Chain-link fence is made of heavy steel wire woven to form a diamond-shaped mesh. It can be used in various industrial, commercial and residential applications. Chain-link was used for highway mitigation fencing along I-75 and SR 29 in Florida. There have been agency and public concerns about the visual aesthetics of chain-link fencing compared to woven-wire as it is less attractive and does not blend into the landscape. Steel posts are always used with chain-link fencing. Chain-link fence fabrics can be galvanized mesh, plastic-coated galvanized mesh or aluminum mesh.
- Most wire sold today for fencing has a coating to protect the wire from rust and corrosion. Galvanizing is the most common protective coating. The degree of protection depends on thickness of galvanizing and is classified into three categories; Classes I, II, and III. Class I has the thinnest coating and the shortest life expectancy. Nine-gage wire with Class I coating will start showing general rusting in 8 to 10 years, while the same wire with Class III coating will show rust in 15 to 20 years.
- *Electrified fencing* – Electric fences are a safe and effective means to deter large wildlife from entering highway right-of-ways, airfields and croplands. The 2-m-high fence will deliver a mild electric shock to animals that touch it, discouraging them from passing through. It is made of several horizontal strands of rope-like material about 1 cm in diameter that can deliver a quick shock that is enough to sting, but not seriously harm humans. Wildlife respond differently to standard electric fences; high voltage fences are generally required to keep bears away. There are public safety issues of having electrified

fencing bordering public roads and highways as there is high likelihood that people will come into contact with the fence (fishermen, hikers, motorists that run into fence).

Post types

- *Wood* – Wood posts are commonly used and can be less expensive than other materials if cut from the farm woodlot or if untreated posts are purchased. Post durability varies with species. For example, osage orange and black locust posts have a lifespan of 20 to 25 years whereas southern pine and yellow poplar rot in a few years if untreated.
- The life expectancy of pressure-treated wooden posts is generally 20 to 30 years depending on the type of wood. Softwoods are the most common wood used for posts when fencing highways. Lodgepole pine and Jack pine are common tree species for fence posts. For Trans-Canada Highway wildlife fences, all round fence posts were pressure treated with a chromate copper arsenate (CCA) wood preservative.
- Wood posts are highly variable in size and shape. For typical 2.4-m-high fencing, non-sharpened wooden posts 3.7 m and 4.2 m long are used. Fence posts are sharpened and then installed by preparing a pilot hole approximately 125 mm in diameter, vibrating the post down to specified post height and backfilling around the post with a compacted non-organic material to ground level. The strength of wood posts increases with top diameter. Post strength is especially important for corner and gate posts, which should have a top diameter of at least 16 cm. Line posts can be as small as 13 cm and should not need to be more than 14 cm on top diameter, although larger diameter posts make fences stronger and more durable.
- *Steel* – Steel posts are used to support fences when crossing rock substrate. They weigh less and last longer than wood posts; the main disadvantage is they are more expensive than wood posts. Steel posts are supplied in 3.7 m lengths and installed in concreted 1000-mm-long sleeves for the 3 m x 8 cm steel posts.
- Tension – Tension between posts can consist of metal tubing on metal posts and reinforced cable on wooden posts.

Reinforcements

- *Unburied fence* – Unburied fences are used in areas where resident wildlife are not likely to dig under the fence. The fence material should be flush with the ground to minimize animals crawling beneath the fence and reaching the right-of-way.
- Buried fence – This is strongly recommended in areas with wildlife capable of digging under the fence (e.g., bears, canids, badgers, wild boar). Buried fence in Banff National Park significantly reduced wildlife intrusions to the right-of-way compared to unburied fence (Clevenger et al. 2002). Buried fence consists of a 1- to 1.2-m-wide section of galvanized chain-link fence spliced to the bottom of unburied fence material. The chain-link section is buried at a 45-degree angle away from the highway and is approximately 1.1 m below ground. Swing gates should have a concrete base to discourage digging under them.
- Cable (protective) – Trees blown onto fences can not only damage fence material but provide openings for wildlife to enter the right-of-way. This is typically a problem during the initial years after construction, but can continue over time. A high-tensile cable strung

on top of fence posts to help break the fall of trees onto the fence material should reduce fence damage, repair costs and maintenance time.

Wildlife exclusion fence with buried apron (Photo: Tony Clevenger).

Concrete base of swing gate to prevent animal digging under wildlife fence (Photo: Tony Clevenger).

High tensile cable designed to break fall of trees onto fence material (Photo: Tony Clevenger).

Terminations

Fence ends are notorious locations for wildlife movements across roads and, thus, for accidents with wildlife. The problem is more acute soon after fence installation as wildlife are confused, unsure where to cross the road, and tend to follow fences to their termination, and then make end-runs across the road or graze inside the fence.

Each mitigation situation is different and will require a site-specific assessment, but as a general rule, fence ends should terminate at a wildlife crossing structure.
If a wildlife crossing cannot be installed at the fence ends, then fences should be designed to terminate in the least suitable location or habitat for wildlife movement—i.e., places wildlife are least likely to cross roads. Some examples are:

- Steep, rugged terrain such as rock-cuts (bighorn sheep and mountain goats excluded).
- Habitats that tend to limit movement, e.g., open areas for forest-dwelling species.
- Human-altered habitats and areas with frequent human activity and disturbance.

Placing animal-detection systems (see Sheet A) at fence ends has been an effective method of alerting motorists of wildlife approaching or crossing roads where at fence terminations. The most rigorous testing of the system took place over a 3-year period in Arizona. Overall, the animal-detection system and associated warning signs met their objective of modifying driver behavior by reducing speeds between 14-18%, (8-10 mph), thereby reducing the risk of collision with wildlife (Gagnon et al. 2010). They encountered few instances when their roadside animal-detection system and signs were inoperable; overall, their "crosswalk" system performed properly on 93% of their test visits. Motorist warning signs activated 98% of the time for both species at some point following the presence of animals in the detection zone. Overall, the system exhibited a relatively minimal amount of false positives or false negatives; following final modifications to the system, the amount of time the system was not operable was negligible (Gagnon et al. 2010).

Dimensions – General guidelines

Highway fencing for large mammals, including most native ungulate species of moose, elk, deer, and bighorn sheep, should be a minimum of 2.4 m high with post separation on average every 4.2 to 5.4 m. In some cases the fence height may not need to be designed for large ungulates. Alternate fence design and specifications will need to reflect not only requirements for species present, but also species that may re-colonize or disperse into the area in the future.
Fencing is an important component of a successful and functional mitigation scheme. However, in high snowfall areas standard fencing guidelines have been modified to address snow-load problems with fence posts and material (mesh type). These issues are a concern throughout many parts of the MRG study area, but less so in lower sections.

For previous work planning mitigation on highways in high snowfall areas we inquired with colleagues working for the Norwegian Directorate of Transportation (Oslo, Norway) and has worked with mitigation fencing for wildlife in areas with high snowfall. Bjørn Iuell prepared some guidelines currently being used in Norway with regard to fence mesh size, poles, distance between poles and fence height (see Appendix C). We have included those guidelines as an Appendix to this report. Colleagues working for the Swedish Road Administration and Norwegian Directorate of Transportation (Oslo, Norway) will be able to provide valuable information on fence designs for parts of the Trans-Canada Highway in MRG. Raised mechanically stabilized earth (MSE) walls may be an option in places where the walls function as fences to block animal movement onto the highway and guide animals to crossing structures (see photo of MSE wall in Sheet E).

Maintenance

- Fences are not permanent structures, nor are they indestructible. They are subject to constantly occurring damage from vehicular accidents, falling trees, and vandalism. Natural events also cause damage and threaten the integrity of the fence. Soil erosion, excavation by animals, and flooding can loosen fence posts and collapse portions of fencing.
- Fences must be checked every six months by walking entire fence lines, identifying gaps, breaks and other defects caused by natural and non-natural events.

References

Allen, T., M. Huijser, D. Willey. 2013. Effectiveness of wildlife guards at access roads. Wildlife Society Bulletin 37:402-408.

Clevenger, A.P., Chruszcz, B., Gunson, K., and Wierzchowski, J. 2002. Roads and wildlife in the Canadian Rocky Mountain Parks - Movements, mortality and mitigation. Final Report (October 2002). Report prepared for Parks Canada, Banff, Alta.

Lenhert, M.A. and J.A. Bissonette. 1998. Effectiveness of highway crosswalk structures at reducing deer-vehicle collisions. Wildlife Society Bulletin 25, 809-818.

Gates and Ramps SHEET C

General purpose

If wildlife become trapped inside the fenced area, they need to be able to safely exit the highway area. The most effective means of escape are through a steel swing gate or an earthen ramp or "jump-out". The number, type and location of escape structures will depend on the target species, terrain and habitat adjacent to the highway fence.

Escape ramp (jump-out) for wildlife trapped inside highway right-of-way (Photo: Tony Clevenger).

Application

- *Swing gates* are generally used (with or without ramps) in areas where highways are regularly patrolled by wardens/rangers. As part of their job, if wildlife are found inside the fence, the nearest gates are opened and animals are moved towards the opened gate. Double swing gates are more effective than single swing gates, especially for larger mammals such as elk or moose. Swing gates are used to remove ungulates and large carnivores (e.g., bears). In high snowfall areas swing gates will be rendered ineffective until snow melts and gates can swing open and closed.

Single swing gate in wildlife exclusion fence (Photo: Tony Clevenger).

- *Earthen ramps or jump-outs* allow wildlife (large and small) to safely exit right-of-ways on their own without the aid of wardens or rangers. Typically wildlife find the ramps and exit by jumping down to the opposite side of fence. Deer and elk are the most common users, but moose, bighorn sheep, bears and cougars use these structures as well. The outside walls of the escape ramp must be high enough to discourage wildlife from jumping up onto the ramp and accessing the right-of-way. However, the walls should not be so high they discourage wildlife from jumping off. The landing spot around the outside wall must consist of loose soil or other soft material to prevent injury to animals. The outside walls must be smooth to prevent bears or other animals from climbing up. For best use, escape ramps should be positioned in a setback in the fence, in an area protected with dense vegetative cover, so animals can calm down and look over the situation before deciding to use the jump out or continue walking along the fence. A right-angle jog in the fence is recommended for positioning the escape ramp but not necessary.

