Banff Wildlife Crossings Project:
Integrating Science and Education in Restoring Population Connectivity Across Transportation Corridors

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EXECUTIVE SUMMARY

Canada's Rocky Mountain front harbors the richest diversity of large mammals remaining in North America. The Trans-Canada Highway (TCH), a major east–west transportation corridor, bisects Banff and Yoho National Parks. For 25 years, Banff National Park has been the focus of efforts to mitigate the impacts of the TCH on wildlife mortality and habitat fragmentation. A range of engineered mitigation measures—overpasses, underpasses, fencing—was designed to reduce wildlife mortality and increase population connectivity. These measures have been incorporated into the design of successive TCH "twinning" projects (widening from two to four lanes) since 1982.

This stretch of four-lane highway comprises the first large-scale complex of highway mitigation measures for wildlife of its kind in the world. The significance of these wildlife crossing structures has led to Banff assuming international leadership in highway mitigation performance and evaluation, design criteria, and connectivity studies for a wide range of animals at a landscape scale. It is the perfect natural laboratory for understanding the conservation value of highway mitigation measures for a variety of wildlife species.

For 12 years, researchers led by Dr. Tony Clevenger have closely monitored how different species use these structures, and in the process have collected an enormous volume of valuable data on crossing frequency, species preference and behaviour. Since 2002, Dr Clevenger has been affiliated with the Western Transportation Institute at Montana State University (WTI). In 2005, the Woodcock, Wilburforce and Kendall foundations, along with WTI, approached Parks Canada's senior managers in the mountain parks with a proposal for continued monitoring and research. A four-year partnership agreement was formalized among the parties to support the Banff Wildlife Crossings Project (BWCP).

The Banff research has amassed the most complete and scientifically sound body of information in the world on how wildlife and populations respond to wildlife crossing mitigation. The research provides a basis from which to assess the effectiveness of wildlife crossing structures and provide recommendations to transportation practitioners and wildlife managers on the environmental and societal benefits of these highway infrastructure investments.

Extensive efforts have been made to share this valuable data with the public and other researchers throughout Canada and the world. These have included numerous lectures, symposia, museum exhibits, workshops, publications in scientific journals and the popular press, and presentations to schools and civic groups.

In 12 years of monitoring, researchers have detected wildlife using these crossing structures more than 185,000 times. Among the findings:

- Grizzly bears are making increasing use of the new crossing opportunities. The number of recorded grizzly bear crossings has soared 35-fold, from five instances in 1996 to 177 in 2008. As a proportion of all wildlife crossings, grizzly bear use went from one of every 2000 crossings to a little more than one in 100 crossings.
- Use by other species has fluctuated. Elk usage declined by 45 percent as a proportion of all crossings during the period, while deer use of the crossing structures has increased dramatically from 45 percent to over 70 percent in a 10-year period.

- Several unique or unexpected observations of species using the Banff wildlife crossing structures have been made. For instance, red fox, striped skunk and hoary marmot have each been detected using the structures. The presence of boreal toads has been recorded on Wolverine overpass, garter snakes were seen at Duthil wildlife underpass, and beavers were detected using the Redearth Creek underpass. These detections have been aided by the use of remote infrared-operated cameras.
- There also have been noteworthy species—primarily moose, wolverine and lynx—detected using the crossing structures less frequently than most large mammals. Current information on the moose population suggests that there are few localized individuals in the middle and lower Bow Valley. Wolverines were detected four times using three different crossing structures. Lynx were detected twice using two crossing structures. To our knowledge, *these are the first detections of wolverine and lynx using wildlife crossings in North America.*
- We found that the presence or absence of an alpha female wolf makes a significant difference in how wolves use the crossing structures. The number of recorded through passages by wolves decreased 13 percent in the month after the mortality of a putative alpha female wolf, despite there being more attempted crossing events during this time than during the month before the mortality. We also found that wolves were more hesitant to use the crossing structures after the mortality event. The number of crossing events where wolves hesitated increased threefold following the death of the alpha female.
- In looking at the relative use by wolves, cougars and coyotes, we found that there was a very low probability of any of these three species being detected at the same wildlife crossing structure during the same time interval. This supports the hypothesis that the three conspecifics avoid each other. Interestingly, when they were detected during the same monitoring check interval, coyotes were almost twice as likely to be detected with wolves as with cougars. Cougars and wolves rarely co-occurred at the crossing structures. That cougars and wolves appeared to avoid using the same crossings suggests that inter-species interactions may be a more important factor in determining species use of wildlife crossings than we have previously thought.

Relationship between population size and passage rates at wildlife crossing structures

Long-term monitoring of wildlife crossing structures along the TCH in Banff has generated an impressive collection of wildlife activity and distribution data since 1996. However, passage rates at wildlife crossing structures have yet to be directly associated with actual population sizes of wildlife in the surrounding landscape. We used aerial and ground survey records of the Bow Valley elk population from 1996–2007 to compare frequency of crossing structure use over time. We calculated the frequency of crossing events at each wildlife crossing structure as a function of population size. We looked for an association between the annual population estimate and the seasonal total of crossing structure passages at each site.

Elk population size and crossing events were strongly associated, particularly at the open span bridge designs along Phase I and II. The Powerhouse underpass had the best overall correlation with population size. Correlations between wolf crossing events and population size were weaker than correlations for elk. Passages at Healy were most consistently correlated with population size. Given the importance of management benefits from these initial findings, we recommend that population studies be carried out to allow for additional assessments of the proximity and strength of association of the two types of data in the Banff and KYLL Field Units.

Use of crossing design types

Analyses from our earlier research showed that some species display a preference for the types of crossing structures they use. Grizzly bears, wolves, moose, deer and elk tended to prefer large, open structures with good visibility, while cougars, and to some extent black bears, tended to prefer smaller structures that provide more cover. For this report, we analyzed our 12 years of monitoring data in a paired comparison of each of the wildlife overpasses with its nearest wildlife underpass. This side-by-side comparison found species-specific preferences similar to the previous results: grizzly bears, moose, wolves and the three ungulate species almost always used overpasses rather than the nearby underpasses, while black bears were inconsistent in their use of the two structure types, and coyotes and cougars showed a relatively equal distribution of movements at the two types of structures.

We also looked at the relationships between the four types of wildlife crossing designs used by the eight species to see whether they were constant over the 12-year monitoring period. The proportional use of the wildlife crossing design types (box culverts, metal culverts, open-span bridge underpasses, wildlife overpasses) was consistent year to year for many species. The most regular and consistent species in terms of design type usage were deer, elk, moose, grizzly bears, and wolves. The relative use of crossing design types by these five species varied slightly or not at all during the 12-year period. However, for cougars, black bears and coyotes the relative proportion of use by crossing design type changed markedly from year to year. It is noteworthy that these three species, which appear to be the least consistent in crossing design selection, are the same species whose use of the crossing structures we found to be affected most by larger conspecifics. These species are most subject to displacement and predation by the larger conspecifics, and this may suggest that cougar and black bear preference for smaller wildlife crossing structures is less a function of selection and more influenced by the presence of larger conspecifics in the study area.

Wildlife response to new and established crossing structures

The frequency of through passages was higher on crossing structures built during the earlier Phases I and II of highway construction than on the more recently built Phase IIIA structures, and in later winters for all phases (see Figure 2.1 through Figure 2.5 for details on the highway construction phases and associated crossing structures). Species-specific passage rates follow these general trends, suggesting that species become more likely to use crossing structures as time passes.

The question of how animals respond or adapt to newly constructed wildlife crossings has direct management implications for the newly constructed Phase IIIB wildlife crossings near Lake Louise, and other soon-to-be-constructed wildlife crossings there that are scheduled for completion in 2012.

Adaptation and learning at the wildlife crossing structures

Our long-term monitoring has demonstrated that there is an adaptation period and learning curve for large mammals using the wildlife crossing structures, and that ungulates adapt more quickly than carnivores. In Banff we have learned about the adaptation period in two ways. First, snow track transects were conducted around the entrances to both established and newly constructed wildlife crossing structures (see above). On average, the "through-passage rate" on new crossing structures was about half that associated with established sections. Next, we examined time-series data from three ungulate and five carnivore species using the Phase IIIA wildlife crossings from inception (1997) to the present (2008). For the eight species, use of the crossing structures increased and then leveled out after an average of four to six years.

The average duration of efforts to monitor wildlife crossing structure use is 17 months. This 12-year dataset allowed us to more fully investigate wildlife adaptation to crossing structures and underscores the importance of long-term monitoring to inform decision making.

Grizzly bear use of the Banff wildlife crossings

Grizzly bear use of the crossing structures has been increasing since monitoring began over 12 years ago, from only five crossings in 1997 to 177 in 2008. Several factors may explain this relationship. First, the grizzly bear population appears to have increased in the Bow Valley since monitoring began in 1996. Second, grizzly bears could be learning that crossing structures provide safe passage across the TCH and thus may be repeat users. And third, many family groups have been documented using the crossing structures. Thus, young bears may be learning to use the crossings when part of a family group. When these subadult bears disperse from the maternal range they may continue to use the crossing structures. Ongoing graduate research by Mike Sawaya on the genetics of bear use of the wildlife crossings will shed more light on what is likely causing the trend toward increased use.

Genetic connectivity of grizzly and black bear populations across the TCH

Until now, studies have not gone beyond showing that various species will use crossing structures, with the assumption that the greater the use, the more successful the crossing structure. Questions remain, however, as to whether these measures actually improve population viability and which species might benefit from them? In a three-year study, DNA samples were obtained from the hair of bears that were using 20 of the 23 crossings, while hair traps and rub trees dispersed through the area were systematically surveyed to obtain comparable genetic information from the bear populations in the surrounding landscape. Individual identifications and genders were determined from samples collected from all three sampling methods.

Sampling success. Of the bear crossing events at the crossing structures, the percentage from which we obtained hair samples (hair-sampling success rate) ranged from 47 to 50 percent for black bears and 50 to 63 percent for grizzly bears between 2006 and 2008. The rate of hair sampling for black bears remained relatively constant, while the rate for grizzly bears declined slightly during the three-year period. Although our hair-sampling system was not designed for cougars or wolves, sampling rates for these two carnivores ranged from 17 to 33 percent for cougars and 29 to 56 percent for wolves.

Summary of genetic analysis. In 2006, 11 black bears (five females, six males) and 11 grizzly bears (four females, seven males) were identified using the wildlife crossings. In 2007, eight black bears (four females, four males) and 12 grizzly bears (six females, six males) were sampled using the wildlife crossings. These are considered minimum estimates of individuals and genders using the crossings as we were unable to sample hair from all individuals and not all samples were adequate for genetic analysis. Samples collected in 2008 are awaiting analysis. The DNA amplification success rate varied between 55 percent and 82 percent for black and grizzly bear samples obtained at the wildlife crossings. Amplification success rates of hair samples from cougars and wolves ranged from 39 percent to 81 percent. In 2006, three wolves (one female, two males) and one cougar (male) were identified, whereas in 2007 a total of five wolves (four females, one male) and three cougars (males) were identified using the crossings.

Spatial pattern of hair sampling and track detections. Data from black and grizzly bears were collected at the wildlife crossing structures using track pads and hair collection methods. During the 2006 and 2007 field seasons, we detected 178 black bear crossing events using track pads, and collected at least one hair sample from 71 (40 percent) of those crossings. For the two years of data that we have been able to analyze, black bear hair collection was highly correlated with the black bear track detections (r^2=0.87). The distribution of black bear hair sample collection was strikingly similar to distribution of black bear track detections. Black bear track detections occurred at 15 wildlife crossing structures, while hair samples were obtained from 14 crossing structures. During the same period, we detected 211 grizzly bear crossings and collected at least one hair sample from 86 (41 percent) of the grizzly bear crossings. Similar to black bears, grizzly bear hair collection was highly correlated with grizzly bear track detections (r^2=0.99). Grizzly bear track detections occurred at 13 wildlife crossing structures, while hair samples were obtained from only four crossing structures. Unlike grizzly bear track detections that were obtained from a wide geographic range of wildlife crossings, hair samples were obtained from a limited number of wildlife crossings.

Temporal pattern of hair sample collection. The collection of hair samples from bears using the wildlife crossings was strongly associated with the month of the year. The temporal pattern of black bear and grizzly bear hair collection was strikingly similar. The peak of black bear and grizzly bear hair collection occurred in June and July. The similarity between species and timing of the peak could be explained by their seasonal movements for foraging and reproduction purposes. We suspect that as bears spend more time in the valley bottom habitat foraging and breeding, there is greater likelihood that they will also need to cross the TCH via wildlife crossing structures.

Individual use of wildlife crossing structures. The mean number of bear crossings per individual identified through DNA analysis was 5.4 for black bears and 6.1 for grizzly bears. There was more variability in the number of crossing events per grizzly bear individual than per black bear individual (range=1–17 vs. range=1–25, SE=1.73 vs. SE=1.53). Among black bears, two individuals were detected from hair collection in a high proportion of crossing events. For grizzly bears, one male individual was detected from hair collection in a high proportion of crossing events. Bear use of crossings may be a function of age, or social and reproductive status, and without knowing the age of an animal, we are unable to know about the other conditions. Cubs of the year are small, which should make them more difficult to detect with our hair sampling system, thus resulting in underestimating their use of crossing structures.

Future direction. In 2009, we will continue to analyze the 2006 and 2007 data, and pursue funding for genetic analysis of the hair samples collected in 2008. While all of the 553 samples collected from the wildlife crossings in 2008 have been extracted and genotyped, many samples that were collected in the core of the study area have not, including 478 rub tree samples and 1,125 hair trap samples. The estimated cost to analyze these samples is $30,049.

Once we have the complete 2008 genetic dataset, we will work with Dr. Mike Gibeau, carnivore biologist for Parks Canada, to compare three noninvasive genetic sampling methods (hair traps, rub tree surveys and scat detection dogs) for monitoring grizzly bears in the mountain parks. This report could be extremely useful for planning proposed bear population surveys along Phase IIIB of the TCH and Highway 93-South in Kootenay National Park.

We will continue to examine the data that has been collected and analyzed. We will evaluate whether the TCH is a barrier to gene flow by calculating the magnitude of genetic differentiation (F_{st}) across the TCH and performing partial Mantel tests to determine the cause of differentiation, if found. We will use landscape genetics to compare the relative magnitude of genetic differentiation across the TCH with other potential barriers to movement. Our collaboration with Dr. Guillaume Chapron provides a unique opportunity to develop a genetic-based population viability analysis (PVA) model. We will parameterize Dr. Chapron's individual-based, spatially explicit model using our genetic data (population size, movement rates, etc.) and use the model to explore the relationship between wildlife crossings and gene flow. The combination of landscape genetic analysis and PVA will give us a better understanding of the link between highway mitigation measures, gene flow and population viability.

Cameras as a cost-effective technology

Through careful analysis and comparison of different detection methods, we have determined that remote cameras are the most cost-effective means of conducting crossing structure monitoring. This method has implications for future monitoring of wildlife crossings in Banff and for other resource managers planning monitoring programs elsewhere. Our analysis comparing monitoring techniques was only possible given the long-term nature of our project, the tools and infrastructure the project has developed over the years to equip so many crossings with remote cameras, and the personnel to design the analysis. We believe these results will significantly change the way wildlife crossings are monitored in the future, in Banff and by others elsewhere.

Road-related mortality of wildlife in the mountain parks

Road-related mortality of wildlife has been a problem in both Field Units and a cause for concern for many years. The long-term trend and prospects are for increasing traffic volumes on the TCH and other roads in the parks. Development of practical highway mitigation will rely on an understanding of patterns and processes that result from highway accidents involving elk and other wildlife. We summarized the occurrence of road mortalities from the TCH and other highways in both Field Units from 1996 to 2008.

- Road mortality rates were 50–100 percent lower for large carnivores along the mitigated section of the TCH than on other stretches of the highway.
- Medium-sized carnivores, primarily coyotes, have much higher mortality rates within the fenced mitigated section of the TCH compared to farther west on the unmitigated portion. At least two factors can explain this phenomenon: 1) fencing was generally not designed to prevent animals coyote-sized and smaller from accessing the right of way; and 2) there are more coyotes in the eastern, mitigated portion of the Bow Valley.
- Ungulate mortality was two to four times lower on the mitigated section of the TCH. This was driven primarily by lower rates of mule deer, elk and moose mortalities. White-tailed deer mortalities were still slightly higher along Phases I, II and IIIA (mitigated) than on Phase IIIB. Moose mortality rates were substantially higher along the unmitigated sections of Phase IIIB and in Yoho National Park than they were farther east. Again,

these patterns could be explained by species distributions along the Bow Valley, with more moose and mule deer farther west of Banff and more elk and white-tailed deer in the eastern part of the study area.

- Large-carnivore mortalities along the mitigated section of the TCH were much lower than along the unmitigated sections. There were some sporadic black bear mortalities in the late 1990s and in 2003 along the fenced section. However, there has been a recent and fairly dramatic upward trend in black bear road mortalities along the unmitigated Phase IIIB. Cougars and grizzly bears were rarely detected as road-kill along any of the sections. Wolf mortalities remain low, and their mortality rates are relatively stable.
- Mortalities among medium-sized carnivores were dominated by coyotes along all three sections. Though the mortality rate was highest along the mitigated section, the trend has declined since 1996 from 23 kills/100km/year to 5 kills/100km/year. Conversely, both Phase IIIB and the TCH in Yoho showed an increasing trend recently in coyote mortalities.
- The overall trend in road mortality rates for elk indicates that mitigation is quickly moving them towards zero along the mitigated section of highway. Further analysis will incorporate traffic volumes and more spatially precise relationships between population estimates and mortality locations.

Dispersal requirements of high-elevation localized species

Increased recreation, a growing transportation infrastructure and even logging outside the mountain parks all have the potential to limit dispersal and thereby fragment and isolate wildlife populations. Mountain goats, bighorn sheep, hoary marmots and pikas are a few examples of high-elevation, localized species (HELS) living in alpine habitat that form metapopulations, or a network of populations linked by dispersal. Currently, the locations of landscape corridors linking HELS habitat in the Canadian Rockies are not well known or understood, nor have the historic and anthropogenic landscape factors that may limit dispersal between patches been clearly identified. Park management should strive to obtain baseline population genetic information and determine how landscape features influence gene flow and exchange of individuals among populations.

We extracted records of species occurrence from the Parks Canada Observation Master Database between 1978 and 2008 for the Banff and KYLL Field Units. Bighorn sheep, mountain goat and hoary marmot populations appear to be the most promising target species for obtaining baseline population genetic information to evaluate how landscape features influence gene flow and exchange of individuals among populations.

Rationale for further monitoring

Unique information on population trends. Currently, only two species of large mammal are reliably censused each year in Banff. Elk are systematically counted on a regular basis and wolf populations are compiled from a variety of formal and informal sources. Aside from the crossing structure data, there is no other database of large mammal population trends in Banff. Other park databases have their limitations (geographic, seasonal, taxonomic) and are not suitable for documenting annual or seasonal changes in relative distribution and abundance of wildlife. The consistent, year-round monitoring data remains the most comprehensive and reliable long-term data in the Banff Field Unit for monitoring changes in species distribution and abundance over time.

Valuable information for public safety and managing human–wildlife conflicts. With most human and wildlife activity located in the valley bottoms, having current, reliable and localized data on the movements of carnivores helps wildlife managers improve visitor and wildlife safety. Updates emailed from the BWCP are used by the Banff Field Unit's human–wildlife conflict specialist to obtain real-time data on the movements, location and direction of travel of species or individual animals of management concern.

Are high-elevation, localized species adapting to highway mitigation? Recent developments in our monitoring methods have improved our species identification and detection probabilities. For species that use the valley bottoms less frequently, it can be easy to miss their important but rare, sporadically occurring movements. Unlike the use of track pads, camera-based monitoring of the crossing structures will provide more reliable information documenting the movements and direction of travel of species with localized distributions needing to disperse across the TCH and Bow Valley.

Maintaining methodological rigor for future analyses. It is not always possible to envision how large-scale, long-term databases can be used. Providing a similar approach to monitoring over the coming years will put Parks Canada and the BWCP in a better position to build upon the data gathered the last 12 years. These data are unique worldwide, as no other highway mitigation project has been so closely monitored for such a long period as the TCH in Banff.

Leveraging funding with partners. The BWCP has been a successful partnership, merging common interests of private foundations, an academic research institute and a governmental agency. Partnership funding consisted of a 2-to-1 match for every dollar of Parks Canada funding. Although this funding scheme is not sustainable for WTI and partnering foundations, the ability to leverage Parks Canada funds with partnering organizations provides significant cost-benefits to carry out research addressing the national park mandate.

Out of Banff: Data needs for highway mitigation planning in KYLL

Until now a large part of our research has been situated in the Banff Field Unit as the mitigated sections of the TCH lie entirely within that management district. Apart from the TCH, other highways in both Field Units also have significant impacts on wildlife populations. Highway 93-South is of particular concern to management because mitigation from a highway twinning project is unlikely within the next 20 years. The TCH in Yoho National Park has lower traffic volumes than the sections in Banff, but has had consistently high mortality rates for wildlife in the last decade. Because of the imminent conflicts between transportation and wildlife conservation, Highway 93-South and the TCH in Yoho National Park are emerging to the forefront of environmental stakeholder and KYLL resource management concerns.

Highway 93-South. Based on recommendations from Huijser et al. (2008), short-term, site-specific mitigation is planned as part of a Parks Canada-funded "Action on the Ground" project. Pre-mitigation baseline information will need to be collected for three monitoring objectives: demographics, movement and mortality.

Kootenay grizzly bear monitoring. During summer 2008, two grizzly bears were killed in two traffic accidents on Highway 93-South. Prior to 2008, only one instance of a grizzly bear killed on this highway had been reported. Increasing traffic volumes, combined with the Kootenay and Vermilion Valleys transforming into excellent bear habitat due to the 2001 and 2003 fires, will only exacerbate conflicts between bears (and other wildlife) and transportation. Little is known about the local grizzly bear population in terms of numbers, distribution and movement between adjacent watersheds, such as the Bow Valley. We recommend research on baseline information on grizzly bear distribution and minimum population size as soon as possible. Our knowledge of the efficacy of different genetic sampling techniques in Banff can be applied to the Kootenay situation.

TCH in Yoho National Park. The next phase of TCH twinning will occur in Yoho National Park. Data have been collected here the last 10–15 years on wildlife road-kill, winter road crossing locations, and to some extent animal movements. For planning the highway's reconstruction it will be important to continue data collection with the same intensity and effort as in the past. This work should be part of the TCH Phase IIIB wildlife monitoring plan currently being prepared. These data will form a solid starting point for initiating work toward recommendations for future mitigation measures, their design and construction.

Future research in Banff and KYLL Field Units. As part of the current twinning of the TCH Phase IIIB a wildlife monitoring and research plan is being prepared. The proposed monitoring plan will guide evaluations of the newly constructed mitigation measures between 2009 and 2014. Monitoring is planned to include: (1) Changes in wildlife–vehicle collisions; (2) Restoring population-level movements across the TCH wolverine, lynx and grizzly bear populations in particular); (3) Identifying key wildlife crossing and culvert design criteria; (4) Changes in distribution and area used by wildlife adjacent to Phase IIIB corridor and larger landscape; (5) Changes in fence intrusions into TCH right-of-way by fencing and Texas gates; (6) Restoration of harlequin duck movements across the TCH; and (7) Assessing effects of TCH on population genetics of high-elevation localized species (bighorn sheep, mountain goats, hoary marmots). Many research activities are suitable for graduate research projects.

1. INTRODUCTION

Canada's Rocky Mountain front harbors the richest diversity of large mammals remaining in North America. This landscape is among the continent's last remaining undisturbed natural areas, and provides an important trans-boundary landscape linkage with the United States (Weaver et al. 1996; Chester 2006). Today the entire Rocky Mountain cordillera on both sides of the border is experiencing rapid change. More people are moving to the area, the energy sector continues to grow and expand, recreational use is on the rise, and highway and rail traffic are on the upswing. Burgeoning suburban development is causing increasing use and expansion of transportation infrastructure throughout the Rocky Mountain cordillera (Hansen et al. 2002). New destination resort developments and their amenities are being built or expanded in most regions. As a result, landscapes that were once relatively intact are becoming increasingly fragmented. Roads are of particular concern in the Yellowstone-to-Yukon bioregion as they have been identified as one of the most severe human-caused impacts in the ecoregion (Carroll et al. 2001).

The goal of many national parks and protected areas is to preserve the biological integrity of unique landscapes from the human-induced change. Yet wildlife populations within national parks are not necessarily more protected than those residing outside their boundaries (Newmark 1995; Parks and Harcourt 2002; Ament et al. 2008). Some parks and protected areas can have wildlife road mortality rates in the tens of thousands (Kline and Swann 1998) with significant impacts on certain populations such as moose (Bangs et al. 1989), snakes (Bernardino and Dalrymple 1992; Rosen and Lowe 1994) and other large mammals (Gunther et al. 1998). Canadian parks are known to lose hundreds to thousands of animals each year from road-related mortality (Damas and Smith 1982).