  Earthen ramps or jump-outs have an important function at fence terminations. Fence ends are typically problematic as wildlife occasionally perform “end runs”, which may lead to having wildlife inside the fenced right-of-way. Fence end problems can be corrected by ensuring that there are at least two jump-outs (one on each side of highway) near each fence end. If wildlife come inside the fenced section of a highway they typically travel close to the fence searching for an exit. By having a jump-out in close proximity to the fence end maximizes the chances that the animal will find the jump-out and exit the right-of-way.

Wildlife"junp-out" escape ramp (Photo: Tony Clevenger).

Maintenance

- Like fences, gates and ramps are not permanent structures, neither are they indestructible. They are subject to constantly occurring damage from vehicular accidents, falling trees, and vandalism. Natural events also can cause damage, obstruct gates and affect how well they perform.
- Like fences, escape structures must be checked every six months to ensure that they are functioning properly and that they perform when needed. Maintenance checks should take place at the same time as fence inspections.

Wildlife Underpasses SHEET D

General design

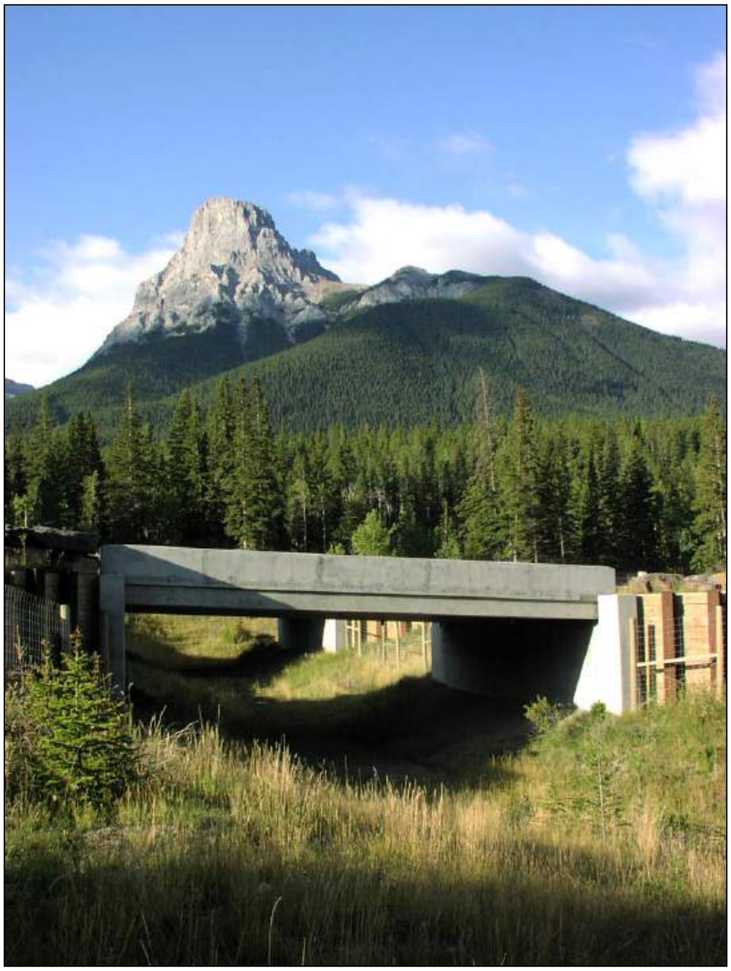
The wildlife underpass is not as large as most viaducts, but is the largest of underpass structures designed specifically for wildlife use. It is primarily designed for large mammals, but use by some large mammals will depend on how it may be adapted for their specific crossing requirements. Small- and medium-sized mammals (including carnivores) generally utilize these structures, particularly if cover is provided along walls of the underpass by using brush or root wads. These underpass structures can be readily adapted for amphibians, semi-aquatic and semi-arboreal species.

Use of the structure

The wildlife underpass is designed exclusively for use by wildlife.

General guidelines

- Being generally smaller than a viaduct or flyover, the ability to restore habitat underneath will be limited. Open designs that provide ample natural lighting will encourage greater development of native vegetation.
- To ensure performance and function, wildlife underpasses should be situated in areas with high landscape permeability that are known wildlife travel corridors and that experience only minimal human disturbance.
- Motor vehicle or all-terrain vehicle use should be prohibited. Eliminating public or any other human use, activity or disturbance at the underpass and adjacent area is recommended for its proper function and for maximizing wildlife use.
- Underpasses should be designed to conform to local topography. Design drainage features so flooding does not occur within the underpass. Highway runoff near structure should not be directed toward the underpass.
- Maximize continuity of native soils adjacent to and within the underpass. Avoid importation of soils from outside the project area.



Open span wildlife underpass (Photo: Tony Clevenger).

Dimensions – General guidelines

Width:

Minimum: 7 m
Recommended: >12 m

Height:

Minimum: 4 m
Recommended: >4.5 m

Types of construction

Span

Concrete bridge span (open-span bridge)
Steel beam span

Arch

Concrete bottomless arch
Corrugated steel bottomless arch
Elliptical multi-plate corrugated steel culvert

Box culvert
Prefabricated concrete

Suggested design details

Crossing structure

- Structures should be designed to meet the movement needs of the widest range possible of species that live in the area or might be expected to re-colonize the area, e.g., high- and low-mobility species.
- Attempt to mirror habitat conditions found on both sides of the road and provide continuous habitat adjacent to and within the structure.
- Maximize microhabitat complexity and cover within the underpass using salvage materials (logs, root wads, rock piles, boulders, etc.) to encourage use by semi-arboreal mammals, small mammals, reptiles and species associated with rocky habitats.
- It is preferable that the substrate of the underpass is of native soils. If construction type has a closed bottom (e.g., concrete box culvert), a soil substrate $\geq$ 6 in (15 cm) deep must be applied to interior.
- Revegetation is possible in areas of the underpass closest to the entrance. Light conditions tend to be poor in the center of the structure.
- Design underpass to minimize the intensity of noise and light coming from the road and traffic.

Local habitat management

- Protect existing habitat. Design with minimal clearing widths to reduce impacts on existing vegetation. Where habitat loss occurs, reserve all trees, large logs, and root wads to be used adjacent to and within the underpass.
- Wildlife fencing is the most effective and preferred method to guide wildlife to the structure and prevent intrusions onto the right-of-way. Mechanically stabilized earth walls, if high enough, can substitute for fencing and are not visible to motorists.
- Encourage use of underpass by either baiting or cutting trails leading to the structure, if appropriate.
- Avoid building underpass in locations where a road runs parallel and adjacent to entrance, as it will affect wildlife use.
- If traffic volume is high on the road above the underpass it is recommended that sound attenuating walls be placed above the entrance to reduce noise and light disturbance from passing vehicles.

Brush and root wads placed along underpass wall to provide cover for mammals (Photo: Nancy Newhouse).

- Underpass must be within cross-highway habitat linkage zone and connect to larger corridor network.
- Existing or planned human development in adjacent area must be at sufficient distance to not affect long-term performance of underpass. Long-range planning must ensure that adjacent lands will not be developed and the wildlife corridor network is functional.

Possible variations

Divided road (two structures)
In-line
Off-set:

Undivided road (one structure)

Maintenance

- If wildlife underpass is not being monitored on a regular basis, periodic visits should be made to ensure that there are no obstacles or foreign matter in or near the underpass that might affect wildlife use.
- Fence should be checked, maintained and repaired periodically (minimum once per year, preferably twice per year).

Wildlife Underpasses with Water Flow SHEET E

General design

This is an underpass structure designed to accommodate dual needs of moving water and wildlife. Structures are generally located in wildlife movement corridors given their association with riparian habitats; however, some may be only marginally important. Structures aimed at restoring proper function and connection of aquatic and terrestrial habitats should be situated in areas with high landscape permeability, that are known wildlife travel corridors and that experience only minimal human disturbance. These underpass structures are frequently used by several large mammal species, yet use by some large mammals will depend on how it may be adapted for their specific crossing requirements. Small- and medium-sized mammals (including carnivores) generally utilize these structures, particularly if riparian habitat is retained or cover is provided along walls of the underpass by using logs, brush or root wads. These underpass structures can be readily adapted for amphibians, semi-aquatic and semi-arboreal species.

Wildlife underpass designed to accommodate water flow (Photo: Tony Clevenger).

Use of the structure

Exclusively for wildlife, but may have some human use.

General guidelines

- Underpass structure should span the portion of the active channel migration corridor of unconfined streams needed to restore floodplain, channel and riparian functions.
- If underpass structure covers a wide span, support structures should be placed outside the active channel.
- Design underpass structure with minimal clearing widths to reduce impacts on existing vegetation.
- Even with large span structures the ability to restore habitat underneath will be limited. Open designs that provide ample natural lighting will encourage greater development of important native riparian vegetation.
- Maximize the continuity of native soils adjacent to and within the underpass. Avoid importation of soils from outside project area.
- Motor vehicle or all-terrain-vehicle use should be prohibited. Eliminating public or any other human use, activity or potential disturbance at the underpass and adjacent area is recommended for proper function and maximizing wildlife use.
- Underpass should be designed to conform to local topography. Design drainage features so flooding does not occur within underpass. Run-off from highway near structure should not end up in underpass.

Dimensions – General guidelines

Dimensions will vary depending on width of active channel of water flow (creek, stream, river). Guidelines are given below for dimensions of wildlife pathway alongside active channel and height of underpass structure.

Minimum:

Width: 3 m pathway
Height: 3 m

Recommended:

Width: >3 m pathway
Height: >4 m

Types of construction

Concrete bridge span (open-span bridge)
Steel beam span
Concrete bottomless arch

Suggested design details

Crossing structure

- Structures should be designed to meet the movement needs of widest range possible of species that live in the area or might be expected to re-colonize the area—e.g., high- and low-mobility species.
- Attempt to mirror habitat conditions found on both sides of the road and provide continuous riparian habitat adjacent to and within the structure.
- Maximize microhabitat complexity and cover within underpass using salvage materials (logs, root wads, rock piles, etc.) to encourage use by semi-arboreal mammals, small mammals, reptiles and species associated with rocky habitats.
- Preferable that the substrate of underpass is of native soils.
- Revegetation will be possible in areas of underpass closest to the entrance, as light conditions tend to be poor in the center of the structure.
- Design underpass to minimize the intensity of noise and light coming from the road and traffic.

Local habitat management

- Protect existing habitat. Design with minimal clearing widths to reduce impacts on existing vegetation. Where habitat loss occurs, reserve all trees, large logs, and root wads to be used adjacent to and within the underpass.
- Wildlife fencing is the most effective and preferred method to guide wildlife to structure and prevent intrusions to the right-of-way. Mechanically stabilized earth walls, if high enough, can substitute for fencing and is not visible to motorists.
- Encourage use of underpass by either baiting or cutting trails leading to structure, if appropriate.
- Avoid building underpass in a location with road running parallel and adjacent to entrance, as it will affect wildlife use.
- If traffic volume is high on the road above the underpass it is recommended that sound attenuating walls be placed above the entrance to reduce noise and light disturbance from passing vehicles.
- Underpass must be within cross-highway habitat linkage zone and connect to larger corridor network.
- Existing or planned human development in adjacent area must be at sufficient distance to not affect long-term performance of underpass. Long-range planning must ensure that adjacent lands will not be developed and the wildlife corridor network is functional.

Mechanically stabilized earth (MSE) wall serving as wildlife exclusion "fence" (Photo: Tony Clevenger).

Possible variations

Divided road (two structures)
In-line:

Undivided road (one structure)

Maintenance

- If the wildlife underpass is not being monitored on a regular basis, periodic visits should be made to ensure that there are no obstacles or foreign matter in or near the underpass that might affect wildlife use.
- Fence should be checked, maintained and repaired periodically (minimum once per year, preferably twice per year).

Wildlife Overpasses SHEET F

General design

Except for a landscape bridge, a wildlife overpass is the largest crossing structure to span highways. It is primarily intended to move large mammals. Small mammals, low-mobility medium-sized mammals and reptiles will utilize these structures if habitat elements are provided on the overpass. Semi-arboreal, semi-aquatic and amphibian species may use the structures if they are adapted for their needs. Types of vegetation and their placement can be designed to encourage crossings by bats and birds.

Recently completed wildlife overpass without landscaping (Photo: Tony Clevenger).

Use of the structure

Wildlife overpasses are intended for the exclusive use of wildlife. Prohibiting human use and human-related activities adjacent to the structure is highly recommended.

General guidelines

- To ensure performance and function, wildlife overpasses should be situated in areas with high landscape permeability, that are known wildlife travel corridors and that experience only minimal human disturbance.
- Maximize continuity of native soils adjacent to and on the wildlife overpass. Avoid importation of soils from outside the project area.
- Should be closed to public and any other human use/activities.
- Reduce light and noise from vehicles by using earth berms, solid walls, dense vegetation or a combination of these placed on the sides (lateral edges) of the structure.

Berm on wildlife overpass (Photo: Tony Clevenger).

Dimensions – General guidelines

Overpass Width:
Minimum: 25–30 m
Recommended: 30–50 m

Fence/berm height:
2.4 m

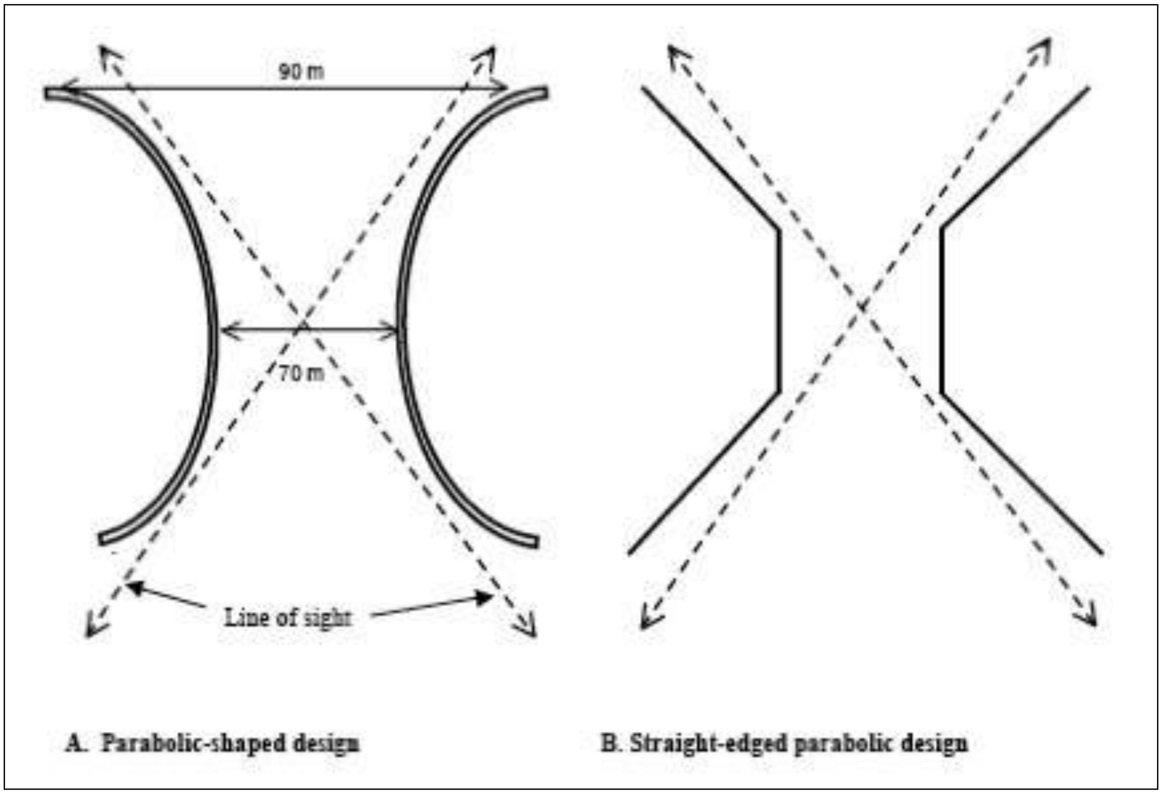
Soil depth:
1.0–1.5 m

Types of construction

Span
Bridge span (steel truss or concrete)

Arch
Pre-fabricated cast-in-place concrete arches
Corrugated steel

Parabolic arch design overpass creates better opportunities for wildlife to locate approach ramps; however, costs are higher than rectangular or straight-edged constructions.



Parabolic-shaped design overpass (A) and straight-edged design (B).

Suggested design details

Crossing structure

- Wildlife overpass should be vegetated with native trees, shrubs and grasses. Species that match or are taxonomically close to existing vegetation adjacent to the structure should be employed. Site and environmental conditions (including climate) may require hardy, drought-tolerant species. Composition of trees, shrubs and grasses will vary depending on target species needs.
- Suggested design consists of planting shrubs on edges of the overpass to provide cover and refuge for small- and medium-sized wildlife. The center section of the overpass should be left open with low-lying or herbaceous vegetation. Place piles of shrubs, woody debris (logs) or rock piles in stepping-stone fashion to provide microhabitat and refuge for small, cover-associated fauna. In arid locations, more piles of woody debris and rocks should be used to provide cover for small and medium-sized fauna.
- Soil depth can vary from 25-50 cm to several meters, depending on the landscaping requirements for meeting the habitat requirements for the species that will be using the overpass. For open habitats soil depths can be less than 0.5 m deep. For forested habitats, soil depths should be sufficient to support 2.4–3.6-m-high trees, i.e., 1.5-2.0 m deep. Regardless of whether the overpass is predominantly open or forested, the structure should

be vegetated with mix of grasses and shrubs of varying height. Soil must be deep enough for water retention for plant growth. Structure must have adequate drainage.

- Local topography can be created on the surface with slight depressions and mounding of material used for fill.
- Amphibian habitat can be created in a stepping-stone fashion or by using isolated ponds. Pond habitat may be artificial with impermeable substrates to hold water from rainfall, or landscape designed areas for high water retention.
- Earth berms, solid walls, dense vegetation or a combination of these should be installed as sound- and light-attenuating walls on the sides of the structure. The walls should extend down to approach ramps and curve around to wildlife exclusion fence. The minimum height of walls should be 2.4 m.

Local habitat management

- Trees and shrubs should be located at the edges of approach ramps to guide wildlife to the structure entrance. The vegetation should integrate with the adjacent habitat. Adjacent lands should be acquired, zoned or managed as reserve or protected area into perpetuity.
- Wildlife overpasses are best situated in areas bordered by elevated terrain, enabling the approach ramps and surface of structure to be at the same level as the adjacent land. If the structure is built on level ground, then approach ramps should have gentle slopes (e.g., 5:1). One or both slopes may be steeper if built in mountainous areas.
- There is a trade-off between slope and retaining vegetative cover on approach ramps. A steep-sloped ramp will retain vegetative cover close to the overpass structure. Gentle slopes (3:1 or 4:1) generally require more fill, which extends the approach ramp farther out away from the structure and will bury vegetation, including trees.
- Wildlife fencing is the most effective and preferred method to guide wildlife to the structure and prevent intrusions onto the right-of-way. Mechanically stabilized earth walls, if high enough, can substitute for fencing and are not visible to motorists.
- Efforts should be made to avoid having roads of any type pass in front of or near the entrance to the wildlife overpass, as it will hinder wildlife use of the structure.
- Large boulders can be used to block any vehicle passage on the overpass.
- Existing or planned human development in adjacent areas must be at a sufficient distance to not affect long-term performance of the overpass. Long-range planning must ensure that adjacent lands will not be developed and the wildlife corridor network is functional.

Possible variations

- Vegetation for screening and fence
- Berms on approach ramps
- Berm in middle of overpass

Maintenance

- Relatively low maintenance. Walls and any fences may need to be checked and repaired.

- During first few years it may be necessary to irrigate vegetation on the structure, particularly if there are extended periods with little rainfall. Sufficient watering (assisted or rainfall) will allow vegetation to settle and take root.
- Monitor and document any human use in the area that might affect wildlife use of the structure and take action necessary to control.

Appendix A3

Highway fencing specifications for high snowfall areas

Norwegian Directorate for Public Roads
February 2005

Provided by:

Bjørn Iuell
Environmental Section
Road Development Department
Directorate for Public Roads
PO Box 8142 Dep, 0033 Oslo, Norway

Highway Wildlife fences in Norway

Mesh:

We usually use mesh of galvanized steel where the vertical wires have a fixed distance (150mm) and the distance between the horizontal wires varies from 160 mm at the bottom to 300 at the top.

Top and bottom wire of the mesh shall have the tension strength of 3600 N (ca. 360 kg), and the rest of the mesh 2800 N (ca. 280 kg). The thickness of the wires is respectively 3.4 mm and 2.5 mm.