Impacts of roads on the environment are attracting the attention of the scientific and conservation community worldwide (Forman et al. 2003, Davenport and Davenport 2006, Beckmann et al. in preparation). In recent years there have been a growing number of international conferences, symposia, and special issues of scientific journals devoted to road ecology (Evink et al. 1996; Hourdequin 2000, Luce and Wemple 2001). The anticipated growth in population and projected highway expansion plans in the Rocky Mountain cordillera, coupled with the resounding concern for maintaining large-scale, landscape connectivity, will continue to generate interest in conservation tools and applications for addressing the diverse issues linking transport, ecology and local communities (Hansen et al. 2002).

A concern among many land mangers is the effect roads have on fragmenting wildlife populations. A recent study of bobcat (*Lynx rufus*) and coyote (*Canis latrans*) populations bisected by a busy southern California freeway was able to show that although individuals successfully crossed the freeway, they did not always contribute to gene flow through reproduction (Riley et al. 2006). The home ranges of these two territorial species abutted but did not cross the highway, resulting in significant genetic differentiation between populations on either side (Strasburg 2006). Further, a recent review paper published in the journal *Conservation Biology* found that currently there is no evidence demonstrating that highway wildlife overpasses are effective at preventing genetic isolation (Corlatti et al. 2009).

Banff National Park (hereafter referred to as Banff) possesses the first large-scale complex of highway mitigation for wildlife of its kind in the world. Nowhere in the world are there as many and diverse types of wildlife crossing structures and associated biological data on wildlife distribution, movement and ecology. Over the past 25 years, the wildlife crossings in Banff have been a model of worldwide importance (Evink 2002; Hilty et al. 2006). The significance of the Trans-Canada Highway (TCH) wildlife crossing structures has led to Banff assuming international leadership in highway mitigation performance and evaluation, design criteria, and connectivity studies for wide-ranging animals at a landscape scale (Evink 2002). In short, it is the perfect natural laboratory for understanding the conservation value of highway overpasses and underpasses for a variety of wildlife species.

Conservation challenges and management needs

The effects of roads on wildlife generally, and of the TCH in Banff specifically, are to reduce wildlife population viability through increasing mortality and disrupting rates of gene flow across the highway. Attempts to minimize these effects must therefore focus on reducing wildlife–vehicle collisions, while ensuring wildlife can access food, shelter and mates across the landscape and throughout the year to enable populations to persist. Achieving ecological integrity under these circumstances requires cooperative efforts from a suite of disciplines including civil engineering, environmental design, transportation planning and biological sciences (Forman 1998).

In 1978, the federal government proposed to expand the width of the TCH in Banff from two to four lanes, a process known as “twinning” the highway (McGuire and Morrall 2000). Measures designed to mitigate impacts of the expanding highway were built in each successive twinning project. Twinning projects have proceeded in a series of phases, beginning with Phase I in 1979 and continuing through the current day with Phase IIIB. Today the TCH through Banff and Yoho National Parks supports the highest volume of through traffic of any North American national park and it is recognized as an important stressor to the ecological integrity of the park ecosystem (Banff Bow Valley Study 1996). Parks Canada’s mandate is to maintain or enhance ecological integrity. Therefore resource managers need to determine whether mitigations are reducing risks of road-related mortality of wildlife, improving the permeability of the highway for all organisms, and providing for the long-term sustainability of populations in the area.

Generally, there has been a lack of indicators or criteria developed pre-construction to adequately assess how well wildlife crossing structures ultimately perform in meeting land management and transportation objectives. Management within Banff has evaluated mitigation performance through long-term monitoring (Clevenger et al. 2002). Results of monitoring and research of Phase I, II and IIIA mitigation measures were used to guide the planning and design of mitigation on Phase IIIB. This adaptive management approach was sought by Parks Canada to streamline planning by obtaining recommendations based on credible science.

From 1996 to 2002 funding for the long-term research of the TCH mitigation was provided entirely by Parks Canada’s Highway Service Centre. In 1996, Tony Clevenger was hired by Parks Canada to assess the performance of Banff’s highway mitigation measures. In 2002, a rigorous, five-year study was completed and a report prepared for Parks Canada (Clevenger et al. 2002). Once this initial phase of monitoring was complete, Parks Canada scaled back funding to maintain only basic monitoring of the crossing structures, with little in the way of support for a continued research program or personnel.

In 2002 the principal investigator became affiliated with the Western Transportation Institute (WTI) at Montana State University, while maintaining the monitoring program in Banff and searching for broader support to reinitiate long-term research. In 2004, funding from the

Woodcock and Wilburforce Foundations provided a base from which to begin pilot research devising a non-invasive method of sampling DNA from bears using the Banff crossing structures (see Section 4, *Genetic connectivity…*). In 2005, the Woodcock, Wilburforce and Kendall Foundations, and WTI, approached Parks Canada's senior managers in the mountain parks with a proposal for continued monitoring and research. A four-year partnership agreement was formalized among the parties to support the Banff Wildlife Crossings Project (BWCP).

An international public–private partnership, 2005–2009

The BWCP research, education and outreach efforts are a combined endeavor of a public–private partnership that includes a federal agency, a university institute and private foundations.

Parks Canada, in particular the Banff and Kootenay–Yoho–Lake Louise (KYLL) Field Units and Highway Service Centre, manages the construction and maintenance of the wildlife crossings and assures they conform with the national park's commitment to protect, as a first priority, its natural heritage so that it remains healthy and whole.

WTI leads the scientific research, education and outreach activities. Tony Clevenger is WTI's principal investigator and has focused his research on wildlife and the TCH since 1996. He has published his results in leading international scientific journals and used his findings to educate transportation professionals and wildlife ecologists, as well as guide other highway projects across the Canadian Rockies and throughout North America.

Project goal and objectives

The BWCP's monitoring and wildlife research, coupled with outreach and education, aims to properly inform the transportation community and wildlife managers of the environmental and societal benefits of Banff's highway infrastructure investments. In addition, the Project seeks to share its findings on wildlife crossing design elements, requirements and their effectiveness. The BWCP goal is to increase transportation and wildlife agency understanding and community awareness so that other busy roads in the mountain parks and other locales in the Canadian Rocky Mountains and the United States benefit from the findings of the BWCP. This will allow other communities to develop sustainable transportation practices that provide ecological connectivity for wildlife across their transportation corridors as well as maintain motorist safety.

The objectives of the BWCP were divided into four areas:

1. Partnership: Maintain and continue the international public–private partnership in conservation science and management of transportation systems in natural and working landscapes. Garner support and interest in the BWCP from Canadian foundations.
2. Science: (a) Conduct research measuring gene flow of grizzly and black bears using wildlife crossings of the TCH and work modeling population viability; (b) Continue monitoring and research of wildlife-crossings use by a variety of wildlife species, including newly constructed Phase IIIB crossings; (c) Based on results, develop science-based guidelines for designing effective wildlife mitigation for transportation projects.
3. Technology transfer and education: Present the research findings in major international journals, books and conferences on transportation and ecology. Provide greater professional understanding and knowledge of measures to reduce highway impacts on wildlife and fisheries through training courses. Support university graduate students active in the project and use information for university classes, courses and symposia.

4. Community awareness: Provide greater understanding and general public awareness of the BWCP and research findings to allow leveraging for similar mitigations for highways across the Yellowstone to Yukon bioregion and North America via field trips, workshops, media coverage, and educational venues (i.e., schools, universities, museums). A particular focus was put on Alberta and the Crowsnest Pass/Highway 3 area working in concert with other educational and non-profit organizations.

Report objectives, content and format

This report describes the BWCP research, education and outreach activities conducted between 2005 and 2009. Parts of this report have been submitted as annual and interim reports to the BWCP partnering agencies and organizations. Because of the long-term nature of our research project we have provided information within two temporal contexts: (1) the partnership period from 2005 to 2009, and (2) the entire project period spanning more than 12 years from 1996 to 2009. Prior to preparing the report we requested input from Parks Canada's resource managers, specifically regarding the report outline, content or analyses that could help their decision making. We have incorporated those concerns and content requests in this report. We include a comprehensive list of activities conducted under the umbrella of technology transfer, education and outreach. Last, in preparing this report we have followed the statement of work and addressed all the objectives of the terms of reference in the Collaboration Agreement between Parks Canada, WTI, and the Woodcock, Wilburforce and Kendall Foundations, and the research contract awarded to the principal investigator (contract KKP 2675).

2. STUDY AREA

The research for this project is situated approximately 120 km west of Calgary, Alberta, in the Bow River Valley along the Trans-Canada Highway in Banff (Figure 2.1). The TCH is the major transportation corridor through Banff and Yoho National Parks, covering 76 km between Banff's eastern park boundary and the park's western boundary at the Alberta–British Columbia border. Traffic volume along the TCH is relatively high for the region, with an average of 17,970 vehicles per day in 2008 and increasing at a rate of 2.5 percent per year (Highway Service Centre, Parks Canada, Banff, Alberta). An ecological description of the study area can be found in Holroyd and Van Tighem (1983) and Holland and Coen (1983).

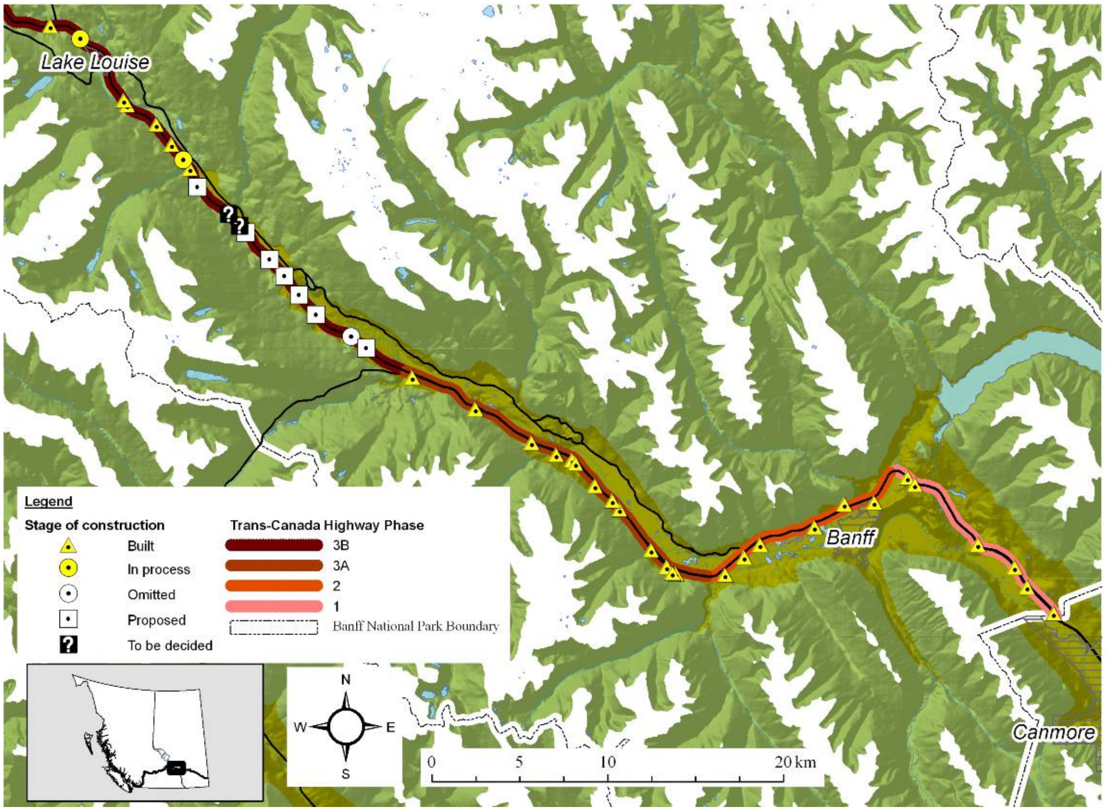

Figure 2.1: Trans-Canada Highway study area, the mitigation phases and their stage of construction.

In the 1970s, safety issues compelled planners to upgrade the TCH within BNP from two to four lanes, beginning from the eastern boundary and working west. Large animals were excluded from the road with a 2.4-m-high fence erected on both sides of the highway, while underpasses were built to allow wildlife to cross the road. The first 27 km of highway twinning (Phases I and II) included 10 wildlife underpasses and was completed in 1988 (Figure 2.2). The next 18 km section (Phase IIIA) was completed in late 1997 with 11 additional wildlife underpasses and two wildlife overpasses (Figure 2.3). The final 30 km of four-lane highway to the western park boundary (Phase IIIB) has been divided into phased twinning projects. A first, 10-km section referred to as Phase IIIB-1 includes eight wildlife crossing structures including two are 60-m-wide wildlife overpasses will be completed in 2009 (Figure 2.4). A second project recently funded by the federal government will twin the remaining sections of Phase IIIB between Castle Junction and the Kicking Horse Pass. Construction on this Phase IIIB-2 section will begin in 2009 and completion is scheduled for 2012 (Figure 2.5).

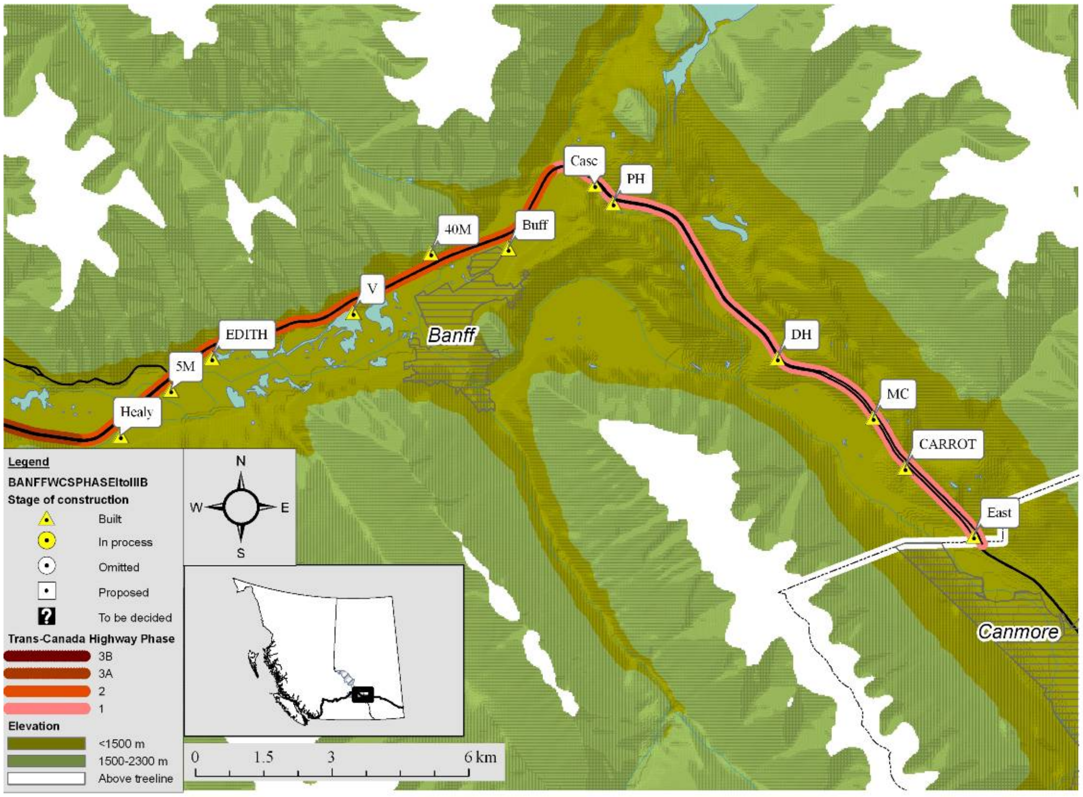

Figure 2.2: Phase I and II wildlife crossing structures on the Trans-Canada Highway.

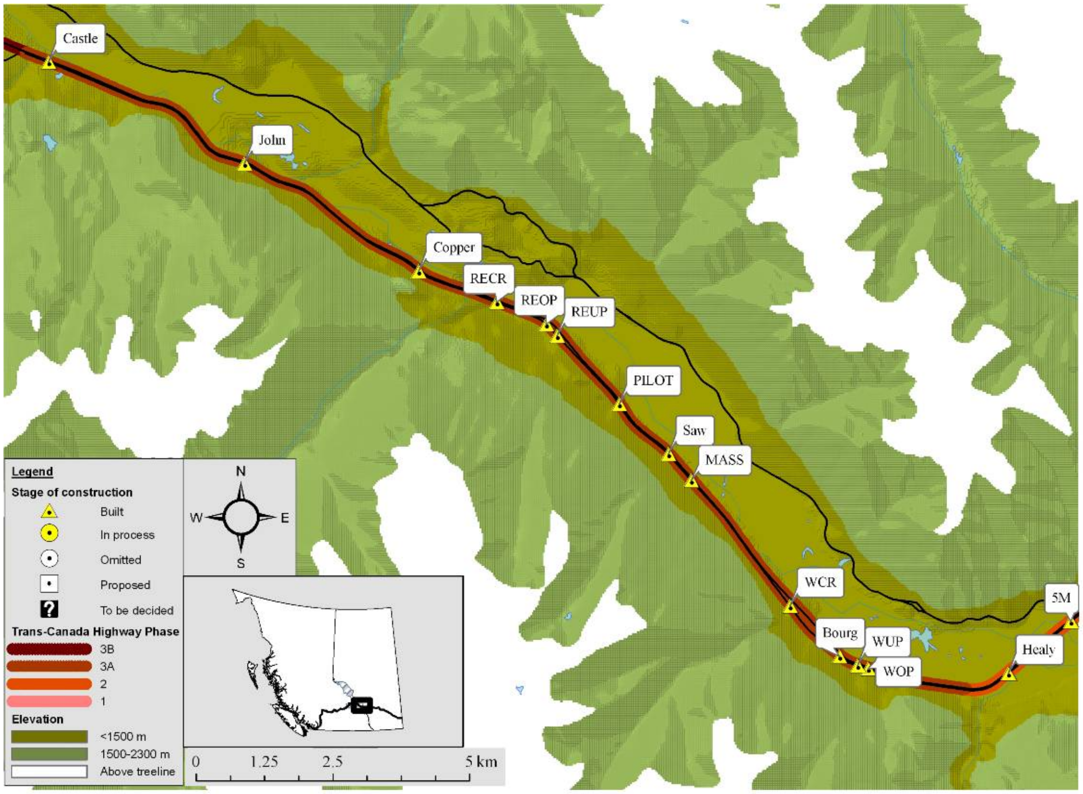

Figure 2.3: Phase IIIA wildlife crossing structures on the Trans-Canada Highway.

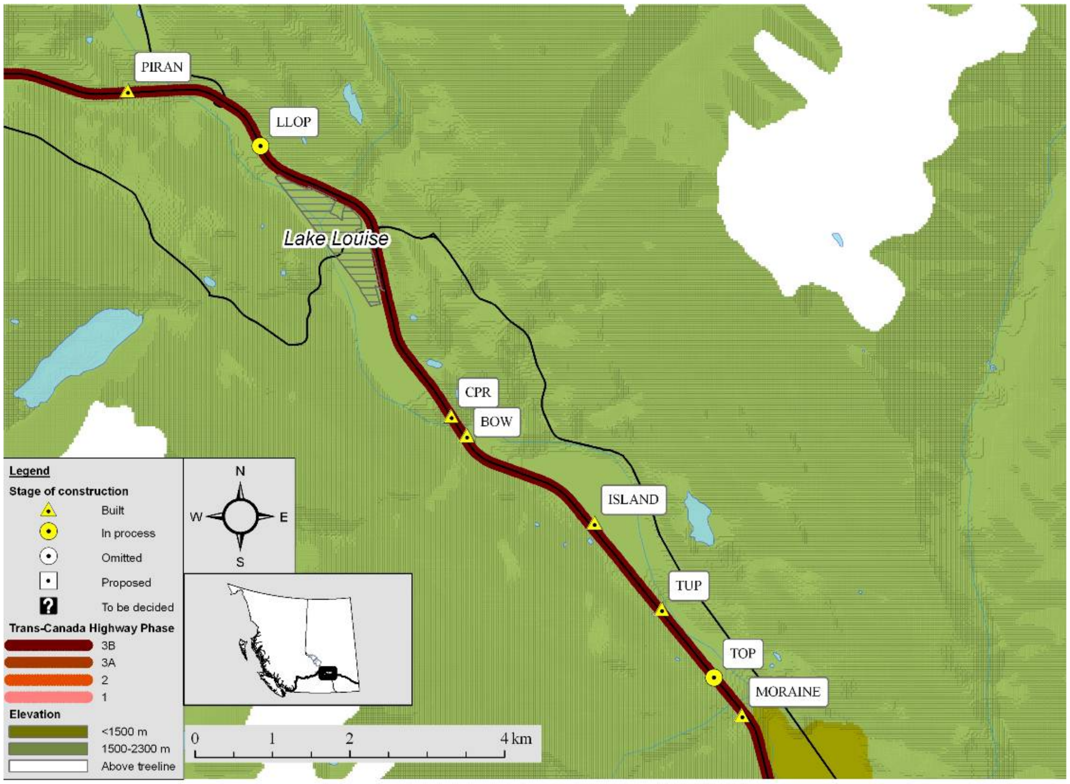

Figure 2.4: Phase IIIB-1 wildlife crossing structures on the Trans-Canada Highway (completion 2009).

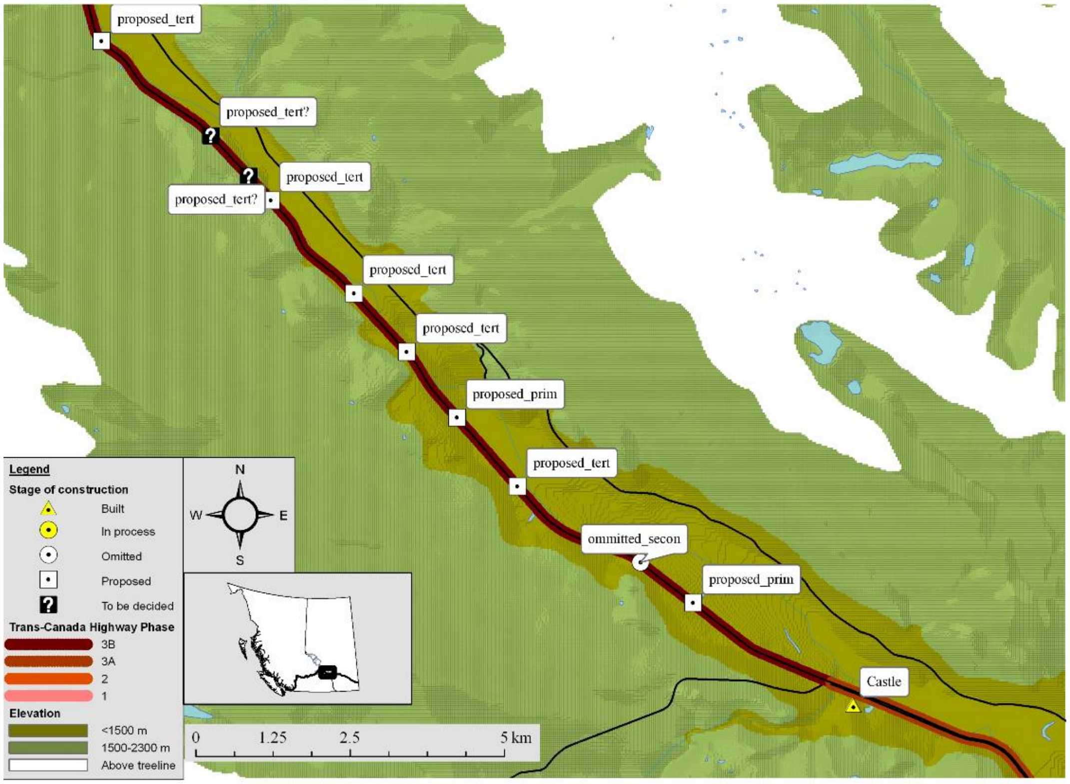

Figure 2.5: Planned Phase IIIB-2 wildlife crossing structures on the Trans-Canada Highway (completion 2012).

3. LONG-TERM MONITORING OF WILDLIFE CROSSING STRUCTURES

3.1. Introduction

Long-term data collection from the monitoring of Banff wildlife crossing structures has been the basis from which we have gained a better understanding of how species adapt, use and benefit from these mitigation measures. As mundane and routine as this data collection may seem, it is the basis for assessing whether population and genetic connectivity are restored, understanding how to adaptively manage future mitigation designs, and transfer knowledge to transportation planners and land managers elsewhere.

Given the high utility and multi-purpose nature of the long-term monitoring data, this section constitutes the largest part of the report. The section begins with a description of the methodology used to collect data on animal movement at the crossing structures and how the tools and techniques have evolved in the last 12 years. Summaries are provided for the partnership period (2005–2009) and the entire length of the project (>12 years, 1996–2009). Patterns of wildlife crossing structure use by large mammals are logically dynamic and can be influenced by numerous intrinsic or extrinsic factors. Thus we describe some interesting findings with regard to wildlife behaviour and adaptation to crossing structures during the last 12 years. Last, looking forward to continued monitoring at the existing structures and those currently in construction, we describe the benefits of a long-term approach and provide recommendations for future monitoring of TCH mitigation in Banff.