In addition to the top and bottom wires of the mesh, we use top and bottom wires 4.2 mm thick and with an tension strength of 5500 N (ca. 550 kg).

The mesh is always attached to the poles on the "outside", seen from the road.

Poles:
We usually use metal poles (galvanized steel). Either T-profile (50 x 50 x 5mm) or round poles with a diameter of 2 " (external diam. 60 mm, 2.9 mm thick material). At the end of the fences, where the fence takes a turn, or "where the fences are exposed to heavier loads", the T-profile poles are increased to 60 x 60 x 6mm.

We also use sloping bars (?), and at the end of the fences, where the fence takes a turn, or "where the fences are exposed to heavier loads", the thickness of the material is increased to 6 mm.

The poles should as a rule not deform with a horizontal load of 1000 N (ca 100 kg) 120cm over ground level.

We also place the fence a little bit further from the road in places where they are exposed to snow from the plowing

The foundation is also important. We recommend at least 100 cm in "solid rock". In soil or wetlands, the poles can go 4-5 m down.

Distance between poles: T-profile –2.5 m, round poles –2.75 m. At the end of the fences, where the fence takes a turn, or "where the fences are exposed to heavier loads", the distance between the poles should not exceed 200 cm.

Height: 250 cm for moose, 220 cm for elk.

Supplemental Material 1

Connectivity Modeling Methods

For our connectivity models, we focused on *black bears, grizzly bears, and wolverines*, because they have huge home ranges so they need to cross roads frequently to access habitat patches, they disperse long distances so they are good species for landscape resistance models (Cushman et al. 2006), and they may be suitable surrogates for other forest dwelling species (e.g., ungulates, cougars, wolves). We gathered *landscape data* to hypothesize resistance to movement for each species: an iterative approach allowed us to test the interactions and relative strengths of each additional environmental variable on the effects on connectivity in this area.

As described in the Connectivity Section, we created *landscape resistance models* hypothesizing resistance to movement for black bears, grizzly bears, and wolverines. We converted each of the landscape data to a landscape resistance model following Cushman et al. (2006). We randomly placed 500 points in our study area weighted on density surfaces for bears and on a snow persistence layer for wolverines. Preliminary runs explored number of points and point placement with relatively little change in path convergence. Least cost path models identify the shortest path of least resistance from point A to point B. We used UNICOR (Landguth et al. 2012) to run least cost paths between the 500 starting points and examined areas where the paths crossed the TCH.

Isolation-by-landscape resistance

We produced dozens of landscape-resistance surfaces representing the factorial combinations of 7 landscape factors: elevation, forest cover, non-habitat, protected areas, roads, ruggedness, and snow cover (Table S1.1). These factors are the landscape features to which black bears, grizzly bears, and wolverines respond most strongly (Cushman et al. 2006, Graves et al 2014, and Balkenhol et al 2009, respectively). Elevation is the most informative measure of physiography, which is why we chose to model across 3 elevation gradients; roads and land cover have well established relationships to habitat quality and movement for a wide range of organisms and for grizzly bears in particular (Proctor et al 2015).

Table S1.1: Metadata for all layers used in the analysis.

Coverage	**Description**	**Source**
Elevation	Digital elevation model meters	Derived from 30-m DEM
Non-habitat	A combined layer that includes features of known impermeability	Geogratis and LLYK Field Unit GIS data
Roads	Road layer including Trans-Canada Highway (TCH), Highways 93 and 95, and other roads	Geogratis and LLYK Field Unit GIS data
Forests	Tree cover percentage classified into forest/non forest areas	Hansen et al. 2013.
Protected Areas	National and Provincial Parks	Geogratis and LLYK Field Unit GIS data
Ruggedness	Topographic Position Index	Derived from 30-m DEM
Snow Cover	Persistent snow layer following Copeland	Ben Dorsey, MRG Field Unit

Note: All coverages were resampled to raster grids with 180-m cell size and projection UTM NAD 1983 Z11 system.

Resistance of these factors to gene flow was modeled across 4 levels for elevation, 2 levels for forest cover, 2 levels for non-habitat, 2 levels for protected areas, 3 levels for roads, 2 levels for ruggedness, and 2 levels for snow cove (Table S1.2). We specified a range of levels for each factor, allowing the relative importance of each factor to be expressed in a multifactor model. In this approach, models are most sensitive to the relative magnitude of the factors, not their specific values. Thus, the levels were chosen to cover the range of each factor on the landscape, and all factors were scaled between 1 and 10, allowing each factor to speak with equal weight. The resistance maps corresponding to each factor were combined into the 3 landscape resistance models by addition. After addition, the minimum value on the combined grids was 8, reflecting the sum of the minimum values of the original eight factors (greenness was the 8^{th} factor, but was not included in final models as it was represented by forest cover). These connectivity models were represented by GIS raster maps whose cell values were equal to the hypothetical resistance of each cell to gene flow. Before analysis, the base maps were resampled to 90-m pixel size and projected to the UTM NAD 1983 Z11 system (Table S1.1).

Table S1.2: Description of factors and levels combined to create our landscape-resistance connectivity models.

Factor and level	Code	Description
Elevation:		
High elevation	EH	Minimum resistance at high elevation
Middle elevation	EM	Minimum resistance at medium elevation
Low elevation	EL	Minimum resistance at low elevation
Null	EN	No relationship with elevation
Non-habitat:		
High non-habitat	HH	High resistance to non-habitat areas
Null	HN	No resistance to non-habitat areas
Roads:		
High roads without crossings	XH_0	High resistance to roads that do not include crossing structures
High roads with crossings	XH_1	High resistance to roads with low resistance areas for wildlife crossing structures
Null	XN	No resistance to roads
Forest cover:		
High non-forests	FH	High resistance to non-forested areas
Null	FN	No resistance to non-forested areas
Protected areas:		
High protected areas	PH	High resistance in non-protected areas
Null	PN	No resistance to non-protected areas
Ruggedness:		
High ruggedness	RH	High resistance to low ruggedness
Null	RN	No resistance to ruggedness
Snow cover:		
High snow	SH	High resistance to low persistent snow areas
Null	SN	No resistance to persistent snow

Elevation

Elevation in the study area ranges from 580 m – 3514 m with a 1924 m mean and 483 m standard deviation. Landscape resistance due to elevation was modeled at four levels, including a null model. Resistance was modeled as an inverted Gaussian function as Cushman et al (2006), and parameterized with a minimum of 1 and a maximum approaching an asymptote of 10. The standard deviation of the curve was 483 m. The levels differed only in the elevation at which the function reached its minimum value. The three levels of elevation had resistance minima at 976 (mean minus 2 times the standard deviation), 1924 (mean), and 2908 (mean plus 2 times the standard deviation) m, respectively (Fig. S1.1, S1.2). These three levels reflect a range of potential relationships between resistance to movement and elevation, with increasing resistance to gene flow at elevation higher and lower than the minima, with a maximum resistance of 10 times that of the minima achieved at the asymptote. The null model predicted resistance of 1 at all elevations (i.e., isolation-by-distance).

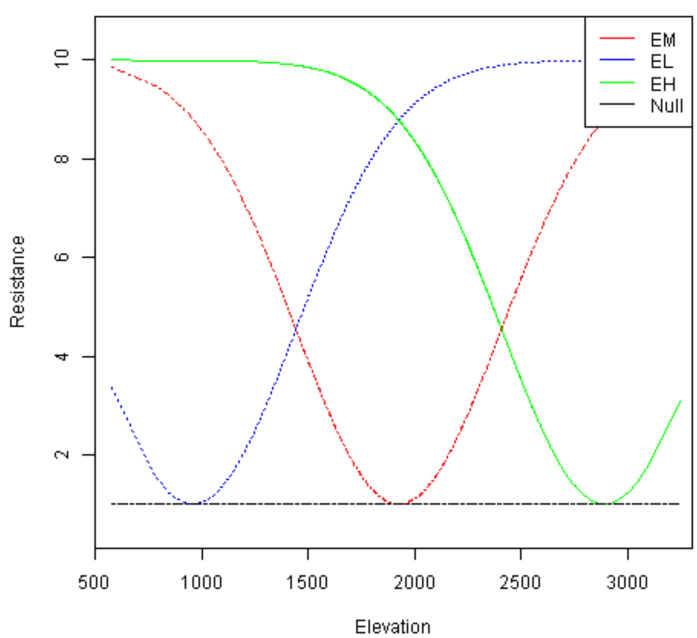


Figure S1.1: Functions used to develop hypotheses regarding resistance due to elevation. The four levels include three Gaussian function of resistance with respect to elevation and one null model. The three Gaussian levels each have a standard deviation of 483 m, minima of 1, and a maximum of 10. They differ only in the elevation at which the minimum resistance is achieved:

976 m for EL, 1924 m for EM, 2908 m for EH (see table 1 for abbreviations). The null model predicts a resistance of 1 for all elevations.

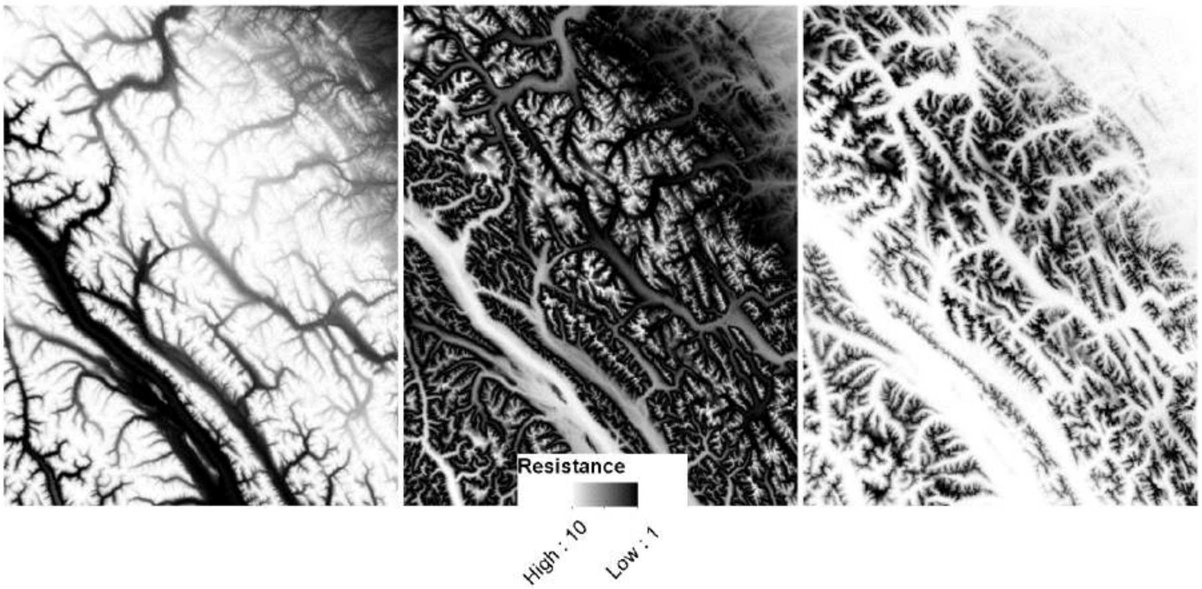


Figure S1.2: The three levels of elevation resistance reclassified based on the Gaussian functions.

Non-habitat

We created a layer for black and grizzly bears and a layer for wolverines that combines features of known impermeability for the different species. This included major lakes, permanent snow and ice, and buildings for bears; we used everything except the snow and ice layer to build the non-habitat layer for wolverines. We calculated a 500m buffer around the features in the building layer using a 500m radius (Proctor et al 2015). Non-habitat except permanent snow and ice was generally classified as "no data" to create pixels impervious to movement, everything else was classified with a resistance value of 1 (see Fig. S1.3). Permanent snow and ice for bears was classified with a resistance value of 10 as bears are known, on occasion, to move through those inhospitable habitats.

Roads

We delineated road features into four classes: (1) Trans-Canada Highway with resistance value of 10, (2) other major highways (e.g., Highways 93 and 95) with resistance value of 6, (3) other roads with resistance value of 2, (4) other areas with resistance value of 1. With the current wildlife crossing structures, we examined three levels of connectivity (Table S1.2): (1) High resistance to roads not including crossing structures, (2) High resistance to roads including low resistance values of 1 for all crossing structures, and (3) no resistance to roads (see Fig. S1.3). Road polylines were converted to raster values with 180 m resolution, while ensuring no diagonal connections (i.e., we did not want to create artificial least resistance pinch points for the LCP algorithm).

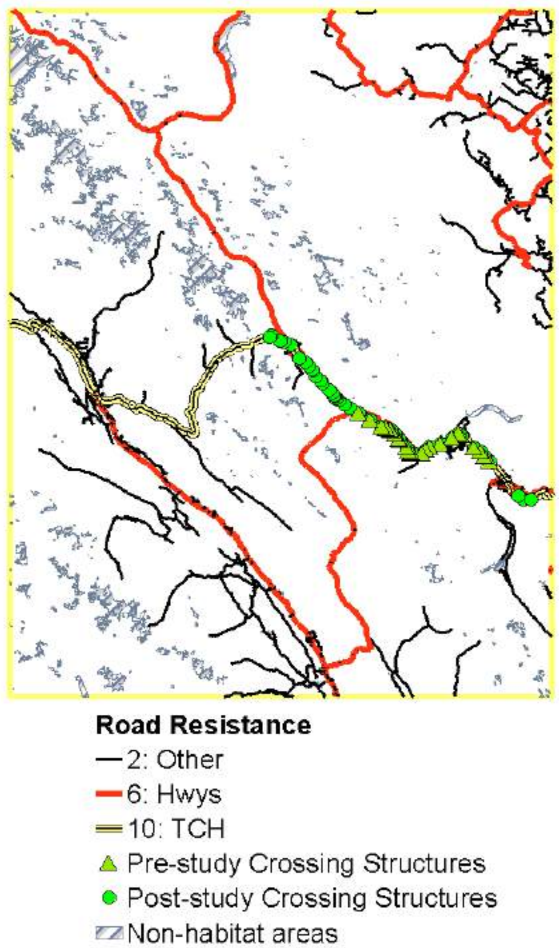


Figure S1.3: Road classification, crossing structure locations, and non-habitat areas (glaciers, lakes, and buildings).

Landcover

We obtained percent tree cover from https://storage.googleapis.com/earthenginepartners-hansen/GFC2015/Hansen_GFC2015_treecover2000_60N_120W.tif (Hansen et al. 2013) as a proxy for forested and non-forested areas. Percentages greater than 30 were given a resistance value of 1 and 10 elsewhere (see Fig. S1.4).

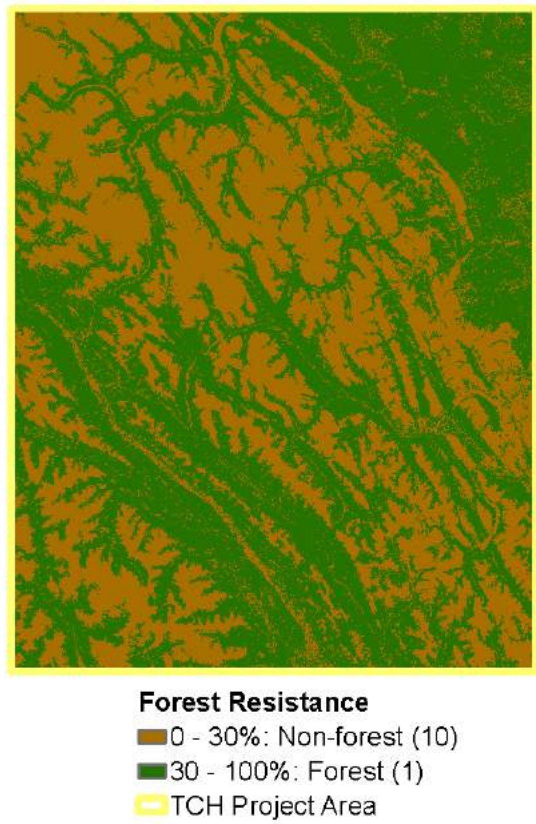


Figure S1.4: Percent tree cover (Hansen et al. 2013) used to define forest and non-forest areas and resistance values.

Protected areas

Protected areas were used to define three levels of high to low resistance: (1) National parks were given a resistance value of 1, (2) All other protected areas such as provincial parks were given a resistance of 5, and (3) outside of protected areas were given values of 10 (see Fig. S1.5).

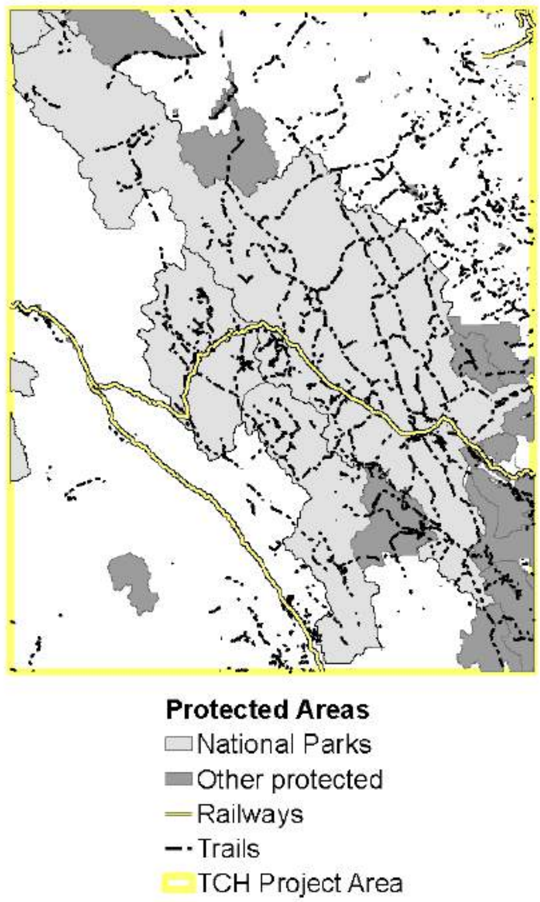


Figure S1.5: Protected areas, railways, and trail systems in the project study area.

Ruggedness

We used the Topography Tools extension in ArcGIS to calculate Topographic Position Index (TPI) from a Digital Elevation Model. We defined terrain ruggedness resistance by reclassifying TPI to values between 1 and 10 (1=low resistance, 10=high resistance) (Fig. S.1.6).