3.2. Methods: Field data collection

All wildlife crossing structures in Phases I, II and IIIA have been continuously monitored for large mammal use since 1996 using track pads (Clevenger and Waltho 2000, 2005; Clevenger et al. 2002). Monitoring consisted of checking the crossing structures and recording animal movement across raked track pads. Track pads spanned the width of the wildlife underpasses and were set perpendicular to the direction of animal movement. Most track pads had a ≈2-m-wide tracking surface, however, at the wildlife overpasses only a single, 4-m-wide track pad was set across the centre. Tracking material consisted of a dry, loamy mixture of sand, silt and clay, 1–4 cm deep (Bider 1968). Each crossing structure was visited every two to four days throughout the year. The quality of tracking medium to detect tracks at each visit was classified as good, fair, poor or "inoperable," the latter generally caused by accumulation of flooding, ice or snow drifts on the track pads.

We identified tracks to species, estimated the number of individuals, their direction of travel and whether they moved through the crossing structure. Species consisted of wolves (*Canis lupus)*, coyotes (*C. latrans)*, cougars (*Puma concolor)*, lynx (*Lynx canadensis)*, black bears (*Ursus americanus)*, grizzly bears (*U. arctos)*, wolverine (*Gulo gulo)*, deer (*Odocoileus* sp*.)*, elk (*Cervus elaphus)*, bighorn sheep (*Ovis canadensis)*, and moose (*Alces alces)*.

In estimating the number of individuals, we used the "too many" designation beginning in July 2006 because we noticed that large groups of ungulates can obliterate the track pad, thus increasing the likelihood of errors in identifying species, counting individuals and determining direction of travel. Thus, crossing events occurring prior to these trampling events would also likely go undetected by the track pad method.

We also recorded the amount of human activity (travel on horses, bikes or by foot) at each crossing structure check. After collecting species movement data from the track pads they were raked smooth for the next visit. Over three years, 2006–2008, during the months of May to October, two strands of barbed-wire were strung across one of the track pads at most crossing structures to obtain hair/DNA from bears using the crossing structures (see Section 4, *Genetic connectivity…*).

Since 2005, motion-sensitive cameras have been increasingly used to supplement track pads to monitor species use of the crossing structures. These cameras (Reconyx Inc., Holmen, Wisconsin) also provide information on time, animal behaviour, and ambient temperature during each crossing event. We found through monitoring animal movement at the crossing structures with both track pads and cameras that cameras were a more reliable, cost effective and less invasive means of monitoring crossing structure use than tracking alone (Ford et al. in press). The results of this work are described in Appendix A.

For this report we summarized movement of wildlife at the Banff crossing structures by TCH construction phase during two periods: (1) the period of the BWCP partnership from 2005 to 2009, and (2) the entire 12-year period that monitoring has been conducted at the wildlife crossings since 1996.

3.3. Summary data, 2005–2009

3.3.1. Phases I and II

Since the beginning of the partnership in April 2005, we recorded a total of 55,553 passages by mammals coyote-size and larger (see section 3.2) and humans using the 10 Phase I and II wildlife underpasses (Table 3.1). Excluding human use, large mammals were recorded at the underpasses a total of 49,743 times. Deer were the most frequently detected species at the wildlife underpasses, accounting for 70 percent of all wildlife use (n=35,146 detected crossings), followed by elk (n=9775 crossings) and bighorn sheep (n=1715 crossings). Among large carnivores, coyotes used the underpasses more than 1600 times, followed by wolves (n=543 detected crossings), grizzly bears (n=429 crossings) and black bears (n=284 crossings). Human use was relatively high compared to wildlife use, ranking third overall with nearly 6000 passes recorded.

Table 3.1: Summary data from monitoring wildlife crossing structures[1] using track pads, fiscal years 2005–06 to 2008–09.

Phase	Crossing structure name	Total use	bear spp	black bear	cougar	coyote	grizzly bear	lynx	wolf	wolv-erine	deer	elk	moose	bighorn sheep	human use
I&II	EAST	9802	1	13	70	137	4	0	1	0	8872	680	2	11	11
I&II	CARROT	1140	0	13	41	88	0	0	0	0	819	142	0	7	30
I&II	MC	5266	0	25	28	107	2	0	3	0	4660	407	0	17	17
I&II	DH	7436	2	94	104	87	2	0	14	0	5549	1521	0	46	17
I&II	PH	3273	1	60	56	172	8	0	4	0	1737	879	0	22	334
I&II	BUFF	7556	0	03	26	207	1	0	3	0	2452	3014	0	46	1804
I&II	V	3632	2	28	46	247	28	0	23	0	1870	859	2	102	425
I&II	EDITH	5265	0	12	30	129	9	0	53	0	2425	606	1	17	1983
I&II	5M	8697	0	20	5	310	18	0	72	0	4560	1102	6	1442	1162
I&II	HEALY	3486	0	16	23	149	113	0	370	0	2202	565	16	5	27
TOTAL PHASE I&II		55,553	6	284	429	1633	185	0	543	0	35,146	9775	27	1715	5810
IIIA	WOP	8777	2	12	14	39	95	0	191	0	8334	53	29	1	7
IIIA	WUP	648	0	4	15	27	1	0	39	0	554	2	1	0	5
IIIA	BOURG	127	1	22	4	18	2	0	4	0	72	0	0	0	4
IIIA	WCR	673	0	7	15	56	6	0	17	1	530	20	0	2	19
IIIA	MASS	1384	0	1	5	38	1	0	40	0	1275	13	0	0	11
IIIA	SAW	229	0	2	1	24	5	0	28	0	165	3	0	0	1
IIIA	PILOT	428	0	8	1	18	6	0	41	0	338	8	2	0	6
IIIA	REUP	318	0	7	5	53	7	0	75	0	132	22	0	0	17
IIIA	REOP	8389	10	9	1	49	145	0	271	0	7748	116	24	0	16
IIIA	RECR	1586	0	4	12	52	3	0	93	2	1298	28	0	17	77
IIIA	COPPER	2553	0	6	5	116	3	0	62	1	2298	52	1	8	1
IIIA	JOHN	433	0	2	5	86	4	0	50	0	267	16	0	0	3
IIIA	CASTLE	2658	0	0	7	102	6	1	95	0	2244	159	6	2	36
TOTAL PHASE IIIA		28,203	13	84	90	678	284	1	1006	4	25,255	492	63	30	203
GRAND TOTAL 2005–2009		83,756	19	368	519	2311	469	1	1549	4	16968	10,267	90	1745	6013

[1] Names and abbreviations of wildlife crossing structures appear in Appendix B.

Since April 2005, the total number of detections of humans using the wildlife underpasses declined by about 5–10 percent per year. However, human use still represents approximately 10 percent of all crossing events detected at the Phase I and II underpasses. Human use was concentrated at Edith, Buffalo, and Five Mile Bridge. Notably, these three underpasses were not part of the non-invasive sampling of bear DNA (see Section 4, *Genetic connectivity…*) during the past three years because of high levels of human use. The actual amount of human use at underpasses is likely greater than what we report because people tend to avoid using the track pads while passing through the structures.

3.3.2. Phase IIIA

Large mammals (including lynx, coyotes and wolverines and excluding humans), were recorded at the Phase IIIA crossing structures a total of 28,000 times since April 2005 (Table 3.1). Deer were the most commonly detected species along Phase IIIA accounting for 90 percent of all wildlife crossing events. Elk and bighorn sheep use was dramatically low compared to the amount of deer use on Phase IIIA (492 and 30 detected crossings, respectively). Wolves were the most frequently detected carnivore (1006 crossings), more than coyotes (678 crossings), grizzly bears (284 crossings) or cougars (90 crossings). Most of the movements by wolves and grizzly bears occurred at the wildlife overpasses. Sixty percent of all wildlife crossings occurred at the two overpasses while the remaining 40 percent were distributed along the other 11 crossing structures. Compared to wildlife use, human use was extremely low, with only 203 detections since 2005.

3.3.3. Summary

Moose, wolverine, wolves and grizzly bears are the only species that have been detected more times at crossing structures along Phase IIIA than on Phases I and II. Coyotes, black bears, elk, deer and bighorn sheep are all more common along Phases I and II. Wolves and coyotes were detected more frequently than elk and bighorn sheep, suggesting that the Phase IIIA carnivore population is likely being supported by deer species. Conversely, elk, bighorn sheep and deer were more common than all predator species detected in Phases I and II. Overall, approximately 66 percent of all wildlife crossing occurred along Phases I and II.

Overall, wildlife are exhibiting species-specific responses to wildlife crossing structures over the three-year study period:

- *Black bear*: Increasing use on Phases I and II, decreasing use along Phase IIIA.
- *Grizzly bear*: Increasing use on Phase IIIA, decreasing on Phases I and II.
- *Cougar*: Sharp increase in use on Phases I and II, stable along Phase IIIA
- *Coyote*: Decline from 2005 to 2006, stable since then along all Phases.
- *Wolf*: Increasing use along all phases, with most of the Phase I and II activity concentrated at Healy and Edith underpasses.
- *Deer*: Declining along Phases I and II since 2006–07, declining steadily on Phase IIIA.
- *Elk*: Stable along Phases I and II, declining on Phase IIIA.
- *Moose*: Stable with low numbers along all phases.
- *Sheep*: Declining use along Phase I and II, very low numbers on Phase IIIA.
- *Wolverine and Lynx*: Rarely detected.

3.3.4. Phase IIIB

Seven wildlife crossing structures are being constructed as part of the first project of the TCH Phase IIIB (see Section 2, *Study area*). The crossing structures are being completed at different times and two will not be finished until fall 2009. We began monitoring wildlife usage as the structures were completed. Note that efforts to establish a consistent monitoring schedule have been delayed by construction activities at or near the wildlife crossing structures. Since December 2007, five of the crossing structures have been monitored for wildlife use.

Despite these monitoring constraints we provide a brief summary of wildlife use at the newly built wildlife crossing structures. There have been a total of 168 detected crossings through November 2008, of which 119 (71 percent) were large mammals (Table 3.2). Early detections of wildlife use were dominated by common, generalist species that we would expect to find using the new structures, such as deer and coyotes. The following species were detected using the crossing structures at least once: wolf, lynx, grizzly bear, elk and black bear. Wolverine, cougars, or smaller felid species have yet to be documented using the Phase IIIB wildlife crossing structures.

Table 3.2: Data summary from monitoring wildlife crossing structures[1] along Phase IIIB using cameras between 18 June 2008 and 31 March 2009.[2]

CROSSING STRUCTURE	MORAINE	TUP	ISLAND	BOW	PIRAN	TOTAL
Black bear	0	0	0	0	2	2
Coyote	0	5	1	3	39	48
Wolf	3	0	2	0	1	6
Lynx	1[3]	0	0	0	0	1
Deer	0	10	23	0	14	47
Elk	0	2	9	0	2	13
Moose	0	0	3	0	0	3
Human	0	3	20	16	9	48
Site total	3	20	58	19	67	168

[1] Names and abbreviations of wildlife crossing structures appear in Appendix B.

[2] Data are based on camera counts when sites were available for monitoring. Construction at or near these sites during the summer months limited monitoring effort.

[3] Was not detected by cameras but tracks in the snow indicated through passage.

3.4. Summary data, 1996–2009

3.4.1. Phase I & II

The long-term monitoring project began in November 1996 and was focused initially on Phase I and II wildlife underpasses. Since then, there have been a total of 141,140 detections of 11 species of large mammals and humans at the underpasses (Table 3.3). Excluding human use large mammals were recorded a total of 125,475 times. Deer were detected in 70 percent of all records (n=77,464 detected crossings) followed by elk (n=32,843 crossings) and bighorn sheep (n=4553 crossings). Among large carnivores, coyotes used the crossings 4614 times, wolves 3661 times, cougars 1081 times, black bears 904 times, and grizzly bears 298 times. Human use was high, ranking third overall with more than 15,000 passes recorded since 1996.

3.4.2. Phase IIIA

Monitoring of the Phase IIIA wildlife crossing structures began in November 1997. Since then we have documented 61,034 passages by wildlife and humans at the 12 Phase IIIA crossing structures (Table 3.3). Excluding humans, there have been a total of 60,208 detected crossings by large mammals. Similar to Phases I and II, deer were most frequently detected using the crossing structures (n=50,089 crossings; 85 percent of all mammal crossings). Among carnivores, coyotes used the structures 2588 times, wolves 1452 times, grizzly bears 381 times, cougars 324 times and black bears 287 times. Human use on Phase IIIA was low compared to Phases I and II (n=826 crossings vs. 15,665 crossings, respectively).

3.4.3. All wildlife crossing structures

A total of 202,174 detections by mammals and humans have been recorded at the Phase I, II and IIIA crossing structures. Without counting humans there were 185,683 crossings by large mammals. Deer made up 62 percent of the crossings detected, while 18 percent were by elk (Table 3.3). The proportion of other wildlife species detections ranged from < 1 percent to 3 percent, while human use accounted for 8 percent of all crossings and occurred primarily on Phases I and II. Among large carnivores, most grizzly bear and wolf crossings were found at the two overpasses and the Healy underpass site, while black bear and cougar crossings were more dispersed among the crossing structures.

Table 3.3: Data summary from monitoring wildlife crossing structures[1] using track pads, November 7, 1996 to March 31, 2009.

Phase	Crossing structure name	Total use, excluding humans	bear spp	black bear	cougar	coyote	grizzly bear	lynx	wolf	wolv-erine	deer	elk	moose	bighorn sheep	human use
I&II	EAST	22,980	0	53	142	399	5	0	170	0	19,591	2604	2	14	35
I&II	CARROT	3183	0	58	94	222	2	0	158	0	1986	650	0	13	152
I&II	MC	11,511	0	149	94	231	4	0	234	0	9718	1059	0	22	58
I&II	DH	16,292	3	228	187	316	9	0	1132	0	10,142	4227	0	48	88
I&II	PH	8504	4	114	105	353	10	0	272	0	4695	2921	0	30	1773
I&II	BUFF	13,386	0	5	47	672	4	0	255	0	4351	7999	0	53	4491
I&II	V	10,986	2	39	130	787	48	0	228	0	4072	4732	2	946	1295
I&II	EDITH	11,644	0	33	135	376	18	0	235	0	8137	2495	3	211	5364
I&II	5M	15,326	1	29	50	656	25	1	219	0	7806	3343	10	3187	2333
I&II	HEALY	11,663	1	196	97	602	173	0	758	0	6966	2813	28	29	76
TOTAL PHASE I&II		125,475	11	904	1081	4614	298	1	3661	0	77,464	32,843	45	4553	15,665
IIIA	WOP	15,160	2	32	36	138	143	1	251	0	14,184	330	42	1	36
IIIA	WUP	1810	0	13	42	104	1	0	58	0	1409	182	1	0	18
IIIA	BOURG	362	1	41	22	136	2	0	7	0	141	12	0	0	9
IIIA	WCR	1737	1	15	62	252	8	0	46	1	1040	308	2	2	46
IIIA	MASS	3165	0	12	20	244	7	0	65	0	2502	315	0	0	26
IIIA	SAW	640	0	6	6	113	5	0	33	0	366	111	0	0	26
IIIA	PILOT	1117	0	41	15	156	11	0	65	0	662	164	3	0	25
IIIA	REUP	1133	0	31	24	236	9	0	114	0	483	236	0	0	43
IIIA	REOP	18,331	9	26	5	181	170	0	341	0	16,499	1058	42	0	49
IIIA	RECR	3243	0	9	34	146	5	0	119	2	2663	239	0	26	330
IIIA	COPPER	5974	0	14	23	303	3	0	85	1	5190	344	3	8	11
IIIA	JOHN	937	0	23	25	332	6	0	83	0	420	48	0	0	12
IIIA	CASTLE	6599	0	24	10	247	11	2	185	0	4530	1582	6	2	195
TOTAL PHASE IIIA		60,208	13	287	324	2588	381	3	1452	4	50,089	4929	99	39	826
GRAND TOTAL 1996–2009		185,683	24	1191	1405	7202	679	4	5113	4	127,553	37,772	144	4592	16,491

[1] Names and abbreviations of wildlife crossing structures appear in Appendix B.

3.4.4. Summary

The 12 years of monitoring the Banff wildlife crossing structures has provided evidence-based data that park management utilizes, not only to assess the performance and design requisites of the structures, but to track population trends and movements of key wildlife species in the Bow Valley. Our wildlife crossing database contains more than 68,000 records and has been a critical part of management-initiated ecosystem- and species-based research conducted in the Banff Field Unit by C. White, T. Hurd, J. Whittington, A. Kortello, E. Kloppers, and other resource managers and researchers.

The value of the long-term and time-series data is immeasurable and increases with time. Twelve years ago when our research began there were eight species-specific, multi-year research projects recently completed or ongoing in the Bow Valley involving grizzly bear, black bear, wolf, cougar, lynx, elk, moose, and coyote. Today, there is currently no ongoing research on species populations or ecology and only a few elk and black and grizzly bears radio-transmittered for management purposes. There is a proposed mule deer and white-tailed deer research project being planned in the Banff Field Unit. Using remote, infrared-operated cameras the cost of continuing monitoring and maintaining the wildlife crossing structure database is insignificant compared to benefits to decision makers regarding management of the Banff Bow Valley ecosystem in both Field Units (see Sections 3.8, 3.9 and 3.10.).

During the 12-year period there were several noteworthy changes in use of the Banff crossing structures by wildlife in the Bow Valley (Table 3.7). An analysis of the proportional change in wildlife crossing use by the 11 species of large mammals reveals substantial change in use over the past 10 years. For instance, elk used to account for nearly 45 percent of all crossing events but that has declined by two-thirds. Detections of deer at the wildlife crossing structures have increased dramatically from 45 percent to over 70 percent in a 10-year period, having peaked at over 80 percent. Use by black bears, wolves, coyotes, and cougars appear to fluctuate gradually over time. Grizzly bears have shown a steady increase in wildlife crossing structure use relative to other species, from less than 0.05 percent of all detected crossings to 20 times that amount at 1.1 percent of all crossings per year.

Table 3.4: Percentage of all crossing events, by species, detected per year.

Species	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
bear spp	0.00	0.00	0.00	0.00	0.00	0.01	0.05	0.01	0.02	0.04	0.01
black bear	1.07	0.93	1.23	0.63	0.47	0.36	0.44	0.44	0.51	0.41	0.54
cougar	0.78	2.18	1.77	0.32	0.31	0.45	0.39	0.15	0.43	0.58	1.16
coyote	4.24	3.76	3.54	3.17	4.98	4.08	6.93	3.86	2.51	2.60	3.10
deer	45.99	46.98	53.28	62.69	73.62	78.90	75.16	79.22	81.24	80.46	73.20
elk	43.65	41.11	30.15	22.25	13.74	12.57	13.03	11.38	11.62	12.34	15.02
grizzly bear	0.05	0.02	0.13	0.10	0.22	0.42	0.32	0.38	0.46	0.57	1.10
lynx	0.01	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.00	0.00	0.01
moose	0.00	0.00	0.06	0.02	0.02	0.13	0.12	0.11	0.13	0.13	0.11
sheep	3.47	4.12	3.38	3.13	1.98	1.22	2.99	3.36	1.66	0.85	2.54
wolf	0.73	0.92	6.44	7.69	4.66	1.84	0.56	1.08	1.42	2.03	3.20
wolverine	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01

Several species not seen in the first six years of monitoring were observed using the crossing structures for the first time in 2002, including red fox (*Vulpes vulpes*), striped skunk (*Mephitis mephitis)*, mink (*Mustela vison*) and hoary marmot (*Marmota caligata*). These detections have been aided by the use of remote infrared-operated cameras.

Since 2002, there have been some unique observations of species that rarely occur near the TCH and the crossing structures. For example, the presence of boreal toads (*Bufo boreas*) has been recorded on Wolverine Overpass, garter snakes (*Thamnophis elegans*) at Duthil wildlife underpass, and beavers (*Castor canadensis*) using the Redearth Creek underpass.

There also have been noteworthy species detected only a few times using the wildlife crossing structures. These are primarily moose, wolverine and lynx. Current information on the moose population suggests that there are few localized individuals in the middle and lower Bow Valley. Although the number of detections of moose at the crossing structures is relatively low, it is consistent and strongly associated with the two wildlife overpasses. Wolverine and lynx are likely more rare than moose in the middle and lower Bow Valley, however, they are more common on Phase IIIB west of Castle Junction and in the Lake Louise–Kicking Horse Pass area (Austin 1998, Golder Associates 2004).

Wolverines were detected four times using three different crossing structures, two of which are creek-bridge underpasses. All wolverine detections occurred on Phase IIIA.

Lynx were detected twice using two different crossing structures on Phase IIIA.

Moose used 12 different wildlife crossings structures a total of 136 times. Most of these crossings were made at the two wildlife overpasses. Moose occasionally used the Healy wildlife underpass and Five Mile Bridge.

It will be necessary to obtain information on species occurrence in the Phase IIIB section prior to or during construction in order to assess changes in species distribution after the mitigation is completed. These data will allow for evaluations of the performance of measures designed to mitigate habitat fragmentation effects of the TCH (Golder Associates 2004).

Species occurrence data also will be needed to determine the "expected use" of each of the Phase IIIB wildlife crossing structures (see Clevenger and Waltho 2000, 2005). These data on expected occurrence will allow for a rigorous analysis of factors at the Phase IIIB wildlife crossings that facilitate passage for large mammals.

Until now it has been difficult to determine a statistically significant correlation of annual trends in wildlife crossing use with relative population size and trends in the Bow Valley. Duke et al. (2001) found significant positive correlations between carnivore use of wildlife crossing structures and their detections on winter corridors transects, suggesting that crossing structure monitoring may be a surrogate index of relative population abundance. A more rigorous and thorough analysis of the use of crossings structures by species and their relative abundance has been constrained by the absence of annual estimates of species populations in the Bow Valley. Annual population estimates are currently obtained from classified counts, surveys and observations of elk and wolves, while annual population monitoring surveys for most other mammals (and terrestrial vertebrates) are not being conducted in either Field Unit.

3.5. Comparison of wildlife overpass and underpass use

Comparing animal movement at crossing structures placed within a few hundred meters of each other enables us to control for potential effects of habitat type and species distributions on wildlife crossing structure use. Both Redearth and Wolverine overpasses have an adjacent underpass structure within 300 m. We pooled wildlife overpass crossing events together from the two sites and compared them with pooled wildlife underpass (n=2) crossing events for large mammals species during the last 12 years (Table 3.5). For each year, we calculated the percentage of movements at each structure type using a crossing structure selection factor, S, based on the formula:

$$S_y = (\text{Overpass-Underpass})/(\text{Overpass} + \text{Underpass})$$

where Overpass and Underpass are the number of crossing events by each species for year y. As S increases animals are more likely to use overpasses than underpasses, and a value of 0 indicates equal movement distribution among crossing structure designs.

Table 3.5: Species use of paired overpasses and underpasses, 1997–2009.

Species	Overpass	Underpass
Grizzly Bear	317	10
Black Bear	58	44
Wolf	597	172
Cougar	41	66
Coyote	319	341
Moose	84	1
Deer	10,377	636
Elk	1388	418

We found that there are species-specific preferences for which structures are used (Figure 3.1). Grizzly bears, moose, deer and elk are almost always found using overpasses rather than underpasses. These species show the strongest and most consistent use among all species. Black bears show fairly inconsistent use of either structure, varying from $S \approx -1$ to $S \approx 1$ from year to year. Cougars and coyotes show a relatively equal distribution of movements at the two structure types, as $S \approx 0$ most years. However, in the early years of monitoring it was found that most cougars preferred the underpasses and in the last year coyotes showed a preference for overpasses. Wolves, for the most part, tended to use the overpasses on a far more consistent basis than underpasses. However, before 2001 and during 2003, there was a tendency for wolves to use the underpasses more than the overpasses. For wolves, the changes in S over time may reflect their adaptation to crossings structure designs, with preference for underpasses in the beginning and then becoming more selective towards overpasses after a few years (see Section 3.8….*Adaptation and learning*).