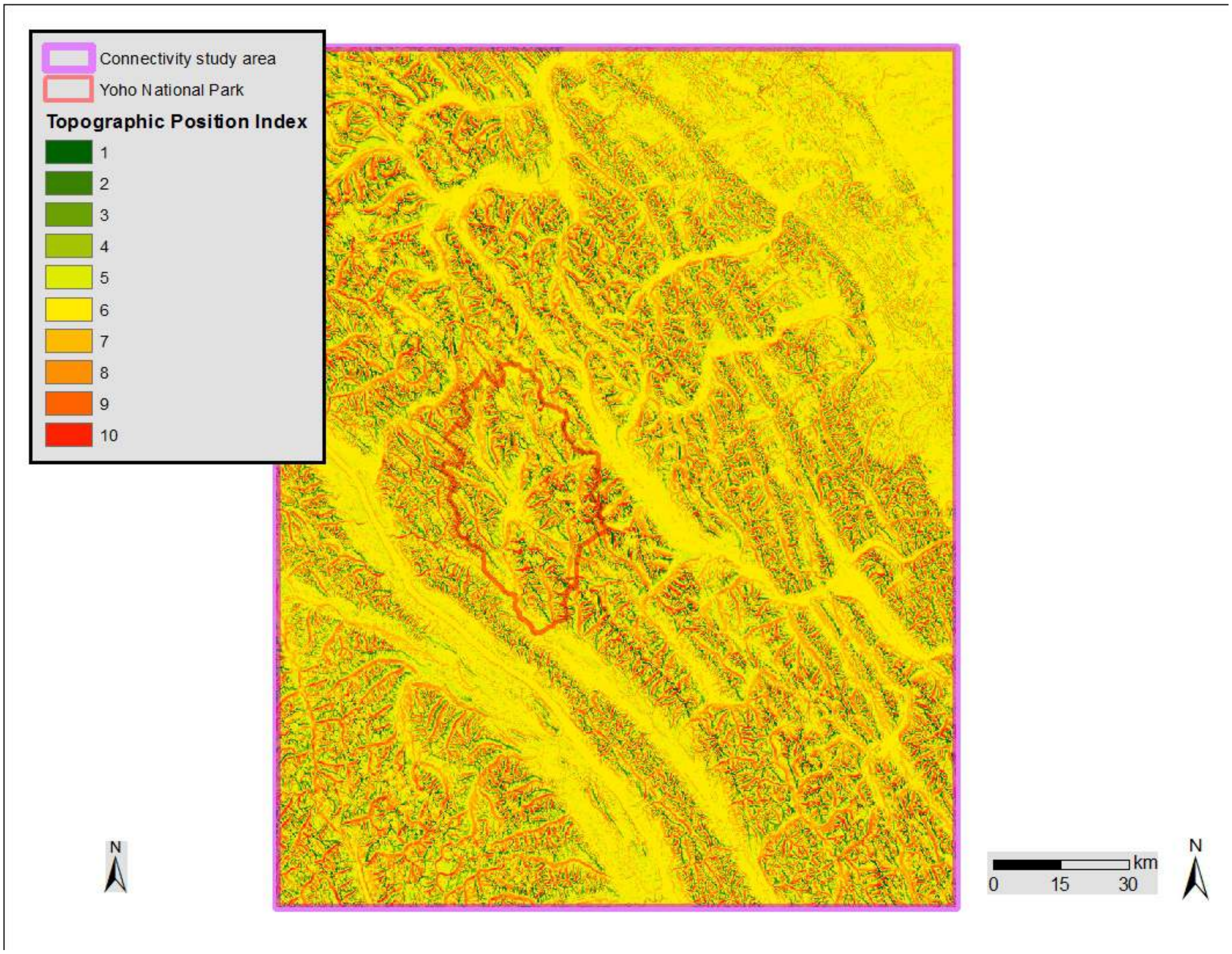


Figure S1.6: Ruggedness (Topographic Position Index) in the project study area.

Snow cover

We created a persistent spring snow cover layer following Copeland et al. (2010). We used Modis Terra data from 14 April to 15 May for the 12-year period, 2000 to 2011, and classified each 500 m pixel by presence or absence of snow (Fig. S.1.7). Pixel values ranged between 0 and 12 with a value of 12 indicating that the pixel contained snow during the one-month period in all 12 years. We reclassified snow cover to resistance as follows (resist values in parentheses): snow 0-3 (10), 4 (9), 5 (8), 6 (7), 7 (6), 8 (5), 9 (4), 10 (3), 11 (2), 12 (1).

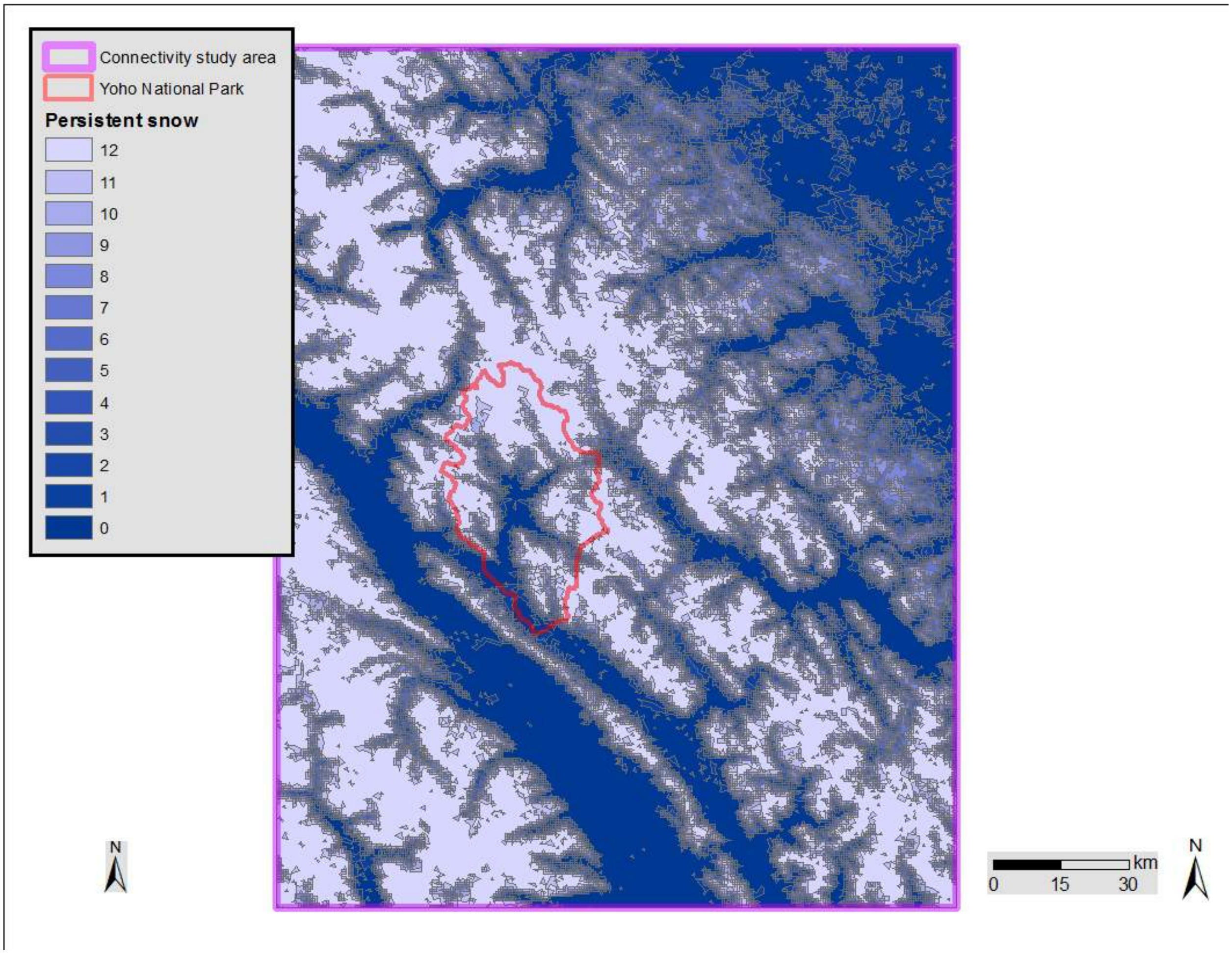


Figure S1.7: Persistent snow cover in the project study area.

Landscape resistance surfaces

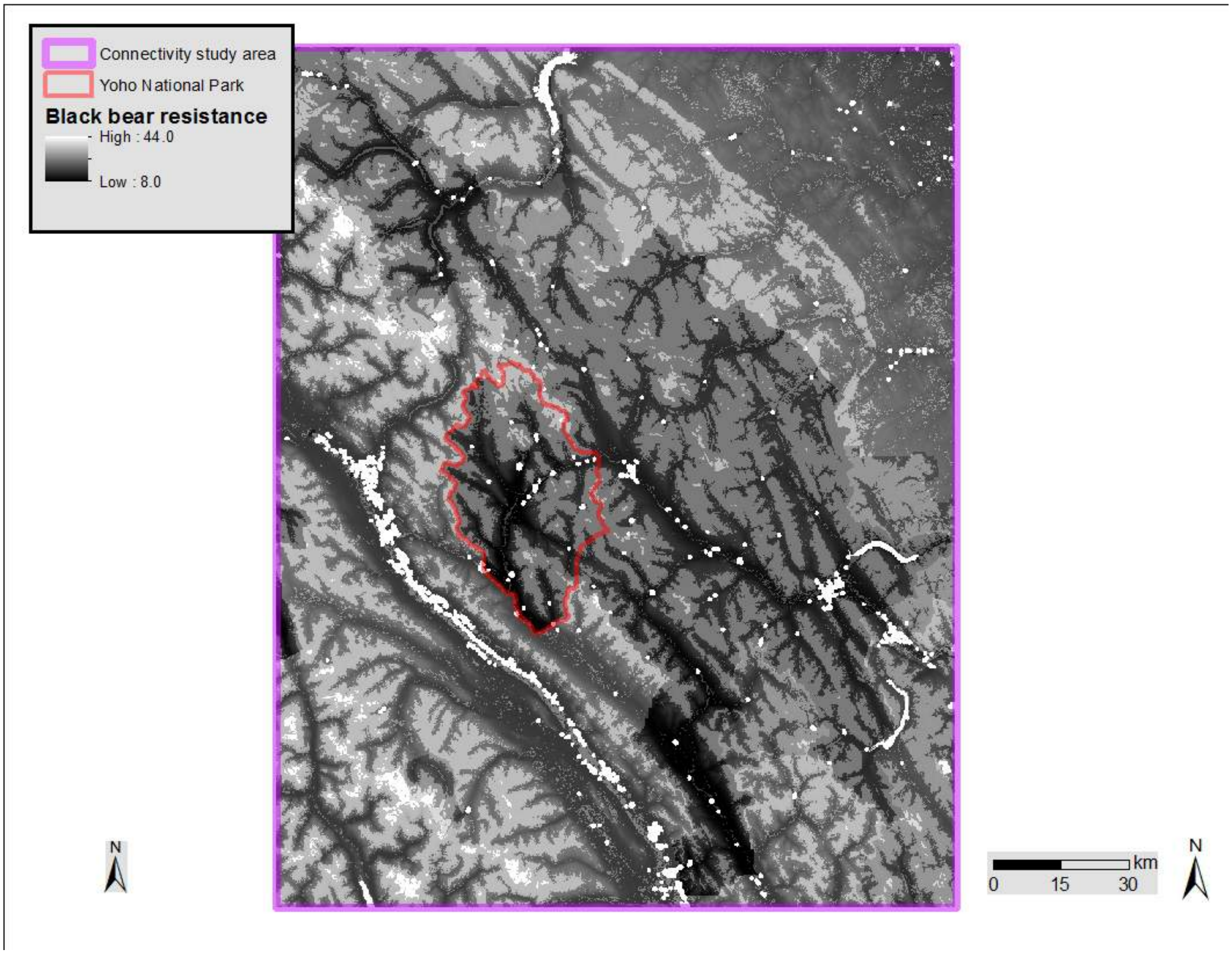


Figure S1.8: Our landscape resistance surface for black bears in Yoho National Parks, British Columbia.