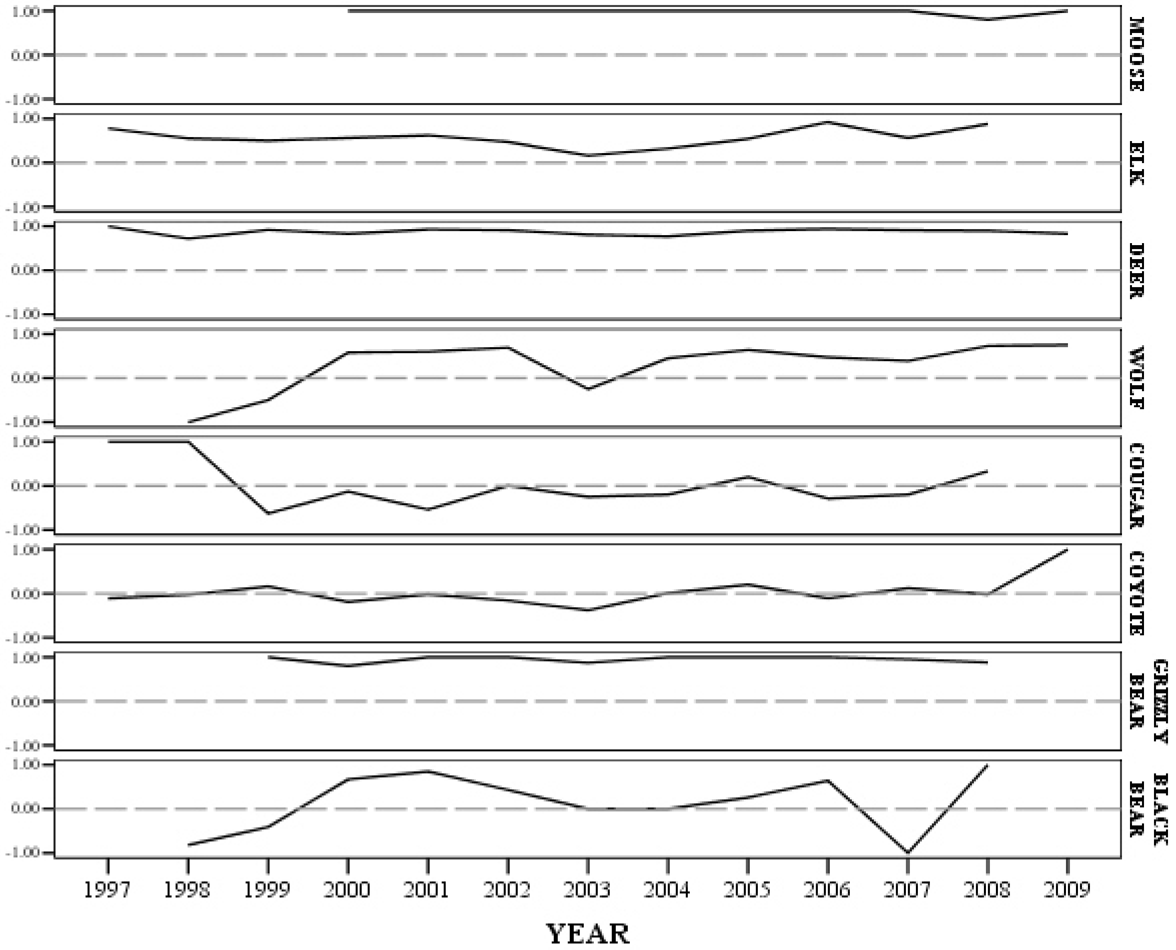

Figure 3.1: Use of paired wildlife overpass and nearest underpass by species, 1997–2009. Value of +1.0 represents exclusive overpass use, -1.0 represents exclusive underpass use and value of 0 (dashed line) represents equal movement at the two structure types.

3.6. Relationship between population size and passage rates at wildlife crossing structures

3.6.1. Introduction

Long-term monitoring of wildlife crossing structures along the TCH in Banff has generated an impressive collection of wildlife activity and distribution data since 1996. These data have been used to assess the relative importance of landscape and structural variables affecting animal passage rates (Clevenger and Waltho 2000, 2005). However, passage rates at wildlife crossing structures have yet to be directly associated with actual population sizes of wildlife in the surrounding landscape for at least two reasons. First, Banff National Park does not maintain a consistent population monitoring program for any species other than elk and wolves, so opportunities to explore the relationship between passage rate and populations are limited to these two species. Second, population estimates for these species are gathered on an annual or bi-annual basis, so statistical power is limited by the number of years of monitoring.

Developing a statistical model to describe the relationship between population size and passage rates at wildlife crossing structures has a number of important benefits to management. First, structural attributes of crossing structures that contribute to a greater-than-expected passage rate by wildlife enable planners to more rigorously design species-specific mitigation measures. Second, if a strong association between population size and passage rate at particular sites can be found, then management can use monitoring of these limited areas to infer population trends in the broader study area. Third, detection rates of animals using crossing structures are relatively high given the constricted nature of the passage, so monitoring crossing structure use may be a more economical means of population monitoring than other index-type measures (e.g., pellet counts, snow tracking). Furthermore, monitoring of wildlife use at crossing structure is relatively weather-independent and possible year-round compared to snow tracking or pellet counts. Thus, the various crossing structures along the TCH can serve as a multi-species "super-transect" if appropriate population size and passage rate associations can be demonstrated.

Use of elk and wolf population estimates to evaluate passage rates at wildlife crossing structures presents an interesting opportunity to examine behaviorally mediated use of the Bow Valley landscape. Namely, as a wide-ranging, gregarious and territorial carnivore, wolves could be expected to show relatively weak associations between population size and passage rates. Habitat use by wolves is likely to be dominated by wide-ranging movements in search of prey and then concentrated use of localized areas while feeding on and guarding carcasses (Hebblewhite et al. 2002). This type of movement pattern would produce highly variable passage rates over time and space. Wolf pack territorial boundaries are thought to occur near the town of Banff, with the Bow Valley pack occurring to the west of town and the Fairholme/Cascade pack occurring east of the townsite. Behavioral differences toward the highway between packs and among individuals within each pack could further contribute to high variance in population/passage rate association among wolves.

Unlike wolves, elk population size is more likely to have a clear association with passage rate because most passages occur near the town of Banff. This population is closely monitored by parks management to ensure human safety and minimize elk habituation to human-use areas. In so doing, the estimate of the entire Bow Valley elk population will be closely linked to the herds occupying the areas near the town of Banff, so passage rates at wildlife crossing structures in this vicinity will likely show the strongest associations with elk population size. Furthermore, unlike wolves, elk are herbivores and feed on a relatively stable and immobile "prey" of aspen and willow browse in the winter and forbs and grasses during the summer. Thus, elk movements along the various crossing structures are most likely to depend on the distribution of vegetation.

3.6.2. Methods

We used aerial and ground survey records of the Bow Valley elk population from 1996–2007 to compare frequencies of crossing structure use over time. Separate elk count records are maintained for the western, central and eastern areas of the Bow Valley (see Hebblewhite et al. 2002). Wolf populations were determined through warden observations, aerial surveys, winter corridor transects and confirmed public sightings. Wolf pack distributions are well documented within the Bow Valley using a combination of direct observation and track records (T. Hurd, Parks Canada, personal communication). Again, wolf populations were separated into western, central and eastern areas.

We calculated the frequency of crossing events at each wildlife crossing structure as a function of population size occurring within the surrounding area. Because time may be required for species to adapt to crossing structure use, we treated Phase I and Phase II separately from Phase IIIA. Thus, population estimates from the western census area of the Bow Valley were associated with Phase IIIA, while estimates from the central and eastern regions were associated with Phases I and II. We divided crossing structure passages by season: winter (December to February); spring (March to May); summer (June to August); and Fall (September to November).

We looked for an association between the annual population estimate for each side of the study area and the seasonal total of crossing structure passages at each site. We used a Pearson's non-parametric correlation to determine the strength of the association and treated each species and season separately.

3.6.3. Results and discussion

Elk and wolf use of wildlife crossing structures varies significantly from year to year, among crossing designs, and between individual wildlife crossing structure locations. We found that population size and elk crossing events were strongly associated, particularly at the open span bridge designs along Phases I and II (Table 3.6). Of these, crossing events at the Powerhouse site had the best overall correlation with population size, with an average Pearson *r* of 0.812. The highest correlation with population size overall was during the spring at Vermilion (*r* = 0.876), at Edith during the summer (*r* = 0.854) and at Powerhouse during the winter (*r* = 0.845). At each site, the highest correlations between crossing events and population size occurred during the summer (n = 11 sites) and spring (six sites), likely reflecting the seasonal timing of the elk census.

Correlations between wolf crossing events and population size were weaker than correlations for elk. Passages at Healy were most consistently correlated with population size (average Pearson *r* = 0.467). The highest overall correlation was at Castle during the winter (*r* = 0.879) although this value includes three years where no passages occurred. Thus, the most robust correlation occurred at Healy during the summer (*r* = 0.708). Unlike elk, the highest correlations within each site were during the winter (eight sites) and summer (seven sites). Again, this likely reflects the timing of the census, which tends to occur during the winter.

These results suggest that there were strong associations between elk population size and passage rate at the Banff wildlife crossing structures. A less robust but nonetheless clear association between population size and passage rates was found for wolves. The results partly confirm our beliefs regarding correlations between the wildlife crossing monitoring data and population trends in the Bow Valley. Given the important management benefits from these initial findings, we recommend that population studies be carried out to allow for additional assessments of the proximity and strength of association of the two types of data in the Banff and KYLL Field Units.

Table 3.6: Correlation between population size and seasonal passage counts at crossing structures along the Trans-Canada Highway, Banff National Park. Grey shading indicates wildlife crossing structures with highest correlations.

		Elk					Wolves				
Site	Statistic	Spring	Summer	Fall	Winter	Mean r	Spring	Summer	Fall	Winter	Mean r
CARROT	Pearson r	0.575	**0.758**	0.572	0.120	0.506	-0.217	**0.232**	0.003	0.178	0.049
	P-value	0.064	0.007	0.066	0.726		0.574	0.493	0.992	0.601	
5M	Pearson r	-0.337	-0.272	**0.479**	-0.305	-0.109	0.138	0.228	0.013	**0.291**	0.167
	P-value	0.311	0.419	0.137	0.362		0.724	0.500	0.969	0.385	
BUFF	Pearson r	0.200	**0.819**	0.751	-0.067	0.426	0.178	0.169	0.131	**0.256**	0.183
	P-value	0.555	0.002	0.008	0.845		0.648	0.620	0.701	0.448	
DH	Pearson r	0.618	0.673	0.764	**0.837**	0.723	0.070	**0.237**	0.199	0.040	0.136
	P-value	0.043	0.023	0.006	0.001		0.858	0.483	0.557	0.907	
EAST	Pearson r	0.785	0.771	0.732	0.424	0.678	0.141	0.233	0.147	**0.269**	0.198
	P-value	0.004	0.005	0.010	0.194		0.718	0.490	0.666	0.423	
EDITH	Pearson r	0.525	**0.854**	0.651	0.385	0.604	0.122	0.227	**0.256**	0.110	0.179
	P-value	0.097	0.001	0.030	0.242		0.755	0.502	0.447	0.747	
HEALY	Pearson r	0.486	0.613	0.704	**0.807**	0.652	0.664	**0.708**	0.538	-0.042	**0.467**
	P-value	0.130	0.045	0.016	0.003		0.051	0.015	0.088	0.903	
PH	Pearson r	0.815	0.808	0.781	**0.845**	**0.812**	0.114	**0.225**	0.152	0.211	0.176
	P-value	0.002	0.003	0.005	0.001		0.770	0.505	0.655	0.533	
V	Pearson r	**0.876**	0.734	0.765	0.183	0.640	0.074	0.113	0.120	**0.266**	0.143
	P-value	0.000	0.010	0.006	0.589		0.850	0.741	0.725	0.430	
MC	Pearson r	0.418	0.420	**0.499**	0.295	0.408	-0.020	0.230	0.182	**0.298**	0.172
	P-value	0.201	0.199	0.118	0.378		0.959	0.496	0.592	0.374	
RECR	Pearson r	0.120	**0.637**	0.250	0.131	0.285	0.196	0.164	-	**0.177**	0.125
	P-value	0.724	0.035	0.458	0.700		0.587	0.652	0.920	0.704	
WCR	Pearson r	-0.114	**0.690**	0.323	-0.092	0.202	**0.266**	-0.309	-	-0.588	-0.236
	P-value	0.738	0.019	0.332	0.787		0.458	0.384	0.377	0.165	
CASTLE	Pearson r	0.226	0.504	**0.566**	-0.034	0.315	0.063	-0.083	0.017	**0.879**	0.219
	P-value	0.503	0.114	0.070	0.920		0.862	0.820	0.964	0.009	
COPPER	Pearson r	0.599	**0.647**	0.623	0.221	0.523	-0.202	0.131	**0.374**	n/a	0.101
	P-value	0.051	0.031	0.041	0.513		0.575	0.717	0.287	n/a	
MASS	Pearson r	0.161	**0.607**	0.230	0.233	0.308	**0.251**	-0.014	-	-0.110	-0.009
	P-value	0.636	0.048	0.496	0.491		0.484	0.970	0.653	0.815	
WUP	Pearson r	n/a	0.586	**0.696**	-0.205	0.359	n/a	0.065	**0.252**	0.186	0.168
	P-value	n/a	0.058	0.017	0.546		n/a	0.859	0.482	0.689	
REOP	Pearson r	0.646	0.477	**0.728**	0.344	0.549	-0.331	-0.005	-	-0.094	-0.195
	P-value	0.032	0.138	0.011	0.300		0.350	0.990	0.320	0.840	
WOP	Pearson r	0.236	**0.676**	-	0.573	0.328	0.075	-0.113	0.354	**0.516**	0.208
	P-value	0.485	0.022	0.613	0.065		0.837	0.756	0.315	0.236	

BOURG	Pearson r	n/a	**0.473**	-	n/a	0.186	n/a	-0.647	-	n/a	-0.388
	P-value	n/a	0.142	0.769	n/a		n/a	0.043	0.722	n/a	
JOHN	Pearson r	0.347	0.547	**0.585**	-0.184	0.324	-0.387	**0.345**	0.048	-0.278	-0.068
	P-value	0.295	0.082	0.059	0.589		0.269	0.329	0.896	0.546	
PILOT	Pearson r	**0.549**	0.180	0.226	0.426	0.345	-0.239	**0.216**	-	0.017	-0.018
	P-value	0.080	0.596	0.504	0.191		0.506	0.548	0.858	0.971	
REUP	Pearson r	0.243	**0.429**	0.317	-0.100	0.222	0.114	**0.337**	-	0.186	-0.025
	P-value	0.471	0.188	0.342	0.769		0.754	0.341	0.015	0.690	
SAW	Pearson r	0.022	**0.410**	-	0.233	0.122	**0.224**	0.162	0.018	0.550	0.238
	P-value	0.949	0.211	0.607	0.491		0.534	0.654	0.961	0.201	

3.7. Wildlife behaviour and response to crossing structures

3.7.1. Wolf response to wildlife crossing structures after mortality of putative alpha female

Introduction

Of particular interest to park managers are the status, distribution and movements of wolf packs within both Field Units (White et al. 1998). The ability of wolves to access elk and other prey species despite potential barriers to movement is recognized as critical for maintaining stable ecosystem processes in the Canadian Rocky Mountains (Hebblewhite et al. 2005). The loss of the alpha male or female within a wolf pack may disrupt movement patterns and behaviour in response to human activity, including roads, crossing structures and human development (Paquet et al. 1996). Therefore, information on how wolves use wildlife crossing structures and how changes within the pack influence connectivity across highways will help us to better understand the conservation value of the crossings. These data will aid in developing elk management strategies and the successful restoration of predator–prey dynamics in Banff's Bow Valley.

Infrared, motion-sensitive cameras are deployed at many of the crossing structures along the TCH. The cameras enable us to document the number of animals using the crossings, their direction of travel, timing of movement, group size, and occasionally gender and age. We are also able to document behaviour of animals as they pass in front of the camera.

On August 25, 2008, the alleged alpha female of the Bow Valley wolf pack was killed on the TCH near Redearth wildlife overpass after escaping through the wildlife fence onto the highway. In an unrelated incident about 1 week later, an adult male wolf from the same pack was killed near the Sunshine interchange. We were interested in knowing whether the loss of the putative alpha female and the sub-ordinate male of the Bow Valley pack would affect movement and behaviour of the remaining pack members through the wildlife crossing structures.

Methods

Behavioral observations of wolves were made based on recordings from motion-sensitive cameras (Reconyx, Inc., Holmen, Wisconsin). For each attempted crossing event, we documented the size of the traveling group (i.e., number of individuals passing within five minutes of each other), response to the barbed wire (i.e., hesitation, no hesitation) and through passage (i.e., crossed or did not cross). Through passage was used to calculate the passage frequency, which is the number of successful crossings divided by the total number of crossing attempts.

We analyzed wolf behavioural responses at the wildlife crossings one month prior to, and one month following, the second wolf mortality (September 4, 2009). We used data from the same period in 2007 as a control, since changes in behaviour may occur over time with changes in prey, season, or juvenile dispersal.

Results and Discussion

We found that the loss of the alpha female likely reduces the permeability of the highway for wolves. The number of through passages decreased by 13 percent in the month after the mortality event (Table 3.7) despite there being more attempted crossing events during this time than during the month before the mortality. We also found that wolves were more hesitant to use the crossing structures after the mortality event (Figure 3.2). The number of attempted crossing events where wolves hesitated increased threefold following the death of the alpha female. In 2007 there was a greater tendency to hesitate at the barbed wire than in 2008, but the ratio of crossing events where we detected hesitant behaviour to those where we did not detect hesitant behaviour was the same over the control period. In 2008, the year of the mortalities, this ratio changes from 0.48 hesitant crossings to non-hesitant crossings prior to the mortality, to 1.25 hesitant crossings to non-hesitant crossings after the mortality. We also found that the mean wolf group size increased after the mortality, however the effect was not statistically significant (Kruskal–Wallis test, chi2=1.992; P=0.158; Figure 3.3).

There are at least two possible explanations for these results. First, the alpha female was the only wolf using the crossings, and the wolves using the crossings following the mortality event were inexperienced at using the crossing structures. This inexperience caused the wolves to be hesitant while using the crossings. In the future, we would expect the proportion of hesitant crossings to drop relative to non-hesitant crossings as wolves become more accustomed to using the crossings. The second possibility is that the alpha female led other pack members through the crossings, and without her, the pack was hesitant to use the highway crossing structures on their own. The fact that the group size and number of crossing attempts increased after the mortality supports the first hypothesis because if all pack members were using the crossings before and after the alpha female mortality, we would likely see a decrease in group size, as there are two fewer wolves in the pack. Results from genetic studies (2006–2008) and additional camera data from 2009 will help confirm these possibilities.

Table 3.7: Changes in passage frequency for wolves one month before and after the death of the alpha female.

Time period	Crossing attempts	Passage frequency
Before mortality	77	0.94
After mortality	98	0.81
Control: before	42	0.93

Control: after	42	0.90

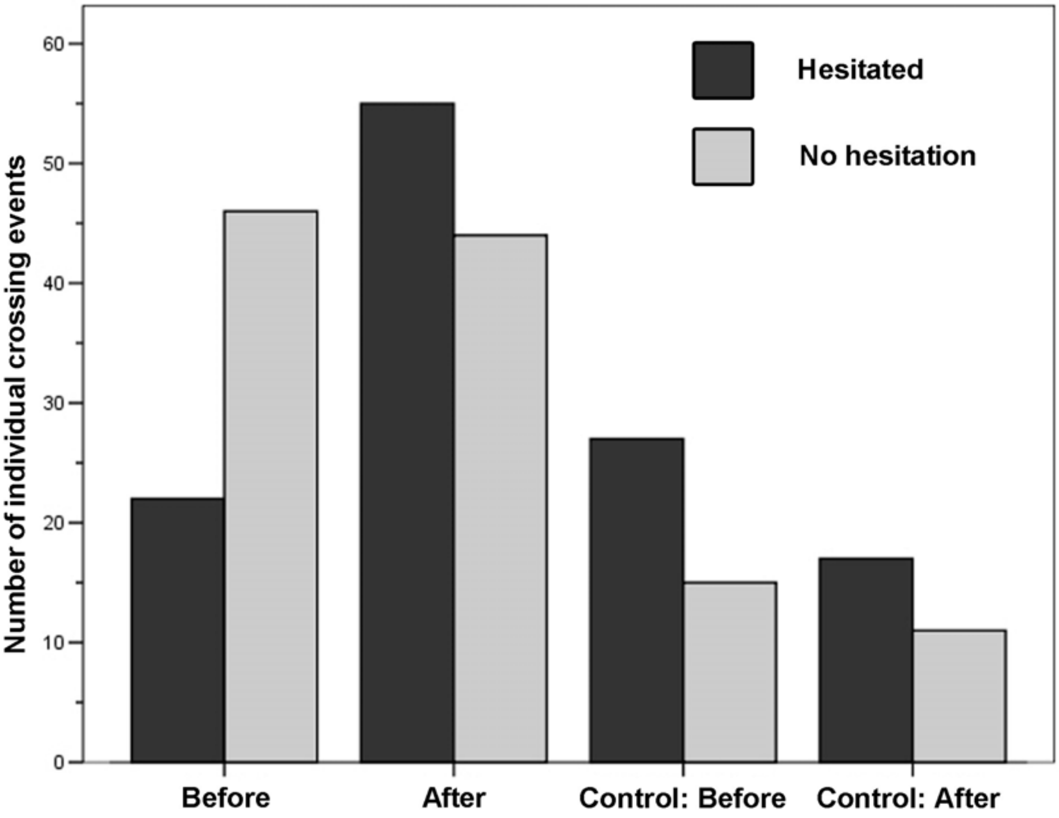

Figure 3.2: The number of crossing events and wolf hesitation response before and after the death of putative alpha female in 2008 and control period in 2007.

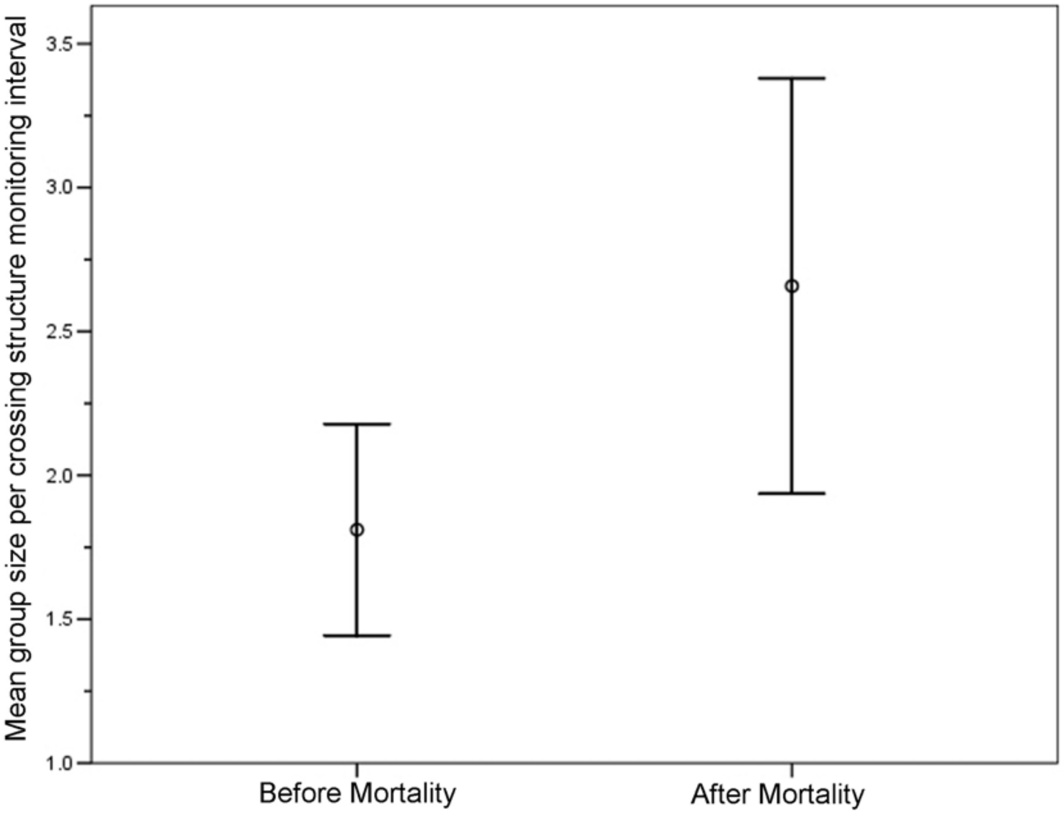

Figure 3.3: Wolf group size before and after the death of putative alpha female in 2008.

3.7.2. Interspecific patterns of wildlife crossing structure use: Wolves, cougars and coyotes

Introduction

Movement of wildlife is often dictated by the distribution of resources and the physiological state of the animal (Kie 1999; Turchin 1998). However, roads may alter wildlife movement and their distributions on the landscape. Wildlife crossing structures are designed to facilitate movement of animals across highways, thus allowing individuals to meet their biological needs, and populations to redistribute with environmental change and ultimately maintain metapopulation processes. When highways are twinned and mitigated with crossing structures and fencing, animal movement patterns are further constrained by the distribution of wildlife crossing structures and the resources they need to access. Resource needs vary by species and individuals, but the use of crossing structures as mitigation reduces the movement opportunities for safe passage to a number of specific locations on a highway. Thus, animals using wildlife crossing structures stand a far greater chance of encountering one another near or adjacent to the structures than they do away from the highway. Over time, spatial and temporal segregation of species may occur at crossing structures as conspecifics attempt to avoid each other or minimize risks of predation by larger species. These interspecific interactions and effects of species-specific use of wildlife crossing structures may be occurring in Banff, given that many of the crossing structures have been in place for a decade or more and large mammals have to select where and when to cross within a 45-km section of the TCH through the Bow Valley.

Previous studies have shown that the use of landscape corridors or wildlife crossing structures may change with species-specific perceptions of the landscape elements (Beier and Noss 1998) or inter-species interactions (Doncaster 1999; Little et al. 2002). Doncaster (1999) found a temporal segregation in use of below-grade tunnels by badgers (*Meles meles*) and Eurasian hedgehogs (*Erinaceus europaeus*) in Great Britain. To test for an effect of inter-specific interactions at crossing structures we examined use by three species that are likely to show the strongest effects of competition in our study area: wolves, cougars and coyotes. Wolves are the dominant predator in the Bow Valley and can kill or displace cougars and coyotes (Kortello et al. 2007) Previous monitoring of nine crossing structures centered around the town of Banff described spatial and between-year patterns of wildlife underpass use by wolves and cougars (Clevenger et al. 2002). Five years of data suggested that there was a temporal and spatial segregation of wildlife crossing structure use by both large carnivores. Cougars are more dominant than coyotes and, like wolves, may prey on them (Hornocker 1970; Boyd and O'Gara 1985; Paquet 1992; Switalski 2003). Thus, coyotes may be displaced by the two larger predators. At the same time, coyotes may track the movement of cougars and wolves to scavenge the carcasses of ungulates killed by those predators (Paquet 1992; Switalski 2003).