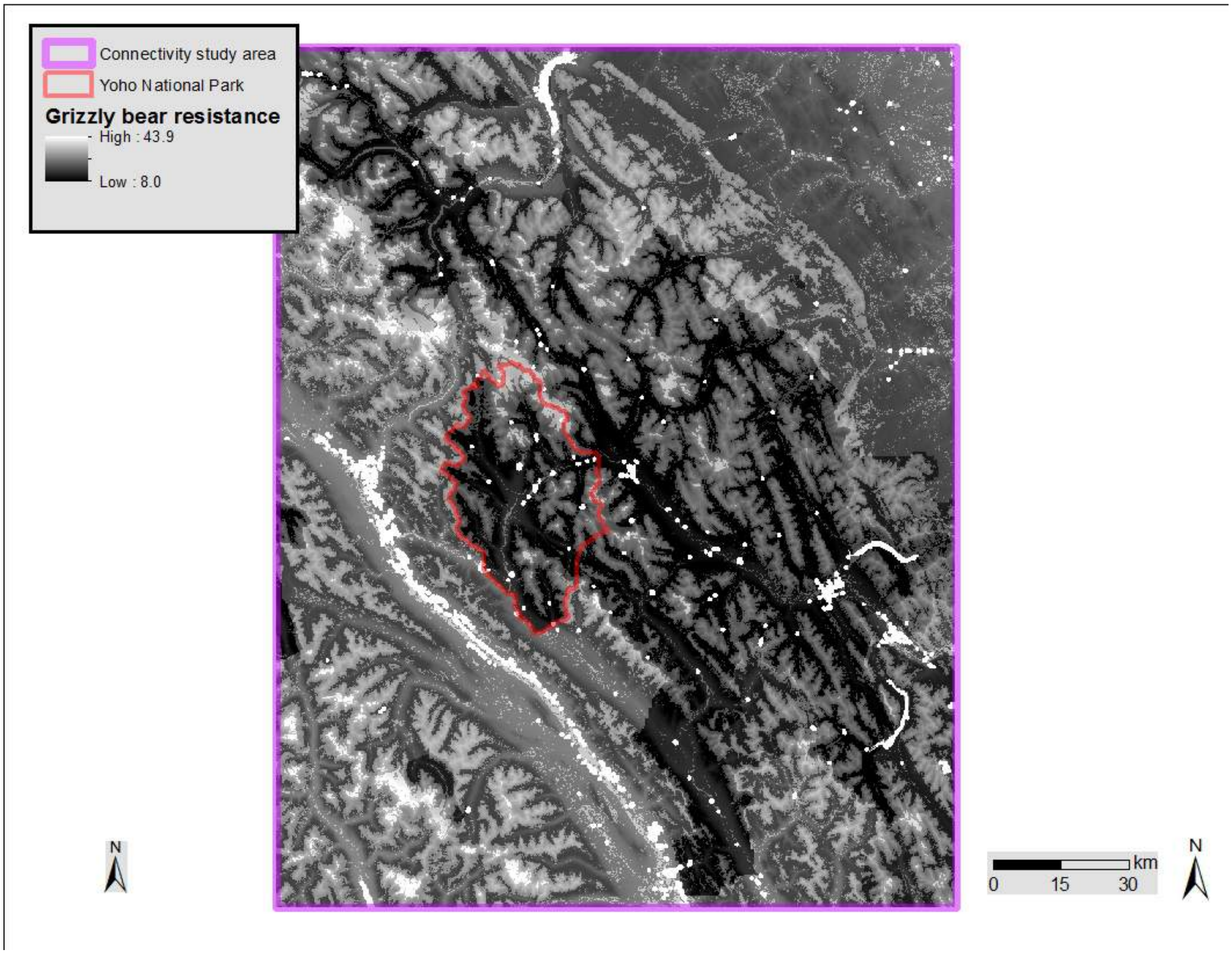


Figure S1.9: Our landscape resistance surface for grizzly bears in Yoho National Parks, British Columbia.

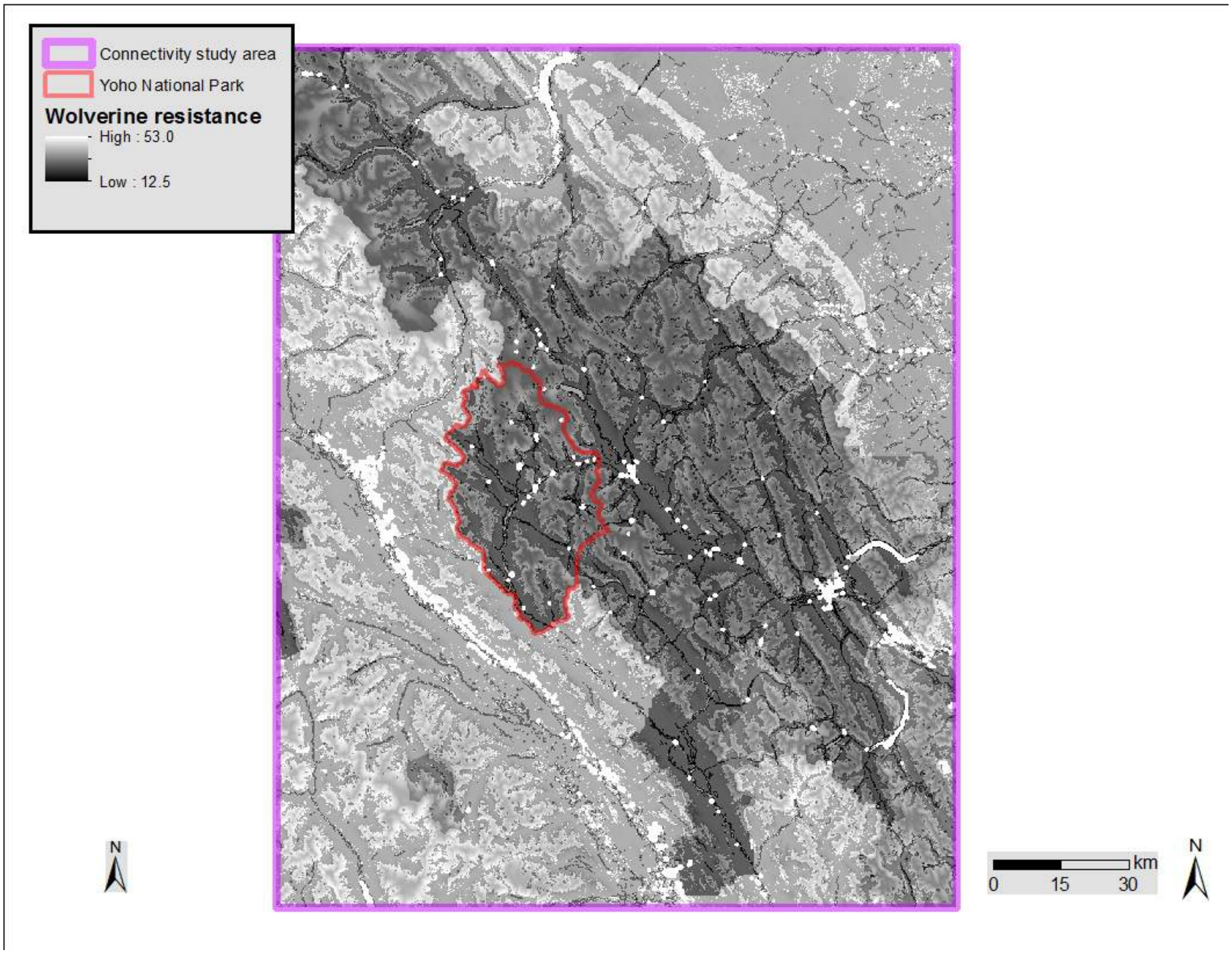


Figure S1.10: Our landscape resistance surface for wolverines in Yoho National Parks, British Columbia.

Least Cost Paths (LCP)

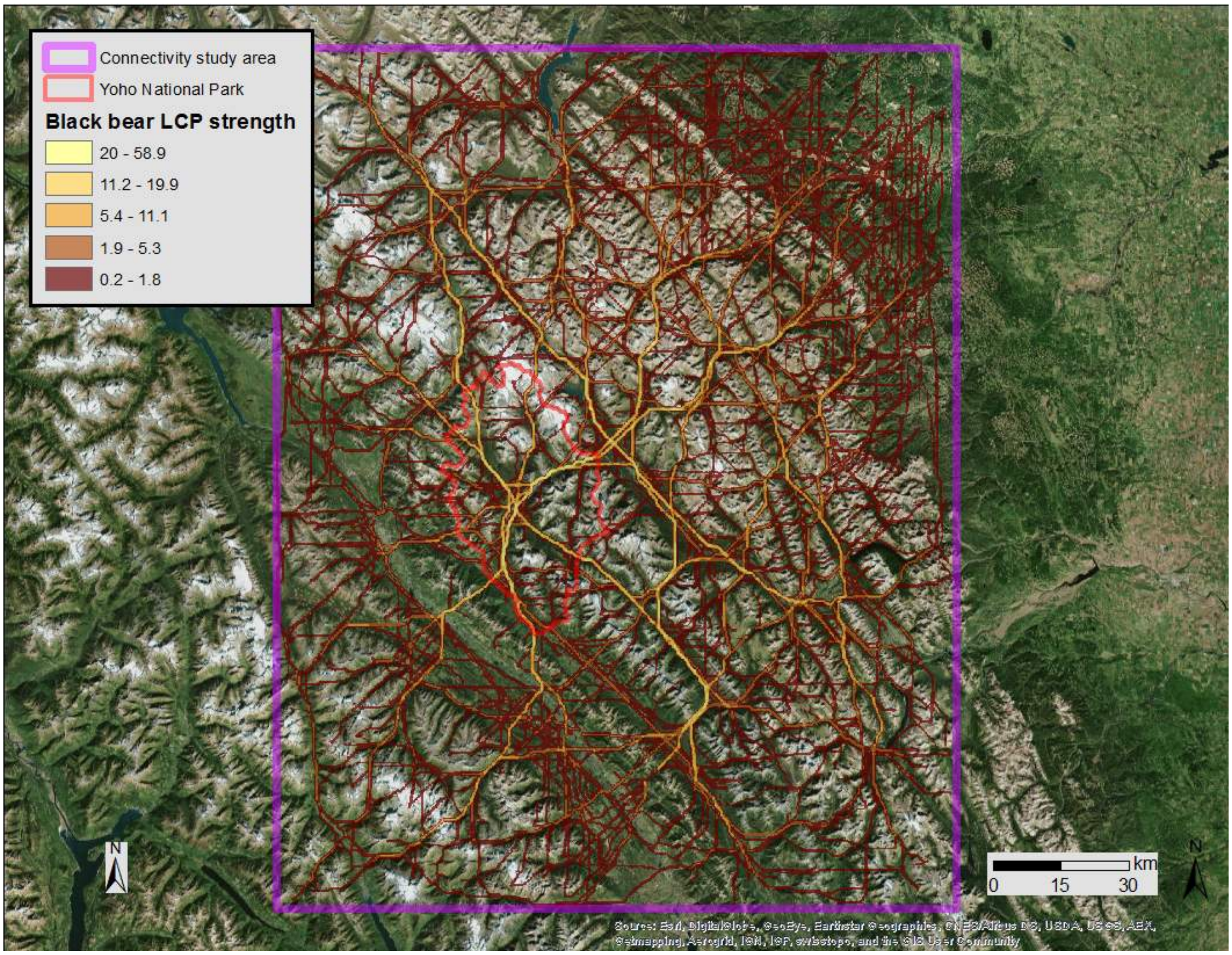


Figure S1.11: UNICOR's least cost paths for black bears in the extensive connectivity study area surrounding Yoho National Park, British Columbia.