We predicted that wolves and coyotes would exhibit the greatest segregation among these three species. Coyotes may be either positively or negatively associated with the other species depending on the relative importance of scavenging and displacement, respectively, on the coyotes' movement.

Methods

We summed the total number of crossing structure checks where each species was detected, irrespective of the number of individuals or the direction of travel. We then calculated the total number of crossing events where two or more species were detected at the same check. We present these data as the probability of detecting both species during one monitoring interval.

Next, we standardized the sampling effort of each crossing structure check by the number of days that lapsed since the previous check to provide a rate (crossing events per day). We summed the total number of individuals for each species, irrespective of direction traveled for each species. We selected all crossing structure checks where at least one of the species was detected, and then performed a Pearson's correlation to determine the strength of association between each species' use of the same structures.

Results and discussion

There was a very low probability of any of these three species being detected at the same wildlife crossing structure during the same monitoring interval (Table 3.8). This supports our initial hypothesis that the three species avoid each other. Coyotes were most likely to be detected without other species present. This is likely a function of their higher population densities relative to the two larger carnivores and the risk of their being preyed upon by these other two carnivores. Wolves were least likely to be detected without other species present, supporting the notion that they are less averse to other species than other species are to them. It also supports our hypothesis that of the three species, wolves are the dominant predator. Interestingly, coyotes were almost twice as likely to be detected with wolves as with cougars. However, it is not clear whether temporal segregation of wildlife crossing structure use occurred between the two species or reflects an optimal foraging strategy by coyotes to follow a large predator in the hopes of finding a scavenging opportunity. Unlike coyotes and wolves, cougars and wolves rarely co-occurred at the same crossing structure. That cougars and wolves appeared to avoid using the same sites suggests that inter-species interactions may be a more important factor in determining species use of wildlife crossings than we have previously thought.

When we examined the intensity with which wolves and coyotes utilized the Banff wildlife crossing structures we found that there was clearly a strong separation and negative spatial correlation in use patterns among the 23 structures. Where wolf use was highest the amount of coyote use tended to be lowest, and vice-versa. Where wolf use was highest, coyote use peaked at neighbouring crossing structures. From this exploratory analysis several questions arise: Do wolf peaks correspond with coyote lows over longer time periods? Are coyote peaks adjacent to wolf peaks over longer time periods? Where wolf and coyote use coincide, at the highest coyote peak in use, can we detect a temporal separation (using cameras) of movement through the crossing structures?

To summarize, it was not surprising that we detected significant negative correlations in wildlife crossing structure use among wolves, cougars and coyotes (Table 3.9). These patterns appear to be fairly consistent among all the crossing structures (Figure 3.4). Future analyses using more sophisticated statistical tools (e.g., general additive models, species occupancy models) will be used to parameterize the degree of species interactions at wildlife crossing structures over space and time. Additional species, including ungulates and humans, will also be incorporated into the modeling framework.

Table 3.8: Probability of detecting species co-occurrence during a single monitoring interval at each wildlife crossings structure (WCS).

Species present	Frequency* of WCS checks
Coyote alone	0.877
Cougar alone	0.809
Wolf alone	0.789
Cougars and wolves	0.016
Cougars and coyotes	0.029
Coyotes and wolves	0.061
All species were present	0.002

*Denominator is the total number of times that species was detected, irrespective of the presence of other species at the site.

Table 3.9: Correlation among species' crossing rate per day determined at each crossing structure check.

Species interaction	N*	r	P
Cougars and coyotes	4904	-0.280	<0.0001
Cougars and wolves	2866	-0.348	<0.0001
Coyotes and wolves	5663	-0.260	<0.0001

*Wildlife crossing structure checks where at least one of the species was present.

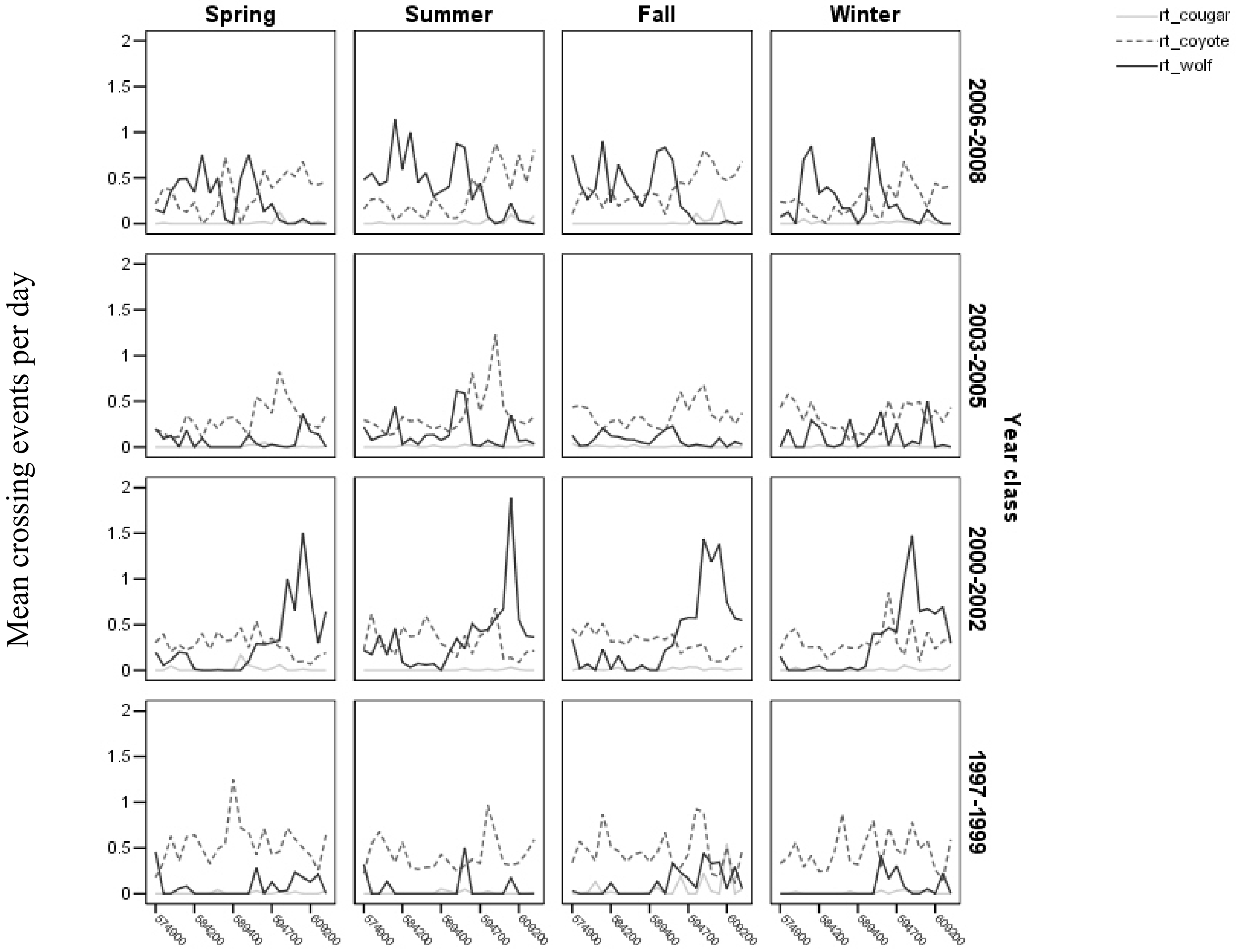

Figure 3.4: Mean crossing events per day by wolves, coyotes and cougars, by season and year, 1997–2008 at 23 crossing structures, listed as UTM coordinate.

3.7.3. Wildlife response to new and established crossing structures

Introduction

The performance of wildlife crossing structures can be evaluated using a number of different metrics (Forman et al. 2003). Regardless of the metric selected, data are required to identify when animals approached the wildlife crossing structures and what the rate of passage was with respect to the number of approaches. This type of fine-scale data only can be obtained by video monitoring or snow tracking at the crossing structures, or by tracking movements of geographic positioning system (GPS)-collared individuals (e.g., see Dodd et al. 2007). Without these methods it is impossible to determine whether an animal attempted to use a wildlife crossing structure, but hesitated and turned around. Snow tracking is one method used to infer how movement changes in the vicinity of a crossing structure entrance. Furthermore, snow tracking can provide an index of relative abundance for wildlife populations near the wildlife crossing structures (Clevenger et al. 2001a). The limitations of snow tracking are that it is highly dependent on weather conditions and restricted to winter months. During winter, bear species will not be detected on a regular basis, and movement of other species may be restricted by snow depth. Still, snow tracking can provide key insights on how species adapt and respond to wildlife crossing structures over time.

The question of how animals respond or adapt to newly constructed wildlife crossings has direct management implications for the newly constructed Phase IIIB wildlife crossings near Lake Louise and other soon-to-be-constructed wildlife crossings scheduled for completion in 2012. Monitoring plans will need to provide sufficient time and data to make strong inferences with regard to wildlife crossing performance. Such habituation periods can take several years depending on the species as they experience, learn and adjust their own behaviours to the wildlife structures (see Section 3.8, *Adaptation and learning…*).

To address the question of how animals respond to newly constructed wildlife crossing structures we monitored the responses of multiple species to wildlife crossing structures of varying age and design type. We present data collected 10 years ago after Phase IIIA mitigation was completed (see Clevenger et al. 2002). We feel that given the onset of a new monitoring plan to assess the performance of the Phase IIIB crossing structures, a reanalysis of these research results will help provide guidance and will demonstrate the need for a long-term monitoring approach.

During four winters between 1997 and 2000 we conducted fieldwork around the newly constructed Phase IIIA wildlife crossings (completed November 1997) and established Phases I and II wildlife underpasses (completed by 1987). Our specific objectives were to determine species-specific responses to the crossing structures by snow tracking, and test whether their responses differed between newly installed structures and older established ones. If animals tended to avoid new structures, or needed time to adapt to them, it would be important to know how much time might be required for animals to respond similarly to new and old structures alike. We predicted that animals would be more hesitant to use the newer wildlife crossing structures than older ones and investigated whether structure design affects the probability of passage.

Methods

We created semi-circular transects around either end of the wildlife crossing structures. Each transect had a radius of 100 m and was centered on the middle of the structure entrance. After 48 hours had passed from a track-clearing snowfall, we visited the sites and documented species-specific responses to the crossings. We classified each track as passage (track entered structure and passed through it) or non-passage (track was parallel with fence, or entered structure but did not cross, or approached entrance to structure but did not enter). We looked at species coyote-sized and larger. We collected data during the winters of 1996–97, 1997–98, 1999–2000, and 2000–01, hereafter referred to as Winters 1, 2, 3 and 4, respectively. In Winter 4 we only looked at crossing structures along Phase IIIA. In Winter 1 we only documented movement by wolves and cougars. Species are hereafter coded as COYO (coyote) and COUG (cougar).

Results and discussion

The frequency of through passages was higher on Phases I and II crossing structures than on Phase IIIA structures, and in later winters for all phases (Table 3.10, Table 3.11, Figure 3.5). The highest passage rates for cougars were found along the creek bridges, open-span bridges and older small culverts. Coyotes and wolves were most successful at open span bridges. Deer were one of the only species to regularly use the overpasses, with their passage rate being highest at these sites. Elk passage rates were highest at the open span bridges. These results suggest that species are more likely to use crossing structures as time passes, even when controlling for the number of encounters at each site. Efforts are underway to complete this study by monitoring transects at Phase IIIA and IIIB sites over the coming winters. These new data will provide information on adaptation to crossing structure use in two ways. First, we will compare Phase IIIA structure use when they were new (this study) and when they were 12 years old (now), which is presumably long enough for the local animal populations to adapt to their presence. We would expect the passage rates from Phase IIIA to be comparable to rates we obtained for Phases I and II nearly 10 years ago. The second analysis consists of comparing use of wildlife crossing structures of similar design but varying in age by comparing use of 4 m x 7 m culverts on Phases IIIA and IIIB.

Table 3.10: Passage rate (crossings/total detections) of species detected at wildlife crossing structures by phase and design.

	Phase I and II						Phase IIIA							
	Creek bridge (1)*		Open span (7)		Small culvert (1)		Creek bridge (2)		Large culvert (3)		Overpass (2)		Small culvert (5)	
	Passage rate	N	Passage rate	N	Passage rate	N	Passage rate	N	Passage rate	N	Passage rate	N	Passage rate	N
Cougar	0.78	9	0.72	25	0.33	3	1.00	3	0.00	2	0.00	0	0.43	7
Coyote	0.67	3	0.60	45	1.00	1	0.28	18	0.29	35	0.41	79	0.44	39
Deer	0.30	10	0.50	127	0.43	7	0.15	47	0.20	45	0.57	49	0.13	40
Elk	0.08	63	0.74	462	0.45	11	0.07	15	0.24	41	0.06	49	0.11	19
Wolf	0.00	2	0.53	49	0.00	9	0.00	1	0.00	1	0.00	2	0.00	1
Mean	0.36		0.62		0.44		0.30		0.15		0.21		0.22	

N: Total number of approaches

* Number in parentheses represents the number of sites with that design along each phase.

Table 3.11: Total passage rate of species at new (Phase IIIA) and established (Phase I and II) wildlife crossing structures, 1997–2001.

	Phase I and II		Phase IIIA	
	Passage rate	N	Passage rate	N
Cougar	0.70	37	0.50	12
Coyote	0.61	49	0.37	171
Deer	0.49	144	0.27	181
Elk	0.66	536	0.13	124
Wolf	0.43	60	0.00	5
Mean	0.58		0.25	

N: Total number of approaches

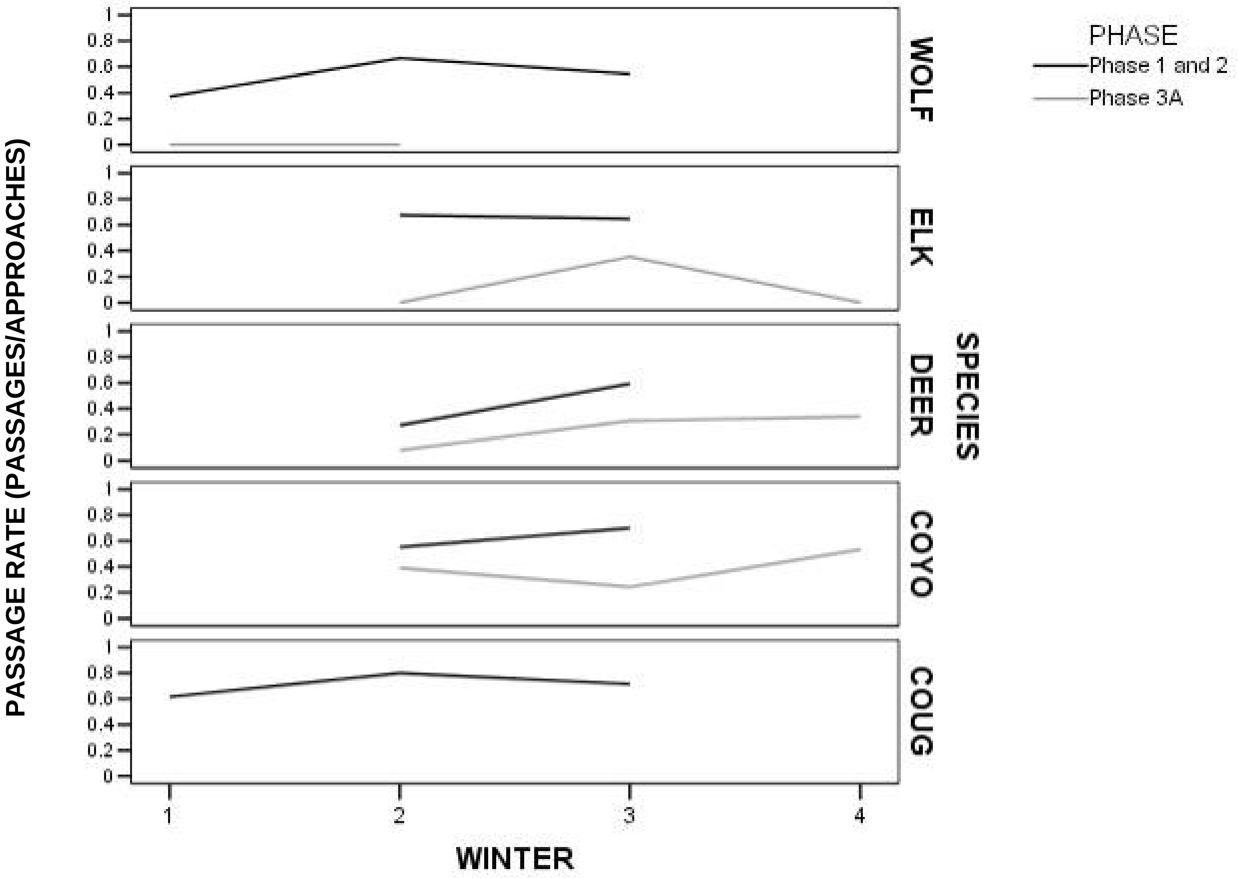

Figure 3.5: Passage rate of four species at new (Phase 3A) and established (Phase I and II) crossing structures during four winters 1996–97, 1997–98, 1999–2000, and 2000–01. Winters are shown on the x-axis as 1, 2, 3 and 4, respectively (COYO=coyote; COUG=cougar).

3.8. Adaptation and learning

3.8.1. Current knowledge

What do we know about adaptation periods and learning curves for animals using wildlife crossing structures? Our long-term monitoring has demonstrated that an adaptation period and learning curve does exist for large mammals and varies between ungulates and carnivores. Similarly, Dodd et al. (2007) found that elk required time to adapt to newly created wildlife underpasses in Arizona before using them on a regular basis. The average monitoring period of 18 studies reporting on wildlife crossing structure use by mammals was 17 months (Clevenger and Huijser in preparation)—not even two years. The few studies that have had more than two years of monitoring showed that animals require an adaptation period and that animal learning is implicated in the regular use of crossings.

In Banff we have learned about the adaptation period in two ways. First, snow track transects were conducted around the entrances to newly constructed and established (>10 yrs old) wildlife crossing structures (see Section 3.7.3, *Wildlife response to new*…). The "through-passage rate" was significantly lower (half the rate, on average) on the newly constructed Phase IIIA crossings compared to the established Phase I and II section. Through-passage rates for all species increased over the four-year period of study. Next, we examined the number of successful crossing events at wildlife crossing structures for ungulates and carnivores (Clevenger et al. 2002). For carnivores it appeared that use levels out or reaches a threshold after annual increases (for some species a steep increase) over four to six years, whereas for ungulates it is a two- to three-year period. The annual increases in grizzly bear use of the Banff wildlife crossings have been frequently used to demonstrate the importance of long-term monitoring (see Figure 3.24). This will be discussed in the next section, which details what we have learned from monitoring between Year 5 and Year 12 and the overall benefits of long-term monitoring in Banff and KYLL Field Units.

That an adaptation period exists is unequivocal—the questions that remain are how long the adaptation period is for each species of large mammal, and does it change if examined at two different time periods? In other words, would we expect to find the same result if we repeated field studies today under the same conditions? This is an important question to answer in order to design monitoring schemes of sufficient scientific rigor and length to provide strong inference when addressing wildlife adaptation and eventual performance assessment of crossing structures.

3.8.2. What does adaptation and learning look like?

What would a simple graph look like that depicts adaptation of wildlife to crossing structures over time? In a generalized graph we would expect the amount of use to increase over time, but at some point in time (an inflection point or asymptote) use would begin to fluctuate annually. Subsequent fluctuations, however, would be smaller in amplitude than the amplitude exhibited during the rising use in the initial years (Figure 3.6).

Figure 3.6: Generalized concept of adaptation of wildlife to crossing structures over time. Y-axis refers to number of detected crossings by a given species. X-axis is a longitudinal reference to number of years monitoring takes place.

In addition to the abovementioned data regarding wildlife adaptation to the Banff wildlife crossings from 1997 to 2001, we can look at much longer time-series of data between 1997 and 2008 to interpret what this adaptation or learning process looks like. The best way to do this is by looking at species-specific graphs of Phase IIIA crossing structure use. Phase IIIA is used because we can track usage from inception of mitigation once construction was completed (November 1997) to the present.

It is worth noting that this is the only data of its kind in the world. Nowhere has anyone been able to monitor consistently and systematically year-round animal use of wildlife crossings over long time periods. What we are able to infer from our long-term research data has not only implications for management and monitoring of wildlife crossings in Banff and KYLL Field Units, but provides evidence-based support for technical design recommendations and monitoring programs elsewhere.

We examined time-series data from eight species of large mammals (three ungulates and five carnivores) using the Phase IIIA wildlife crossings over a 12-year period, from inception (1997) to the present (2008). Compiled below for each species (Figure 3.7 to Figure 3.22) are two graphs: (1) the number of crossing events per year by wildlife crossing design type (n=4), and (2) the total number of crossings on Phase IIIA with their confidence interval and a fitted line that smoothes out the points and indicates trend in use.

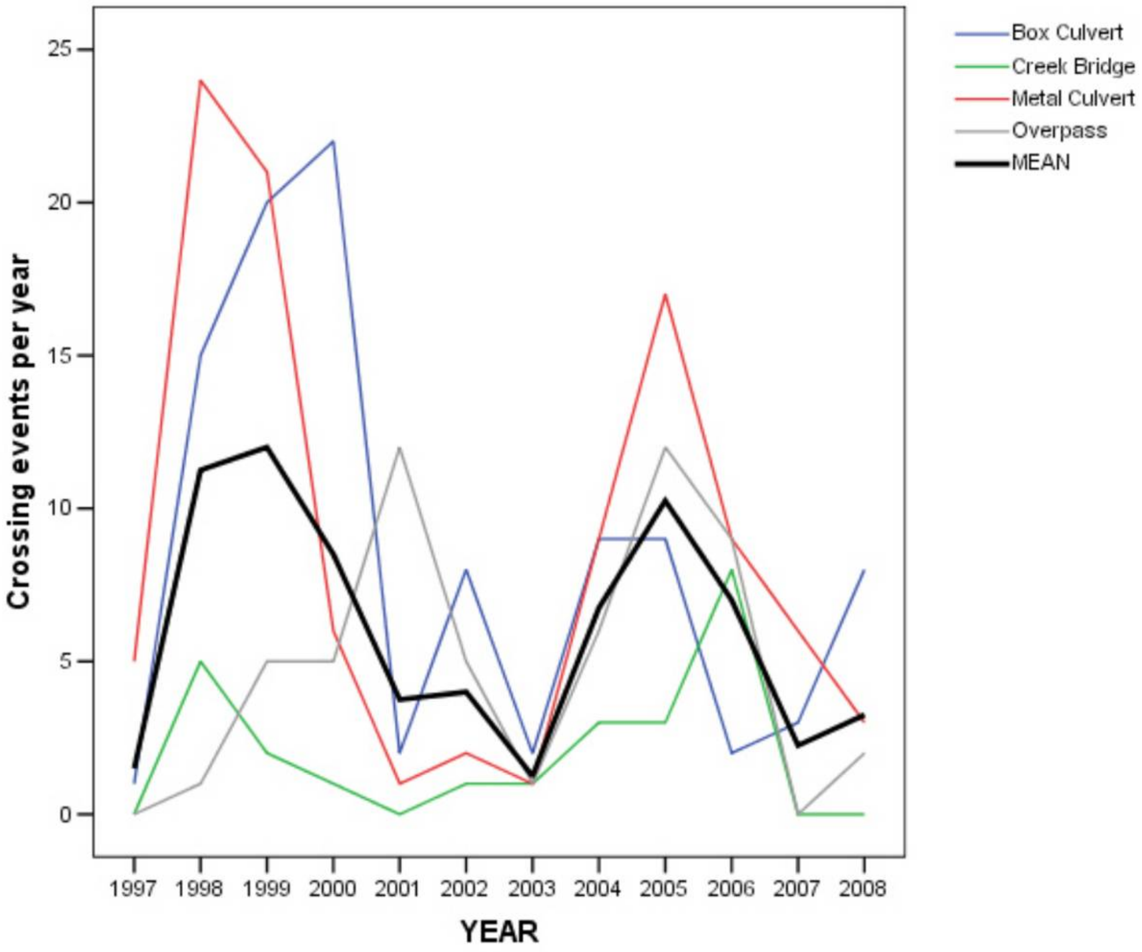

Figure 3.7: Number of black bear crossing events by crossing structure design type on Phase IIIA from 1997 to 2008.

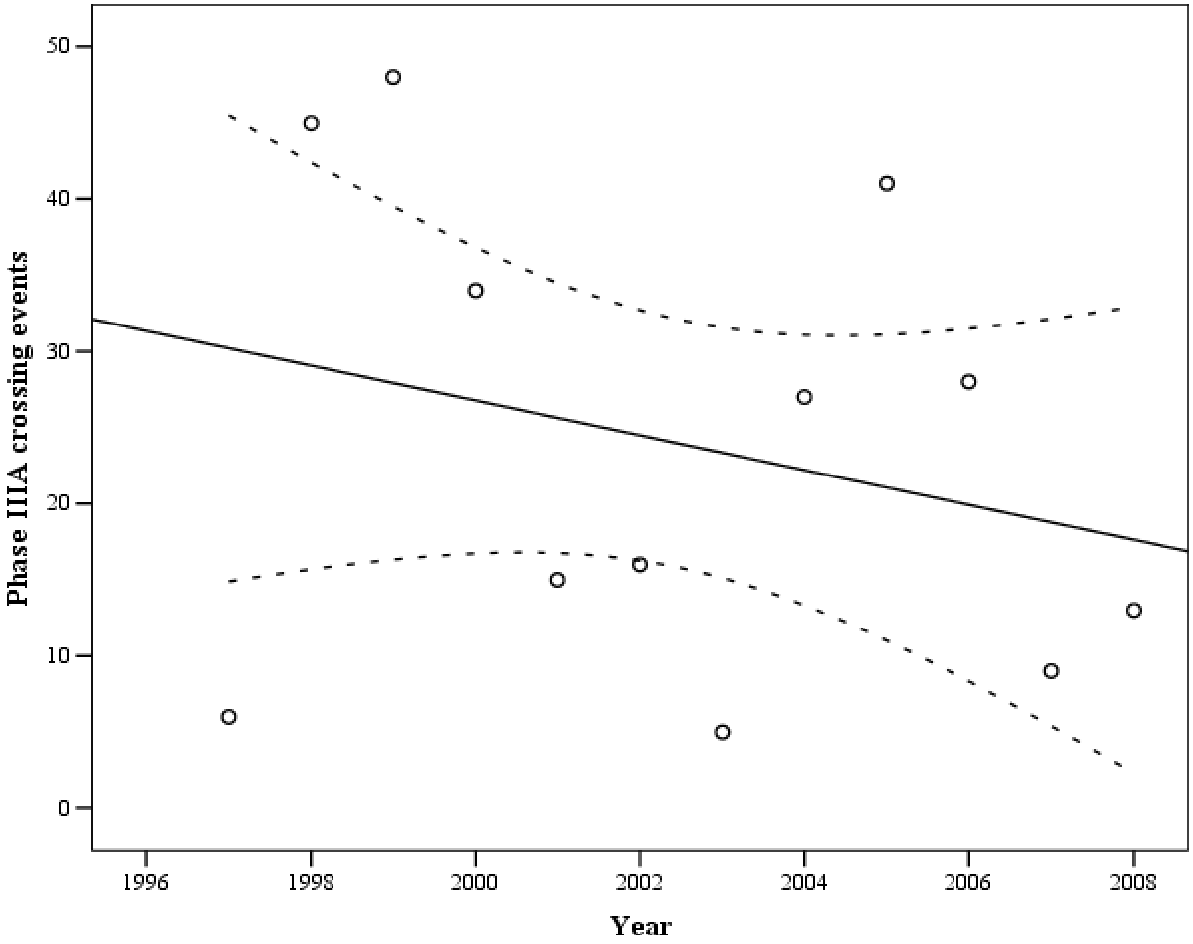

Figure 3.8: Total number of black bear crossing events (open circle) on Phase IIIA from 1996 to 2008, with confidence interval (dotted line) and fitted line (solid line).

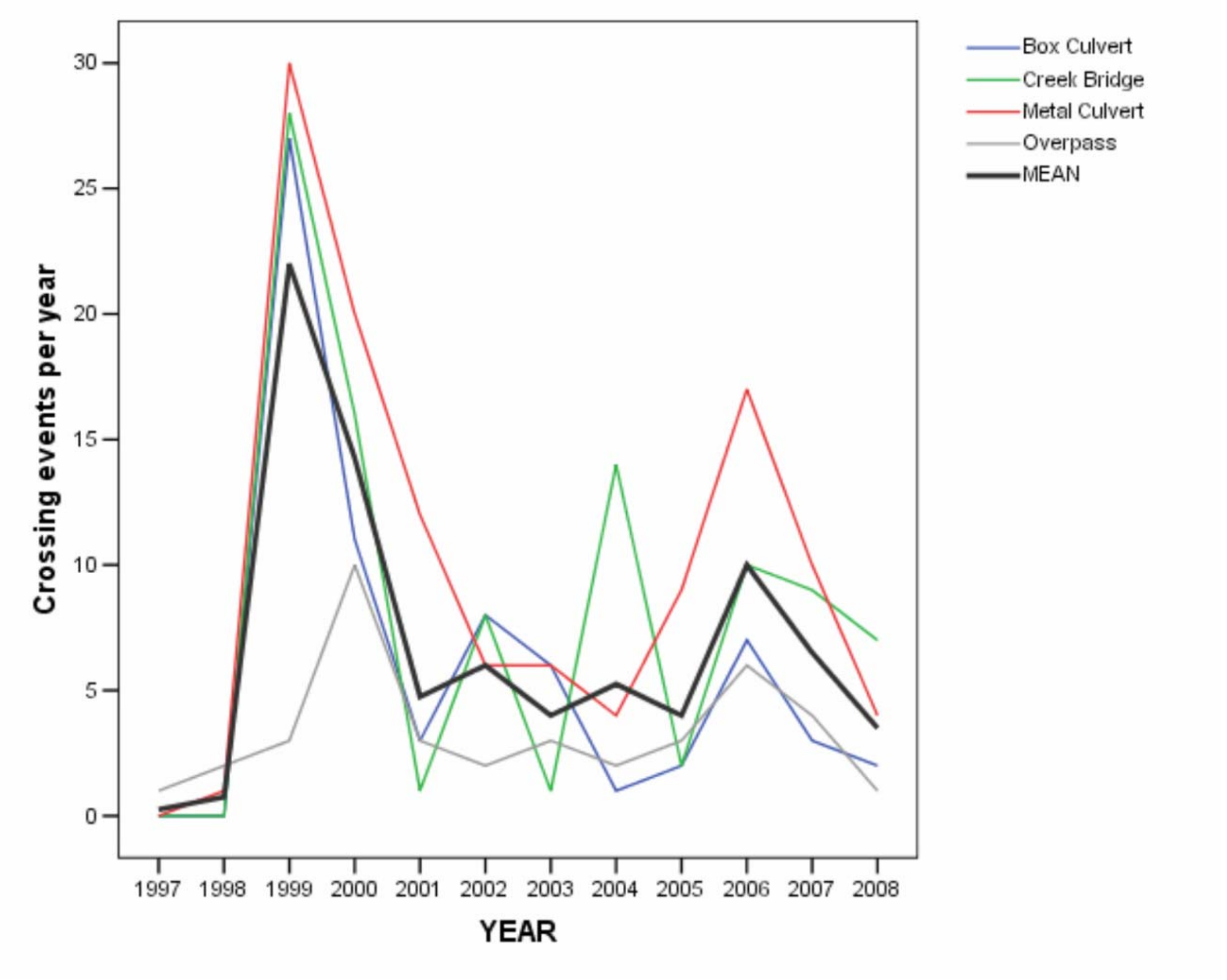

Figure 3.9: Number of cougar crossing events by crossing structure design type on Phase IIIA from 1997 to 2008.

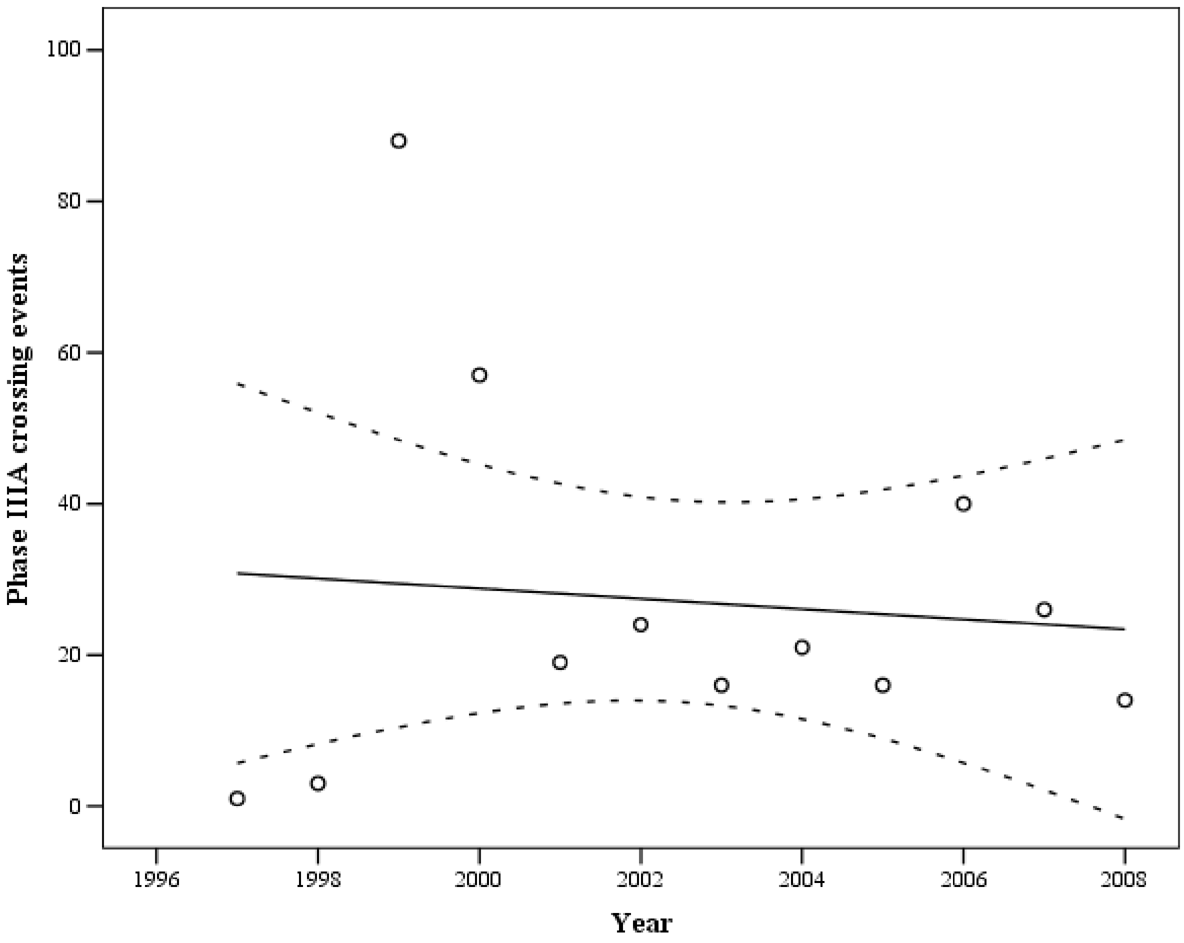

Figure 3.10: Total number of cougar crossing events (open circle) on Phase IIIA from 1996 to 2008, with confidence interval (dotted line) and fitted line (solid line).

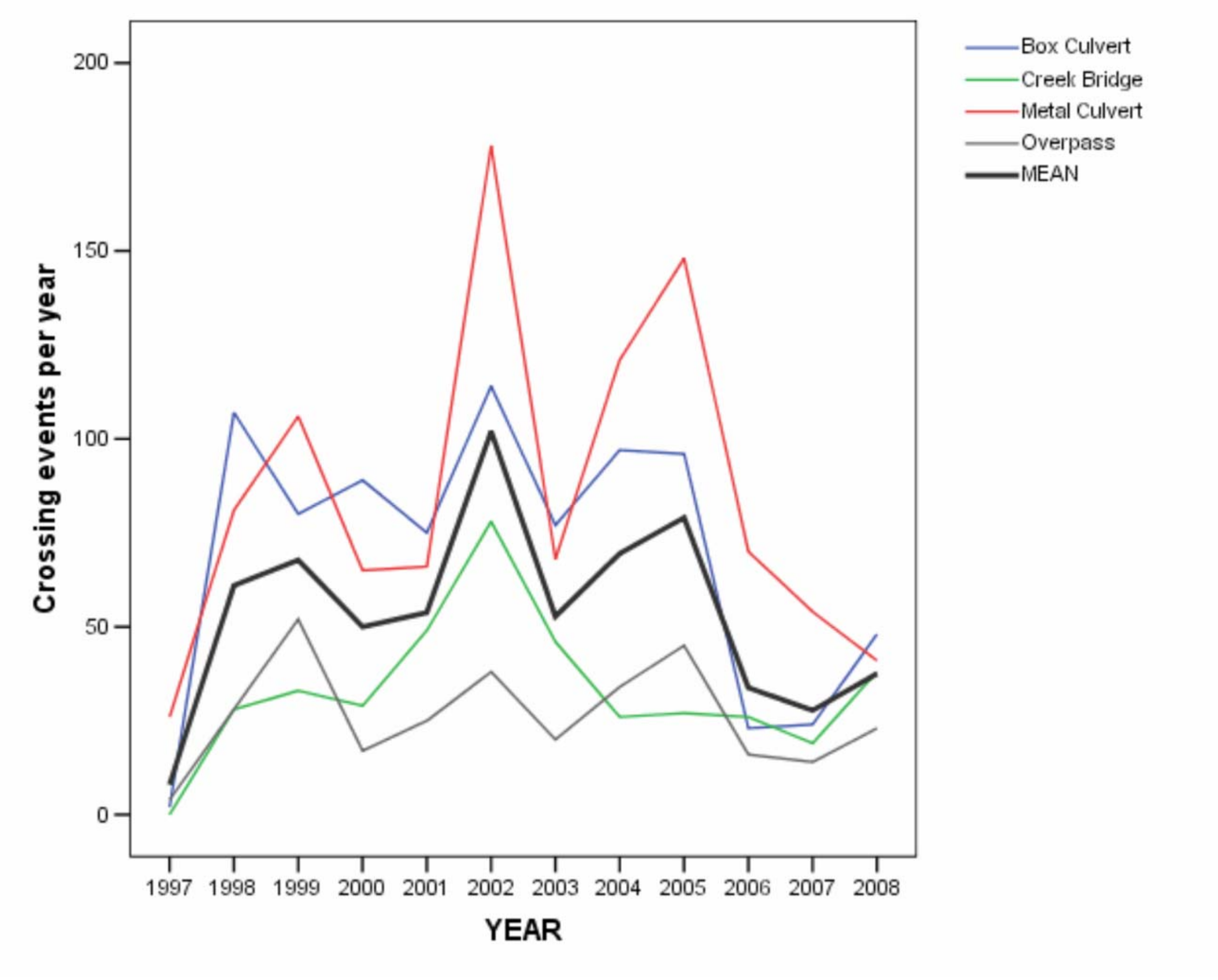

Figure 3.11: Number of coyote crossing events by crossing structure design type on Phase IIIA from 1997 to 2008.

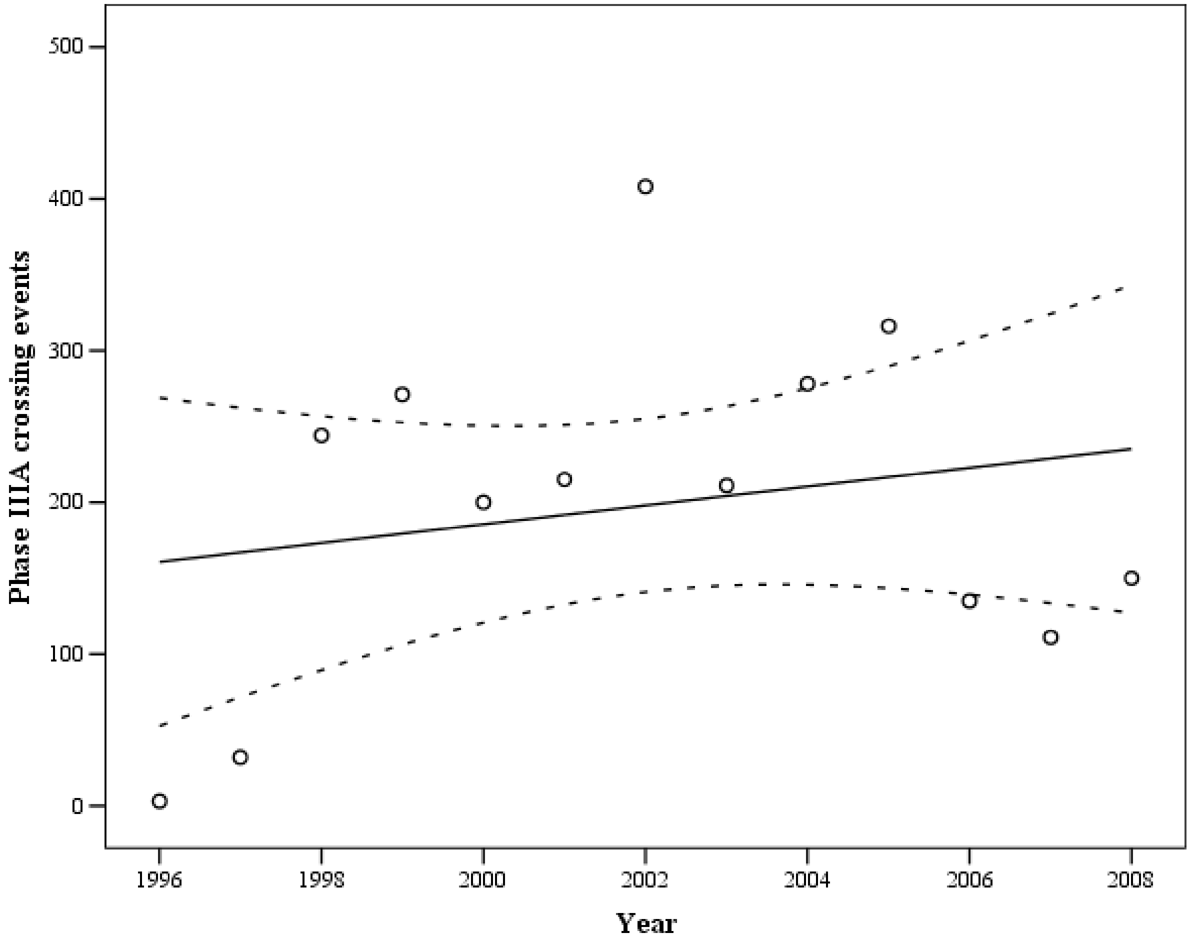

Figure 3.12: Total number of coyote crossing events (open circle) on Phase IIIA from 1996 to 2008, with confidence interval (dotted line) and fitted line (solid line).

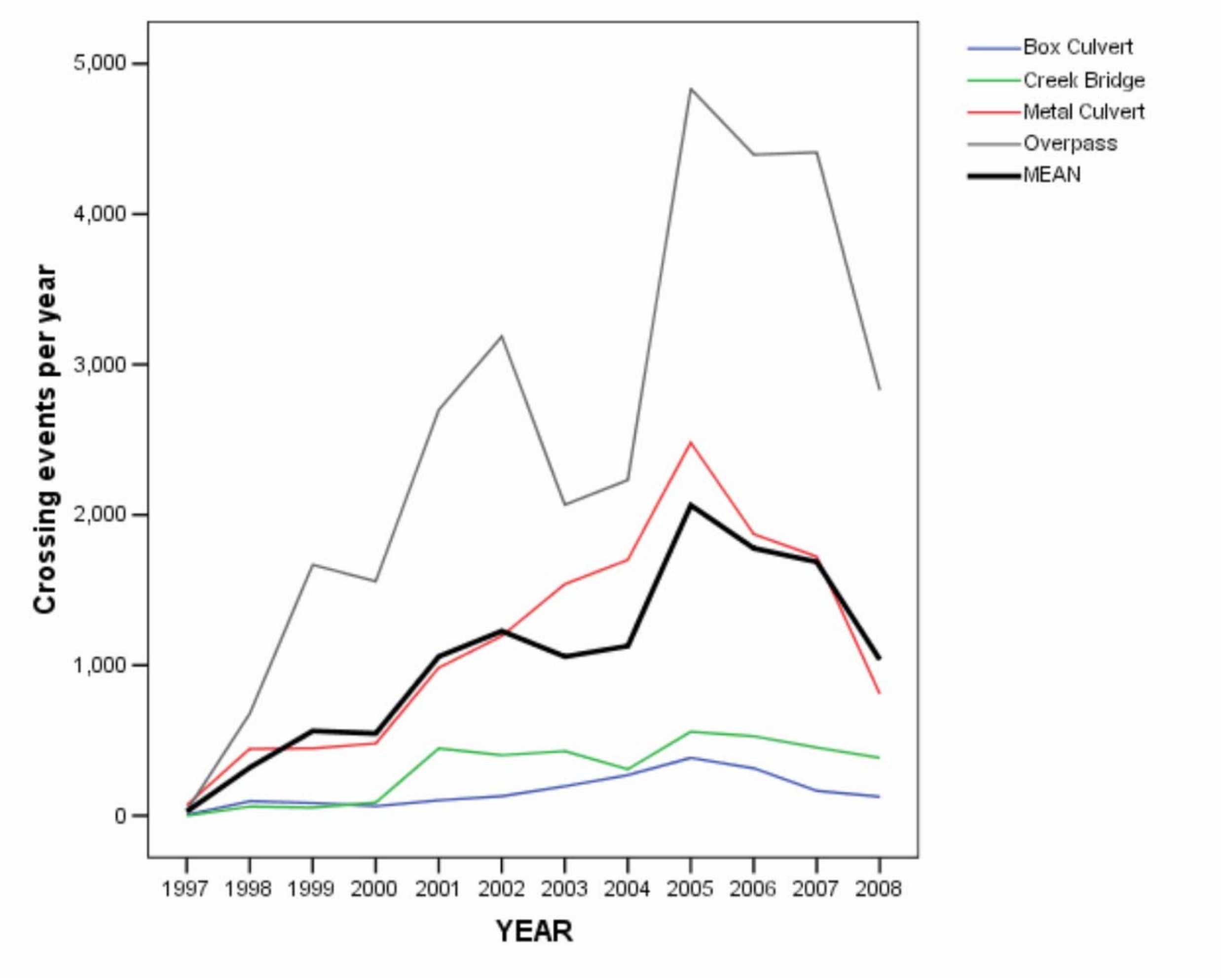

Figure 3.13: Number of deer crossing events by crossing structure design type on Phase IIIA from 1997 to 2008.

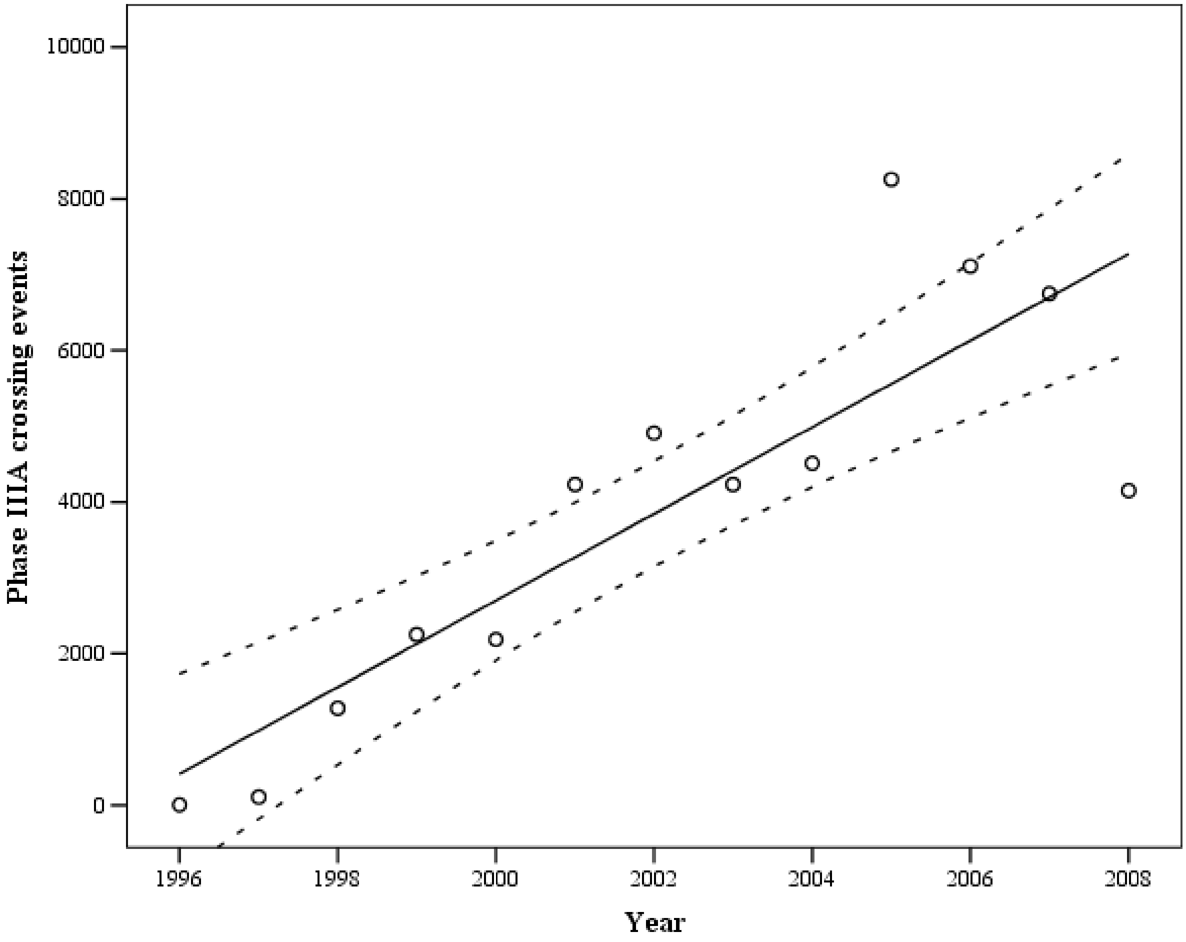

Figure 3.14: Total number of deer crossing events (open circle) on Phase IIIA from 1996 to 2008, with confidence interval (dotted line) and fitted line (solid line).