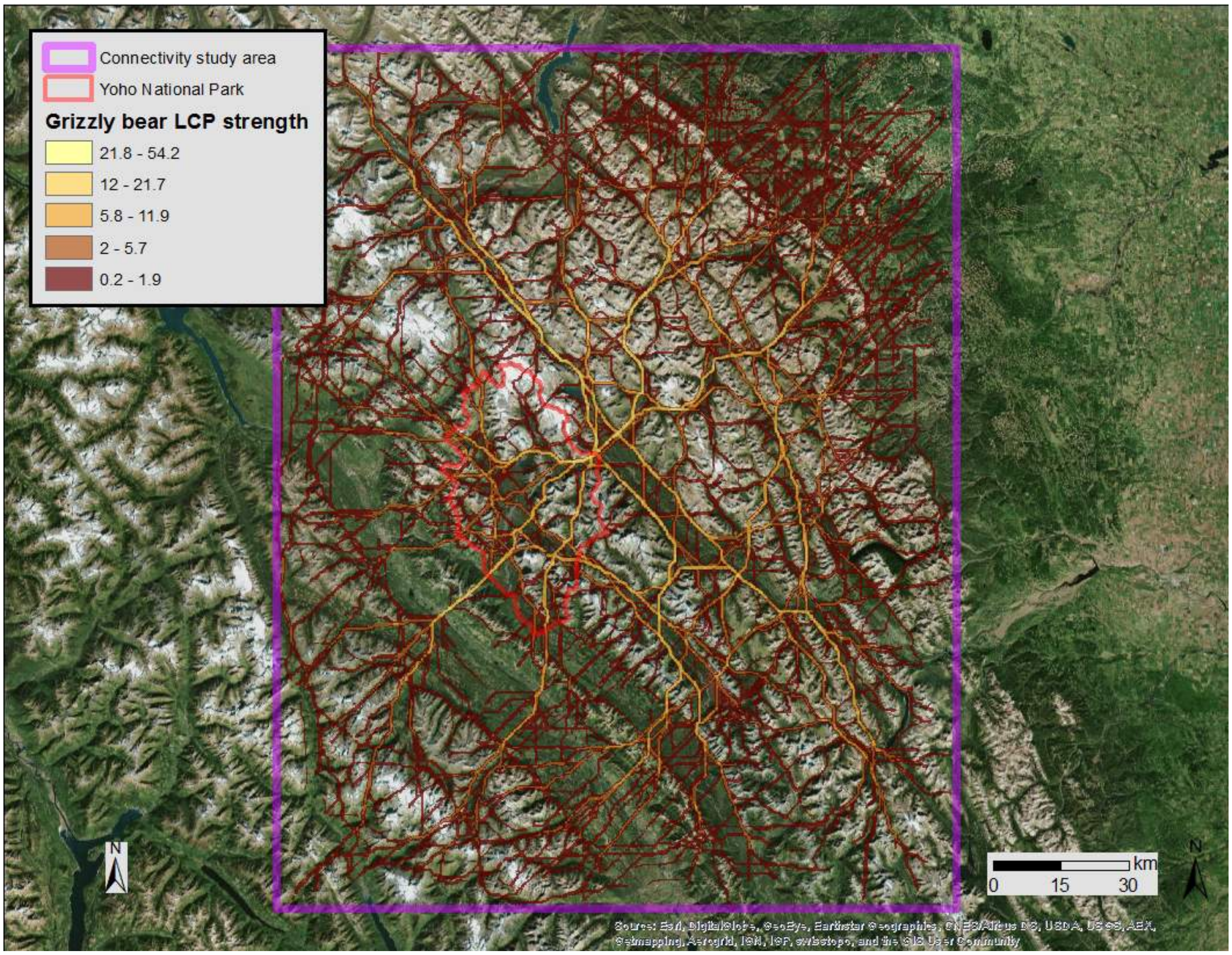


Figure S1.12: UNICOR's least cost paths for grizzly bears in the extensive connectivity study area surrounding Yoho National Park, British Columbia

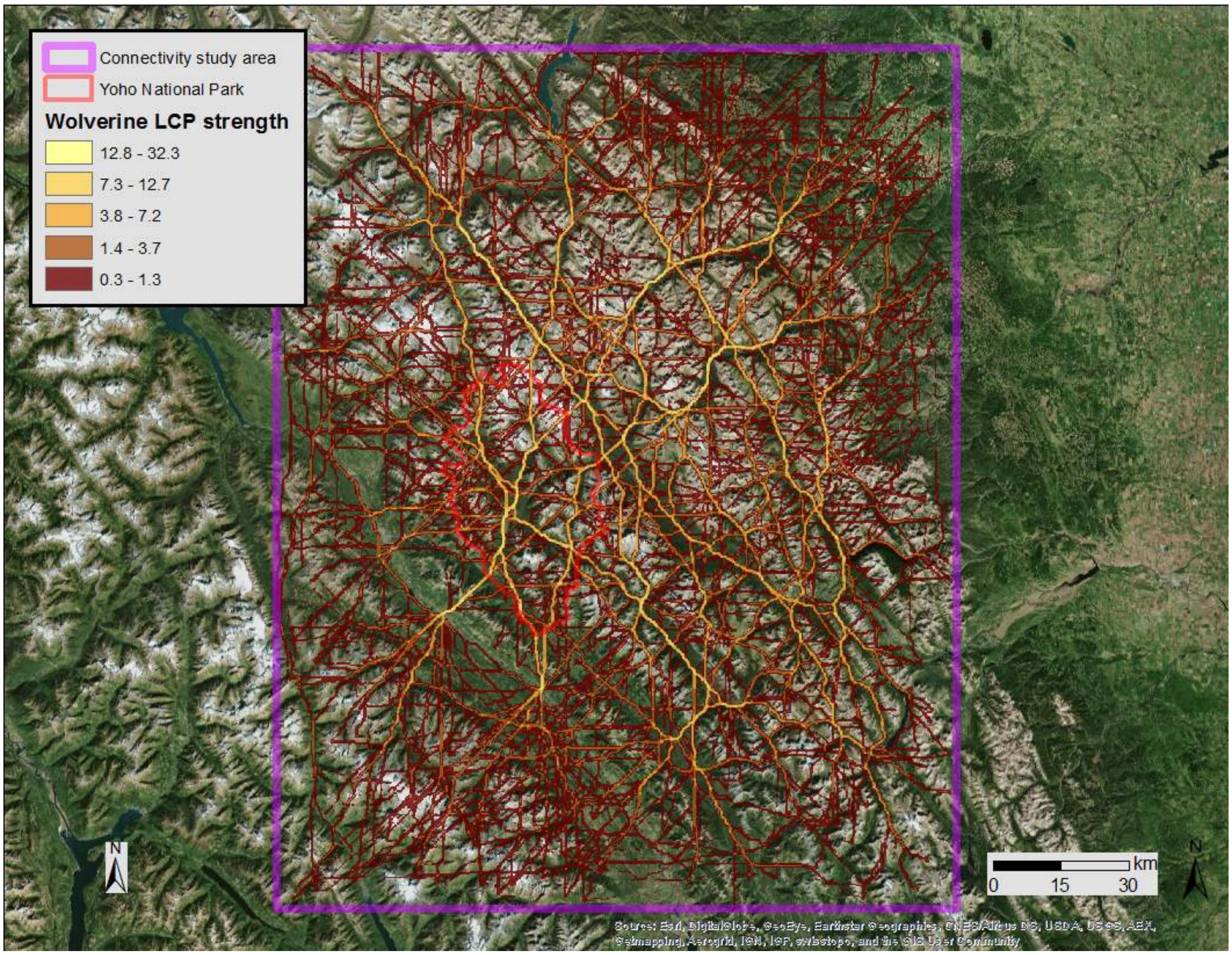


Figure S1.13: UNICOR's least cost paths for wolverines in the extensive connectivity study area surrounding Yoho National Park, British Columbia.

References

Balkenhol, N. 2009. Evaluating and improving analytical approaches in landscape genetics through simulations and wildlife case studies. Doctoral Thesis. University of Idaho, Moscow, ID

Cushman, S.A., K.S. McKelvey, J. Hayden, M.K. Schwartz. 2006. Gene flow in complex landscapes: testing multiple hypotheses with casual modeling. The American Naturalist, 168:486-499.

Graves, T., R. Chandler, J.A. Royle, P. Beier, K. Kendall. 2014. Estimating landscape resistance to dispersal. Landscape Ecology 29:1201-1211.

Hansen, M. C., P. V. Potapov, R. Moore, M. Hancher, S. A. Turubanova, A. Tyukavina, D.

Thau, S. V. Stehman, S. J. Goetz, T. R. Loveland, A. Kommareddy, A. Egorov, L. Chini, C. O. Justice, and J. R. G. Townshend. 2013. “High-Resolution Global Maps of 21st-Century Forest Cover Change.” Science 342 (15 November): 850–53. Data available on-line from: http://earthenginepartners.appspot.com/science-2013-global-forest.

Landguth, E.L., B.K. Hand, J. Glassy, S.A. Cushman, M.A. Sawaya. 2012. UNICOR: a species connectivity and corridor network simulator. Ecography 35: 9-14.

Proctor, M.F., S.E. Nielsen, W.F. Kasworm, C. Servheen, T.G. Radandt, A. G. Machutchon, and M.S. Boyce. 2015. Grizzly bear connectivity mapping in the Canada-United States Trans-Border Region. Journal of Wildlife Management 79: 544-558.