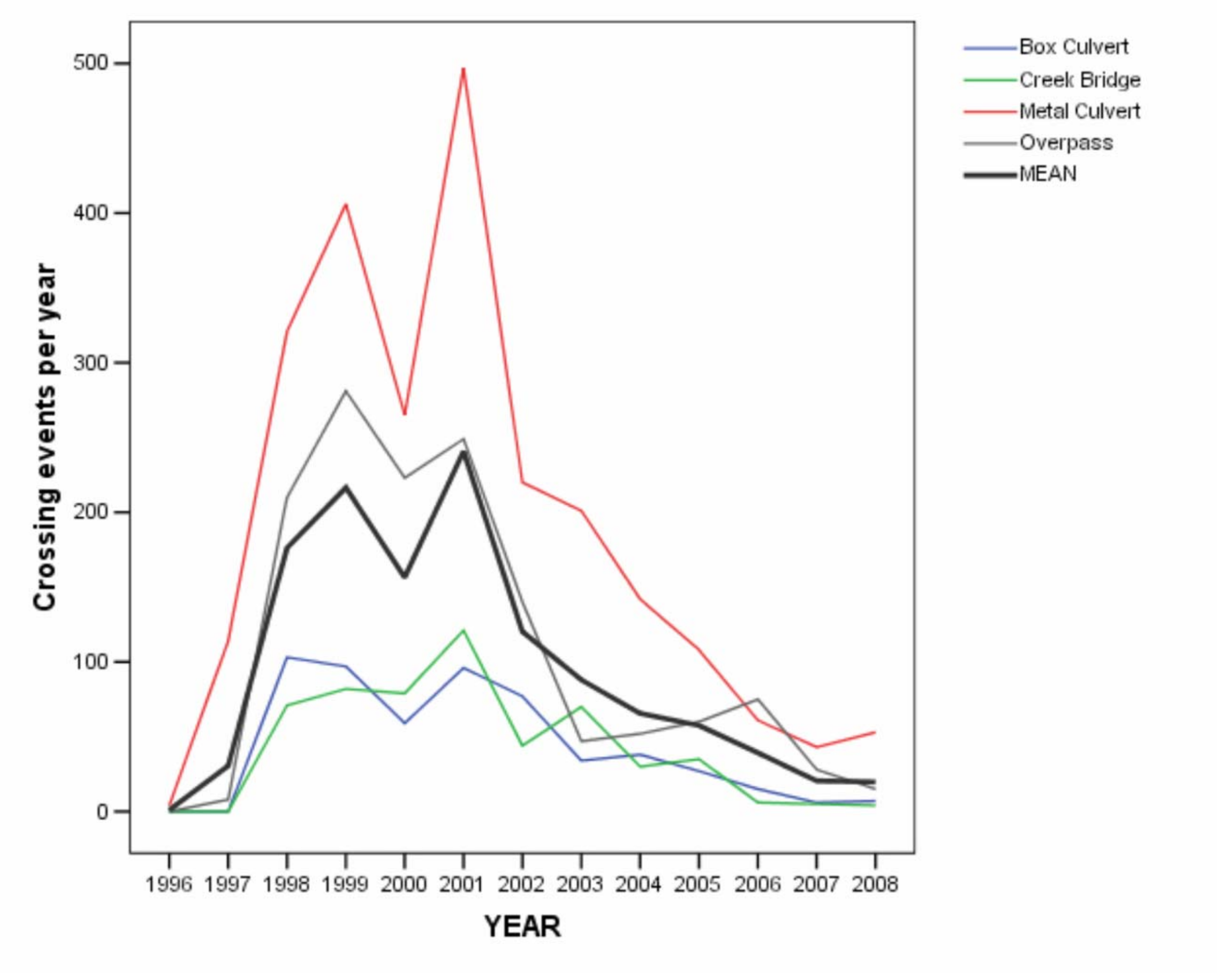

Figure 3.15: Number of elk crossing events by crossing structure design type on Phase IIIA from 1997 to 2008.

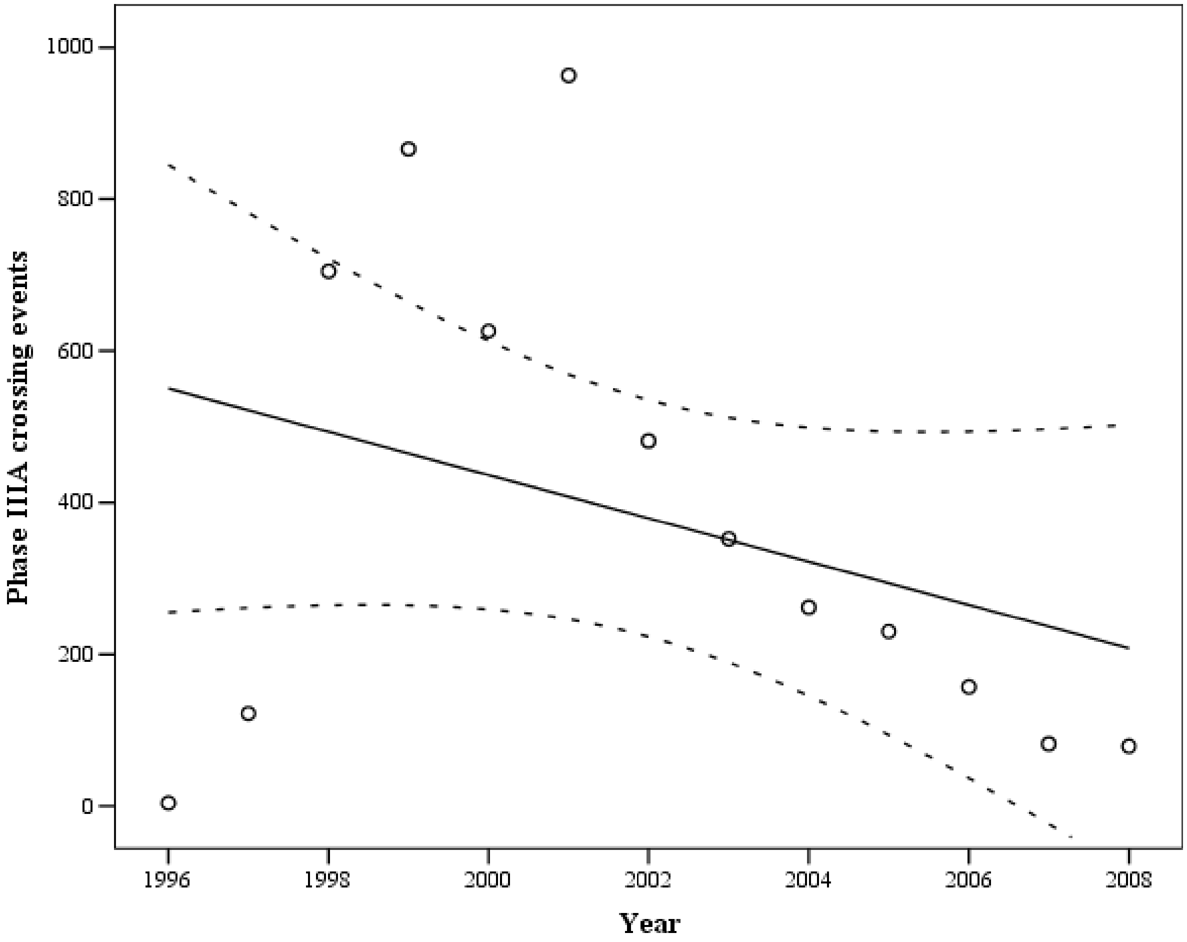

Figure 3.16: Total number of elk crossing events (open circle) on Phase IIIA from 1996 to 2008, with confidence interval (dotted line) and fitted line (solid line).

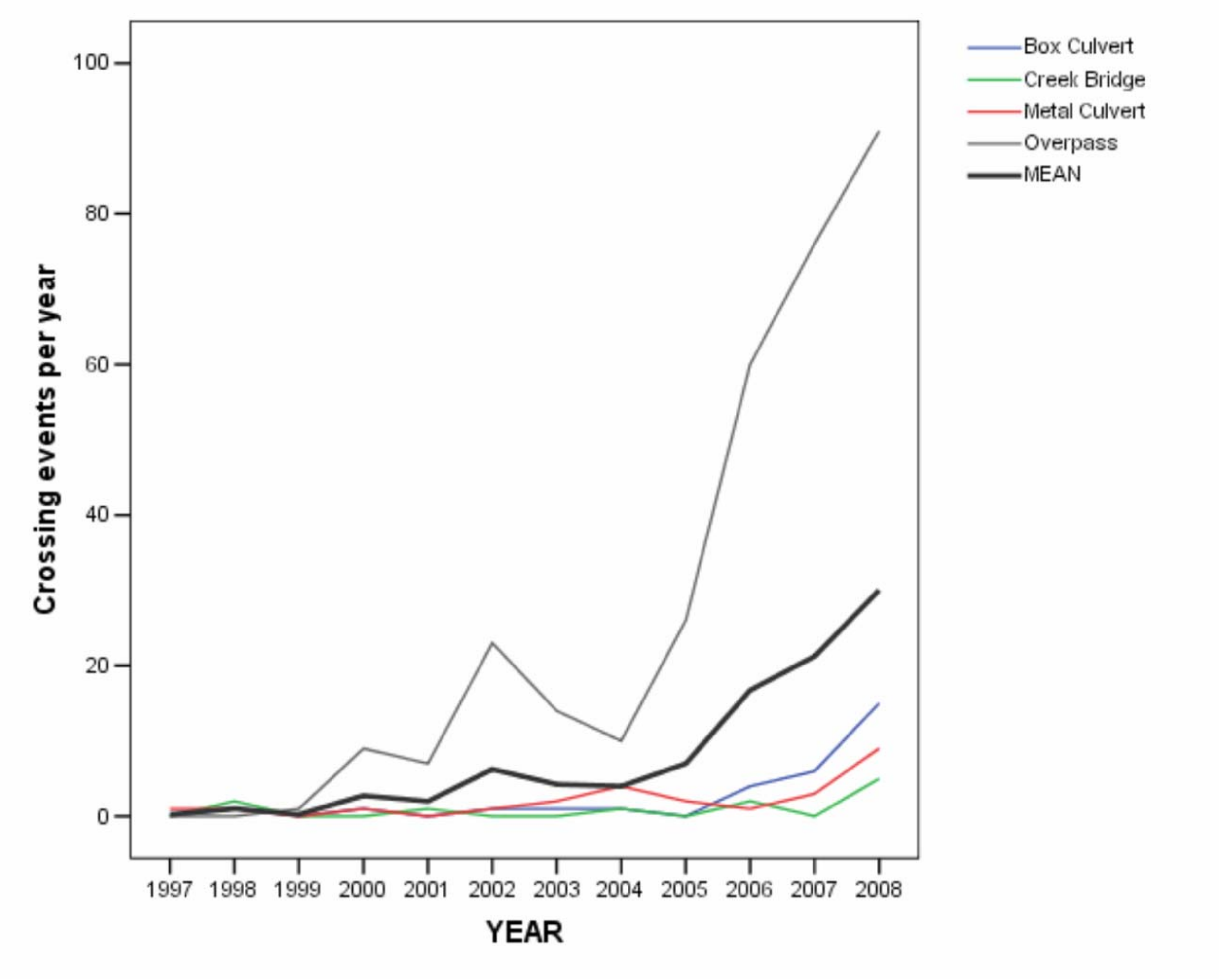

Figure 3.17: Number of grizzly bear crossing events by crossing structure design type on Phase IIIA from 1997 to 2008.

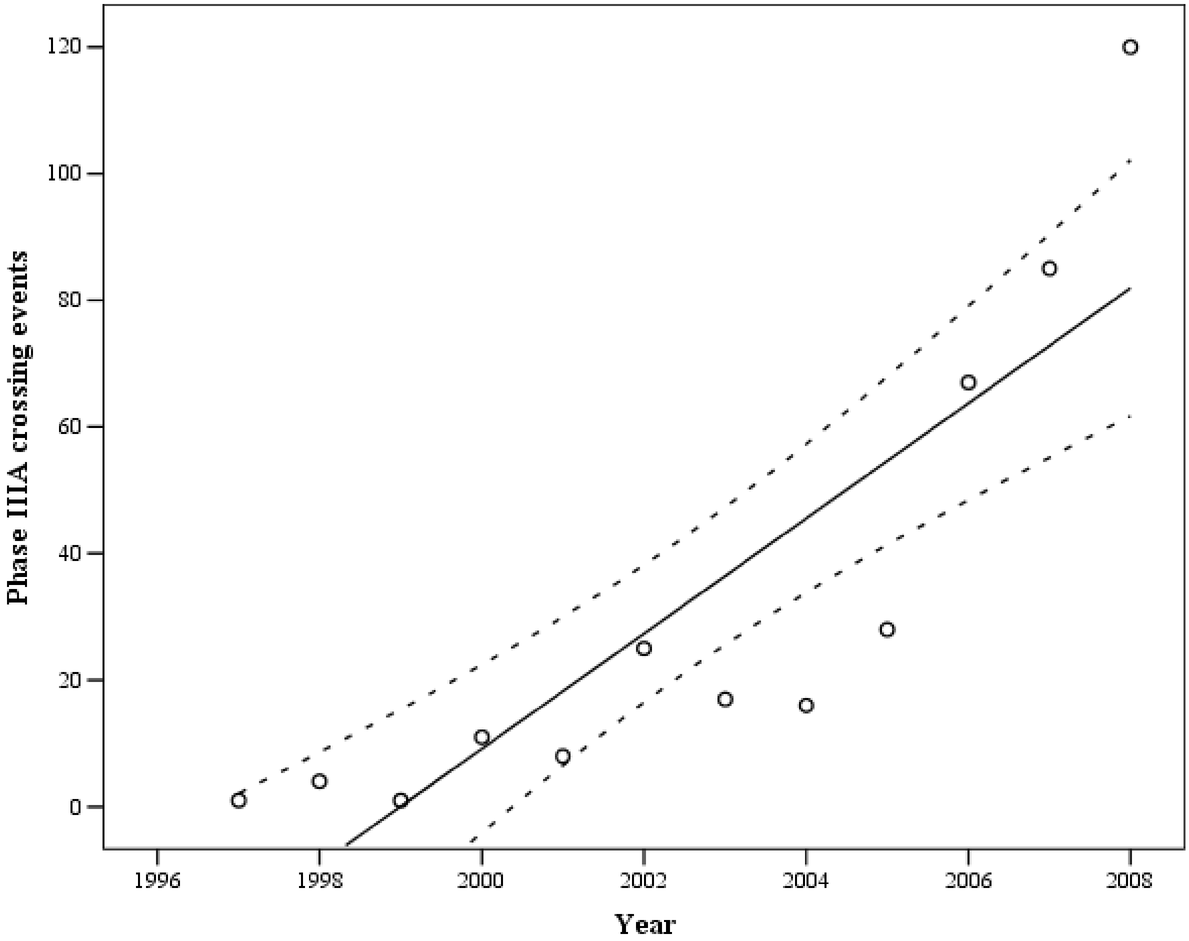

Figure 3.18: Total number of grizzly bear crossing events (open circle) on Phase IIIA from 1996 to 2008, with confidence interval (dotted line) and fitted line (solid line).

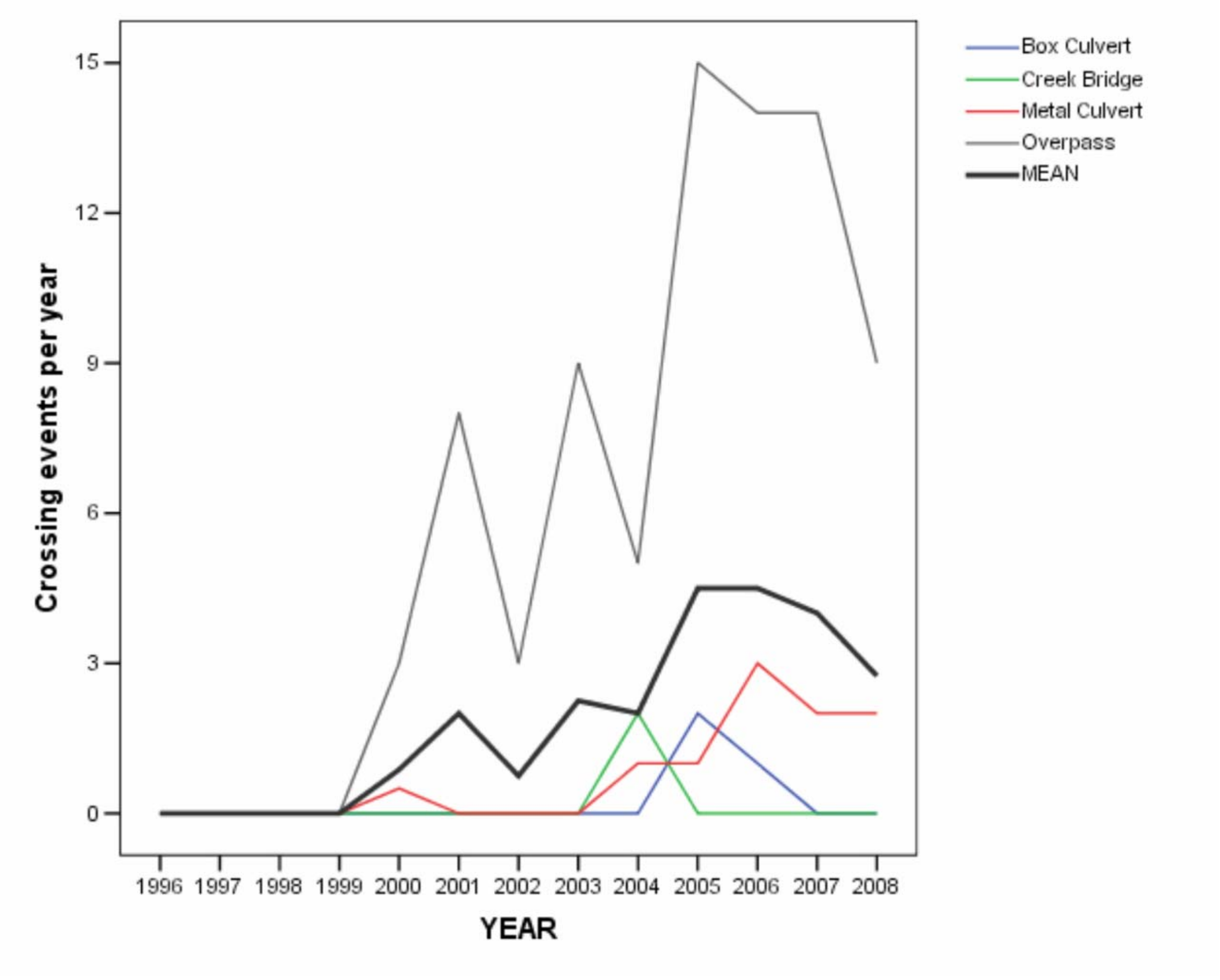

Figure 3.19: Number of moose crossing events by crossing structure design type on Phase IIIA from 1997 to 2008.

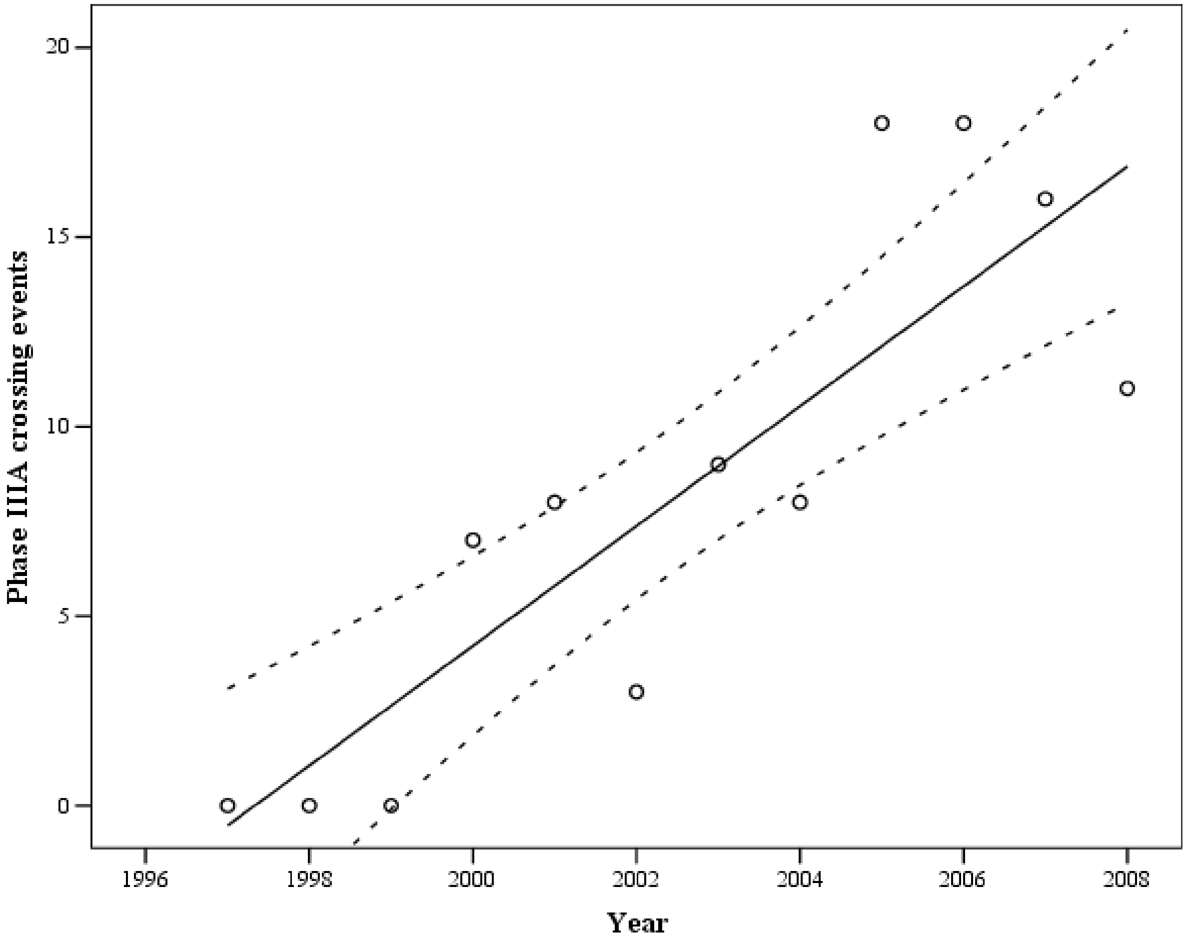

Figure 3.20: Total number of moose crossing events (open circle) on Phase IIIA from 1996 to 2008, with confidence interval (dotted line) and fitted line (solid line).

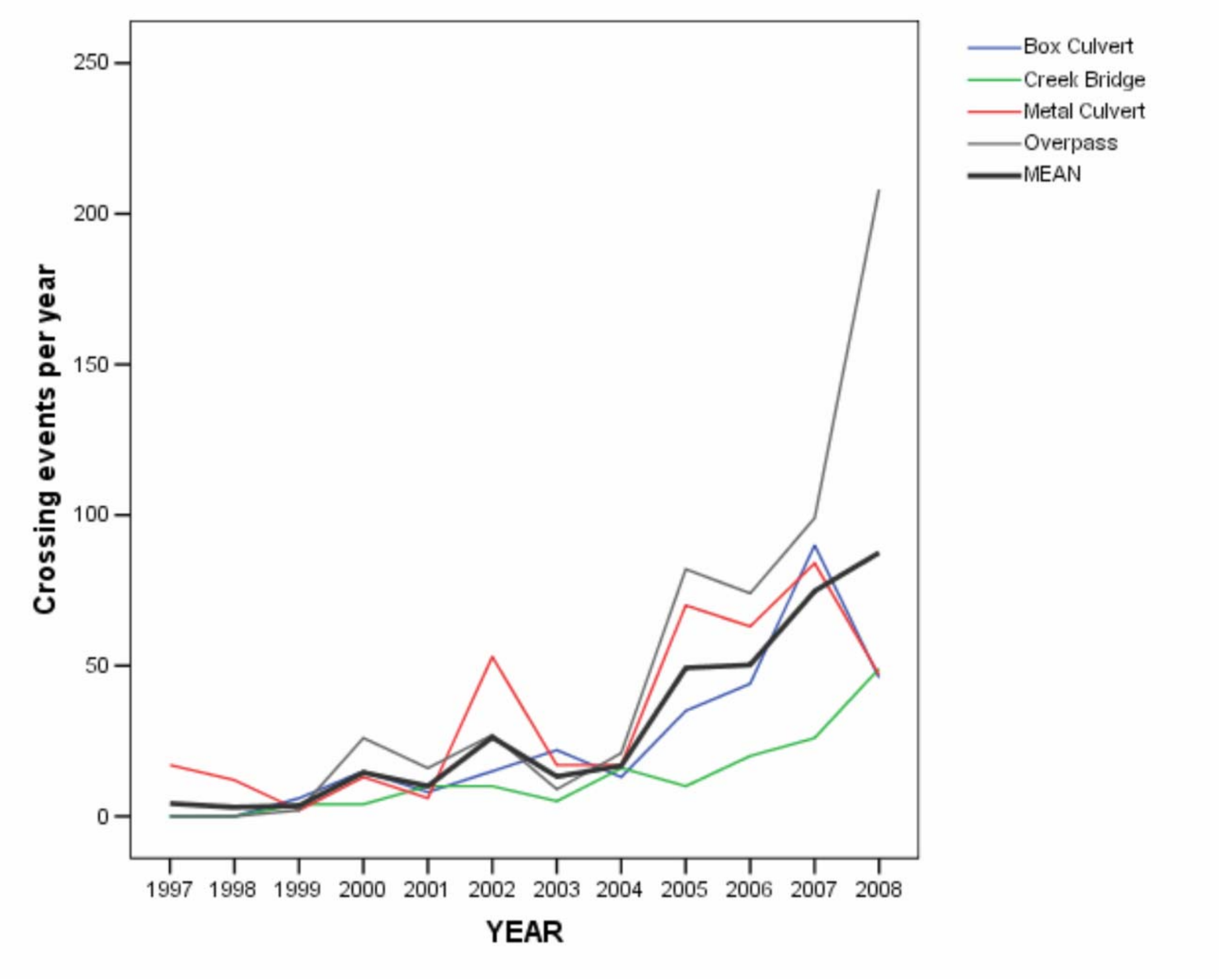

Figure 3.21: Number of wolf crossing events by crossing structure design type on Phase IIIA from 1997 to 2008.

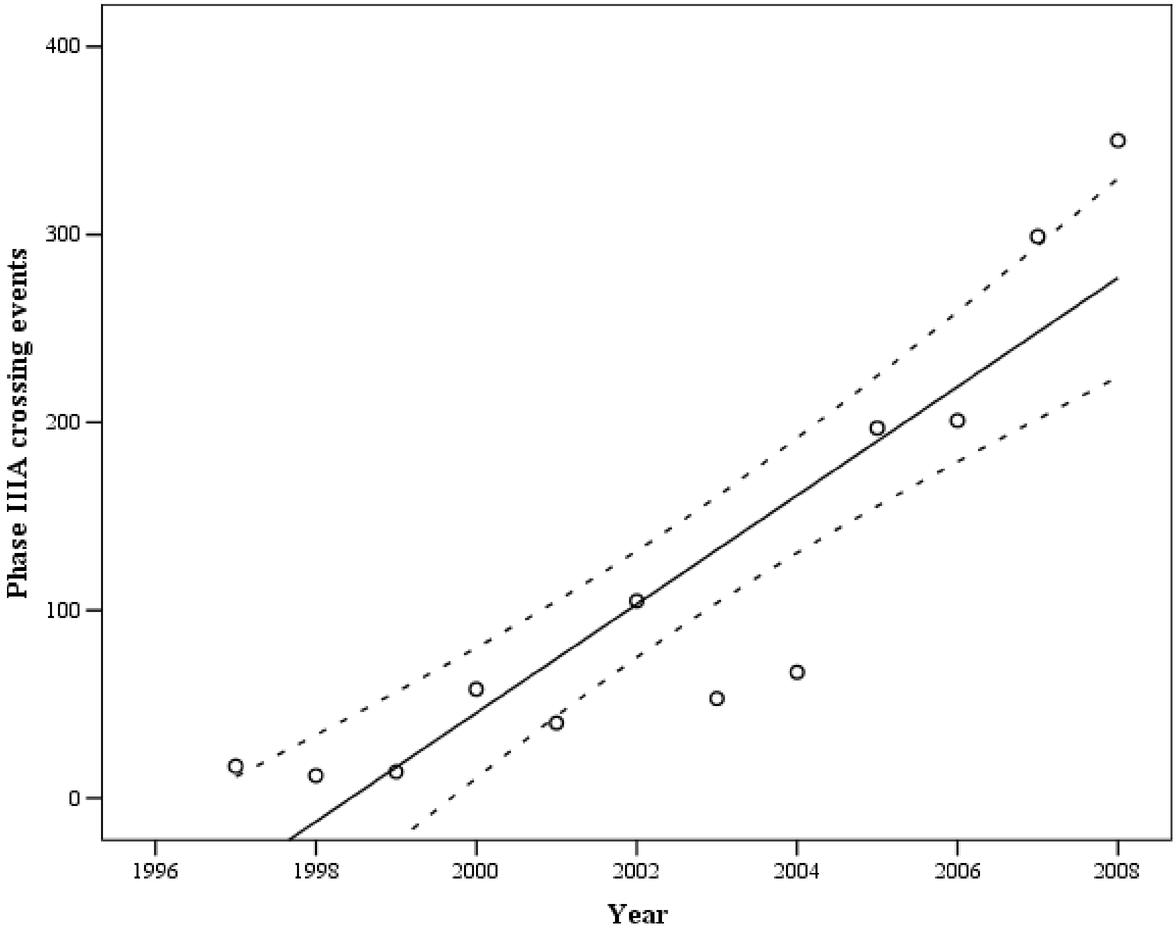

Figure 3.22: Total number of wolf crossing events (open circle) on Phase IIIA from 1996 to 2008, with confidence interval (dotted line) and fitted line (solid line).

3.8.3. Use of crossings by design type

What is clear from these figures is that the relationships between the design types used by the eight species are relatively constant over time. This suggests that use of a coefficient of variation, which assumes that individuals are moving through a greater variety of crossing structure types as time goes on (i.e., they are adapting), would not be a reliable method to measure adaptation. The figures above show that there are strong preferences (i.e., selection) for design types of wildlife crossing structures and they are consistent over time. The level of use may change at individual crossing structures, but overall the response to wildlife crossing design type does not change and has been relatively constant during the 12-year period.

The most consistent species in terms of use of crossing design types are deer, elk, moose, grizzly bears, and wolves. The relative use of crossing design types by these five species varied slightly or not at all during the entire 12-year period. The proportion of use by crossing design type for cougars, black bears and coyotes, however, changed markedly from year to year. Cougars were found to alternate between box culverts, metal culverts and creek bridge underpasses, while the wildlife overpasses were consistently used least of all (Figure 3.9). Black bears alternated between box culverts, metal culverts and wildlife overpasses, while creek bridge underpasses were consistently the least utilized (Figure 3.7). Last, the highest relative proportion of crossing structure use by coyotes alternated between box culverts and metal culverts, while wildlife overpasses and creek bridge underpasses were consistently used the least Figure 3.11). It is noteworthy that these three species, which appear to be the least consistent in crossing design selection, are the same species that we found to be affected most by larger conspecifics when using the wildlife crossings (see Section 3.7.2, *Interspecific patterns*…). These species are most subject to displacement and predation by the larger conspecifics in the study area (grizzly bear/black bear; wolf/cougar; and wolf/coyote). This may suggest that cougar and black bear preference for smaller wildlife crossing structures (Clevenger and Waltho 2005) is less a function of selection and more influenced by sharing of wildlife crossing structures with larger conspecifics in the study area.

3.8.4. Long-term trends

We plotted the total use of Phase IIIA crossing structures during the 12-year period and found usage trends increasing for four of the eight species, stable for two species, and decreasing for two species. Deer, moose, grizzly bears and wolves had increasing trends in use during the 12-year period and all were strongly positive increases with few outliers (Figure 3.13, Figure 3.17, Figure 3.19, and Figure 3.21). Although cougar and coyote had stable trends over time, their annual use was highly variable (Figure 3.10 and Figure 3.12). Elk and black bear use decreased over time, and the trends were highly variable with many outliers (Figure 3.8 and Figure 3.16).

3.8.5. Duration of adaptation and learning periods

The last part of this section examines the annual pattern of Phase IIIA crossing structure use from scatterplot figures shown above to estimate the duration of adaptation and learning periods. We examined the scatterplot for each species and identified the length of time required for use of crossing structures to reach an initial inflection point or asymptote (see above) since mitigation inception in 1997. We refer to this as the initial period. For the eight species we determined the number of years of monitoring that was required to reach a discernable initial inflection point.

For example, in grizzly bears initial inflection occurred after six years, whereas for black bears it occurred after three years (Figure 3.18 and Figure 3.8, respectively). For several species there was a second inflection point that closely followed the first. We determined the number of monitoring years to reach the second inflection point, as it may more accurately represent the adaptation period. The number of years that characterize the initial (first inflection) and second (subsequent inflection) adaptation periods for the eight species are shown in the scatterplot graphs above (Figure 3.8, Figure 3.10, Figure 3.12, Figure 3.14, Figure 3.16, Figure 3.18, Figure 3.20, Figure 3.22) and summarized in Table 3.12. The estimated initial adaptation periods range from three years (cougar, black bear) to six years (grizzly bear, wolf). More liberal estimates of adaptation periods characterized by the second period range from three years (cougar, black bear) to nine years (grizzly bear, wolf). The average estimated initial adaptation period for the eight species was 4.4 years, while the average second period was 5.9 years.

Table 3.12: Number of monitoring years estimated for adaptation to wildlife crossing structures for eight species of large mammals in Banff National Park, 1997–2008.

Species	Initial period (years)	Second period (years)
Deer	4	6
Elk	4	6
Moose	5	7
Cougar	3	3
Black bear	3	3
Grizzly bear	6	9
Wolf	6	9
Coyote	4	4
Average (± SD)	4.4 (1.2)	5.9 (2.4)

The estimates provided results from a much longer time-series of data than used previously, yet they are remarkably comparable to our earlier estimates derived from four to five years of monitoring for carnivores and approximately three years for ungulates (Clevenger and Waltho 2003). The results we present are also congruent with data we presented earlier in the report based on four winters of snow tracking around newly constructed and established wildlife crossings (see Section 3.7.3, *Wildlife response to new*…).

The value of long-term monitoring of the TCH Phase IIIB is critical to the maintenance of wildlife populations in Banff and the national park ecological integrity objectives (Banff Bow Valley Study 1996; Parks Canada 1997; Golder Associates 2004). Monitoring for Phase IIIB will be particularly important given the presence of species of high conservation concern, such as wolverine, lynx and grizzly bear. Currently there is virtually no information with respect to how two of these three species respond to crossing structures (wolverine, lynx). Thus, we recommend that monitoring of the TCH Phase IIIB wildlife crossings be carried out for a minimum of five years and preferably a longer period to be able to reliably assess crossing structure performance in meeting the ecological objectives of the twinning project.

What have we learned from long-term monitoring of the Banff wildlife crossings? This will be answered in more detail in the following section but simply stated, much has been learned with regards to the right half of the scatterplot graphs, after the apparent peaks in crossing structure use in 2000–2002. We've also learned how use fluctuates over time. By examining time-series data from multiple species we have a much better understanding of what are the key factors that drive the observed patterns and the inter-species interactions and relationships regarding wildlife crossing use.

3.9. From 2002 to 2009: What we have learned from continued monitoring

Since 1996 our research on the effects of roads and mitigation measures on wildlife populations has been conducted in the Canadian Rocky Mountains, centered in the Banff and KYLL Field Units. This is the longest-running research project in the world that specifically investigates solutions that help reduce the conflicts between busy highways, wildlife conservation, and habitat connectivity.

The wildlife crossings in Banff are a model of worldwide importance. The quality of science that went into their design and construction and the contribution it is has made to the critical and emerging field of road ecology is undisputable. Most Canadians remain largely unaware of these accomplishments and the far-reaching impacts the Banff wildlife crossings have had on influencing sustainable transportation practices worldwide. Even within the Parks Canada Agency, people are largely unaware of the impact the Banff research results have had on planning and design of highway mitigation outside the park boundaries. The need to increase public and community awareness of the Banff research results and benefits of the wildlife crossing mitigation resulted in the Banff Wildlife Crossings Project (BWCP) focusing partly on education and outreach initiatives (see Section 10, *Outreach & Education*).

From the project inception in 1996 until 2002, funding for the research and monitoring of the TCH mitigation was provided entirely by Parks Canada's Highway Service Centre. The research project responded with a rigorous, five-year study documented in a >400 page report to Parks Canada (Clevenger et al. 2002). Once this initial phase of monitoring was complete, Parks Canada scaled back funding to maintain only basic monitoring of the Phase I, II and IIIA crossing structures, with little in the way of support for a continued research program and personnel. In 2002, Tony Clevenger became affiliated with WTI. In 2004, he obtained research support from the Woodcock and Wilburforce Foundations. In 2005, the Woodcock, Wilburforce and Kendall Foundations, and WTI approached Parks Canada's senior managers in Banff and KYLL Field Units with a proposal for continued monitoring and research. A three-year partnership agreement was formalized between the parties to support the BWCP. The research continued to focus on systematic year-round monitoring of the Banff wildlife crossings. However, new research began investigating whether populations benefit from the wildlife crossings. This report covers the work conducted as part of that partnership agreement.

Twelve years is longer than most research projects are conducted (Figure 3.23) and a long time to dedicate to a specific research topic in one study area. There are many valid reasons to justify a long-term approach to the Banff research, but the main reason is the emerging nature of road ecology research worldwide and the extent of what is unknown about road impacts on wildlife populations (Forman et al. 2003; Transportation Research Board 2002; National Research

Council 2005). The long history of TCH mitigation projects, the unrivaled number and types of mitigation measures, all embedded within a study area teeming with baseline ecological data, securely places Banff on the leading edge of road ecology research. Few, if any, places in the world are able to carry out this kind of research with the intensity and complexity as Banff, entirely due to the uniqueness of the attributes of the study area. Having long time-series data is one of those key attributes. As time passes, the value of the research data increases exponentially, given the increased opportunities to investigate novel research questions that can directly influence management and planning of transportation infrastructure designed to preserve the integrity of natural landscapes and ecosystems.

Figure 3.23: Duration of ecological studies reported in the literature (modified from Tilman 1989).

3.9.1. Added value of long-term monitoring

The value of long-term research and monitoring is indisputable (Hobbie et al. 2003; National Research Council 2005). However, how do we explain why it is important to monitor crossing structures for more than just two to three years? And what was learned from 12 years of monitoring that would not have been learned if monitoring was terminated earlier? The research on adaptation and learning periods presented earlier are prime examples of how long time-series data enables greater confidence in management decision-making with regard to mitigation planning and design.

Our report compiling work conducted between 1996 and 2001 provided novel and what then was seen as compelling results on patterns and trends of wildlife crossing structure use by large mammals based on five years of data (Clevenger et al. 2002). At that time, five years seemed to be an extraordinarily long time from which to examine multi-annual trends and patterns of animal use of crossing structures. It was evident that even with five years of data, despite this being unprecedented, only part of the picture could be explained. The question begged: What would the graphs look like if there were five additional years added to the x-axis?

Now that those five years (and more) have been added to the graph, we have a much clearer picture of species' patterns of use and variability over the years. We are gaining a better, more reliable understanding of interspecific interactions at the crossing structures. With additional long-term monitoring data we are able to confirm with greater certainty the importance of crossing structure design types and how adjacent habitat elements influence use. We strongly emphasize the importance of gaining more reliable knowledge and greater accuracy in data analysis of wildlife crossing selection (Romesberg 1981; Sinclair 1991; Anderson 2001).

We recommend continuing analyses of the factors that facilitate use of wildlife crossings. First, we recommend repeating the analysis on Phase IIIA (Clevenger and Waltho 2005), nearly 10 years after the initial analysis was completed. Now after 11 years the Phase IIIA crossings are well established and provide contrast to the previous analysis conducted when they were new. After three years of monitoring the Phase IIIB crossings we recommend a second analysis. The Phase IIIB analysis will shed important light on the factors that facilitate animal movement at the wildlife crossings and further examine whether relationships previously found between species and crossing structure attributes at new wildlife crossings (Clevenger and Waltho 2005) are supported. These analyses will provide stronger inference regarding the factors explaining wildlife crossing structure use, and lead to more science-based information for crossing structure design and planning in future twinning projects in the KYLL Field Unit.

3.9.2. Grizzly bear use of the Banff wildlife crossings

One of the more convincing arguments for long-term monitoring comes from data collected on grizzly bear use of the Banff wildlife crossings and is illustrated in Figure 3.24, which depicts the increased use by bears of the structures over the 12 years of monitoring. These data demonstrate the importance of long-term monitoring for developing sound recommendations for planning the design of wildlife crossing mitigation.

The histogram never fails to engage the public, transportation practitioners and scientists, and tells a convincing story of the value of long-term monitoring. A recent article in the local newspaper (Rocky Mountain Outlook, March 12, 2009) covered the results and was a highly effective communication piece and "good news story" for Parks Canada.

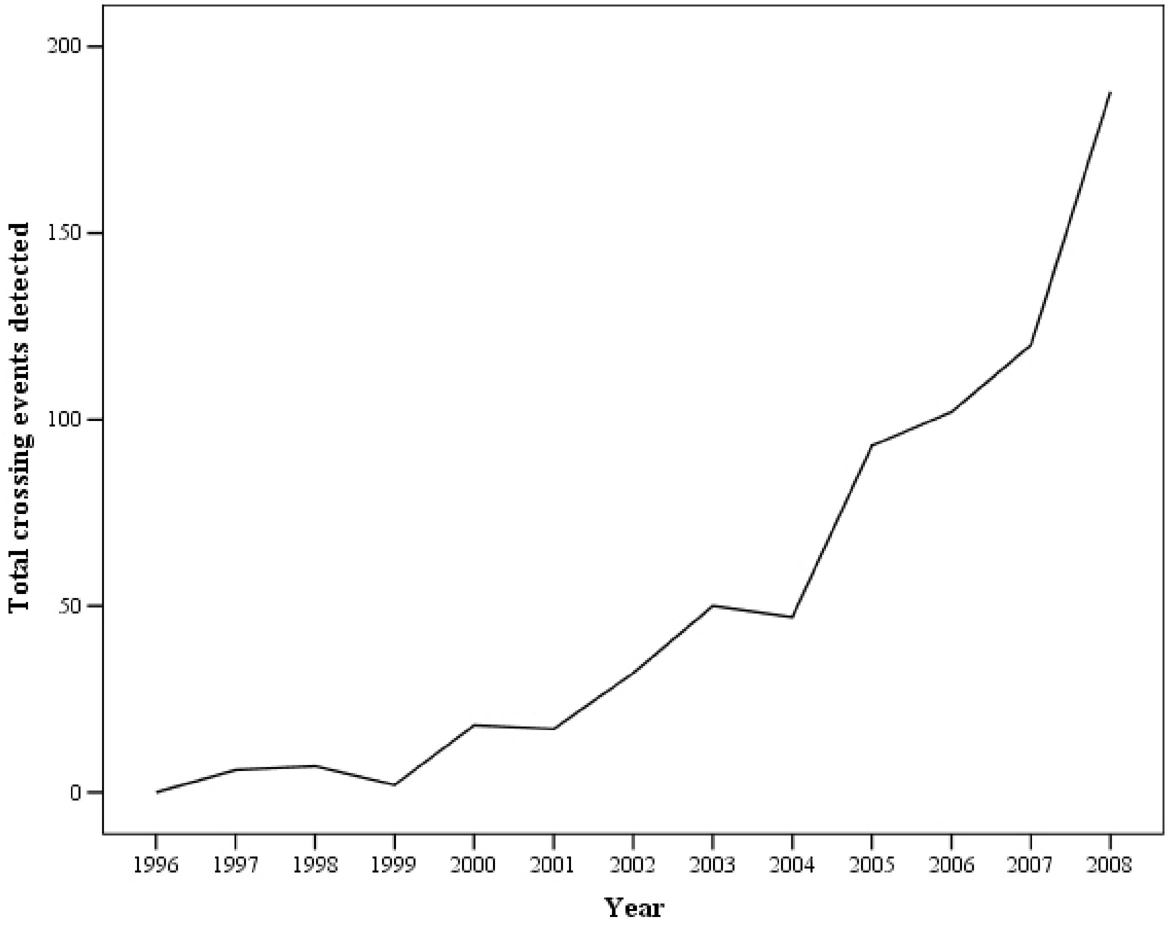

Figure 3.24: Total crossing events detected by grizzly bears at the Banff wildlife crossing structures between 1996 and 2008.

Grizzly bear use of the crossing structures has been increasing since monitoring began over 12 years ago, from only six crossings in 1997 to 177 in 2008. Several factors likely explain this relationship. First, the grizzly bear population appears to have increased over the last 12 years, although some sources within Parks Canada believe the population has remained stable. Nevertheless, even if the grizzly bear population is increasing, it has not increased as steeply as grizzly bear use of wildlife crossings indicate. Second, grizzly bears are likely learning that crossing structures provide safe passage across the TCH and thus may be repeat users. And third, we have documented many family groups using the crossing structures, which means that young bears are learning to use the crossings when part of a family group (established users plus new users). When these subadult bears disperse from the maternal range they continue to use the crossing structures, as they are familiar and feel secure using them.

Most importantly, the grizzly bear data clearly underscore the importance of more than two to three years of monitoring in order to make informed recommendations. Recommendations for wildlife crossing structure design based on short monitoring periods of three years or less will likely result in overbuilt structures and more mitigation infrastructure, which means greater cost, than is necessary. If our recommendations for Phase IIIB wildlife crossings (Clevenger et al. 2002) were based on only three years of monitoring, we would have concluded from the amount of grizzly bear use that the Phase IIIA crossing structures were not functional at the level of individuals (total number of crossings) or population (evidence of demographic benefits). In turn, our recommendation would have been for many more wildlife crossing structures for Phase IIIB for greater highway permeability. The recommended crossing structures would have been significantly larger in size than our current recommendations, and would have resulted in a twinning project budget that was double the current cost of Phase IIIB mitigation.

Funding monitoring that is designed to encompass wildlife adaptation and learning periods (e.g., five to seven years) will be substantially more cost-effective in the long run than a short-term monitoring approach destined to provide spurious results and less reliable data for future highway twinning mitigation planning and design. The economics alone are convincing. Monitoring costs are at most $200,000 to $300,000 per year, while the margin of error in mitigation planning based on flawed monitoring data can translate into many millions of dollars or nearly double an entire twinning project budget.

3.9.3. Detection of species of conservation concern

Monitoring of the wildlife crossing structures for more than just a few years has allowed for documentation of wildlife crossings by species of high conservation concern. Wolverine and lynx, as well as boreal toads, were found using wildlife crossing structures. These are the only known detections of wolverine and lynx using wildlife crossings in North America. Although these few data do not allow for any clear recommendations on their wildlife crossing needs, the fact that these species were detected using crossings is a positive sign for any agency or manager tasked with their conservation around highways.

The TCH Phase IIIB mitigation measures are designed to provide habitat connectivity and genetic interchange for key species such as wolverine and lynx (Golder Associates 2004). These species were rarely detected using the existing wildlife crossings primarily due to their relative scarcity in the lower Bow Valley. However, given their greater abundance in the middle and upper Bow Valley, wide-ranging behaviour and low densities, sufficient monitoring periods will be needed to assess the performance of mitigation measures for these rare species.

3.9.4. Cameras as a cost-effective technology

Over the years we have discovered remote cameras to be a cost-effective means of conducting crossing structure monitoring (see Appendix A, Ford et al. in press). This method has implications for future monitoring of wildlife crossings in Banff and for other resource managers planning monitoring programs elsewhere. Our analysis comparing monitoring techniques was only possible given the long-term nature of our project, the tools and infrastructure the project has developed over the years to equip so many crossings with remote cameras, and the personnel to design the analysis. We believe these results will impact the way wildlife crossings are monitored in the future, in Banff and by others elsewhere.

The significance of the long-term monitoring data for transportation and natural resource management is made evident throughout this report. Devising a relatively low-cost method of monitoring wildlife movement that can be deployed at dozens of wildlife crossings will provide a cost-effective means for continued monitoring of wildlife populations and restoration of movement corridors across transportation infrastructure.

3.9.5. Population-level benefits of Banff wildlife crossings

If monitoring the Banff crossings concluded after five years, a rigorous evaluation of the genetic and demographic benefits of the TCH mitigation would not have been possible. When monitoring began in 1996 there was skepticism by many and criticism from within the local scientific community that the existing Phase I and II wildlife underpasses were not functional for wildlife passage, particularly for large carnivores (Banff Bow Valley Study 1996). The skepticism and concern regarding the performance of the Banff wildlife crossings grew over the ensuing years among the public and scientific community.

After several years of monitoring the crossing structures articles from the research project were published in scientific journals demonstrating that mitigation significantly reduced wildlife mortality and the crossings were being used frequently by nearly all large mammals in the Bow Valley (Clevenger and Waltho 2000; Clevenger et al. 2001b). The general perception that the Banff crossings were not ecologically functional began to disappear. Over time and with additional scientific research results published, the public, environmental non-governmental organizations and scientists became convinced from the data from our monitoring and research project that the Banff wildlife crossings were indeed effective in reducing wildlife-vehicle collisions and fragmentation of wildlife habitat. The Banff mitigation soon became recognized as a model for transportation planning, and the overpasses an icon for other aspiring mitigation projects in North America. The transformation from discredit to belief was not simple or swift; extensive time, effort and dedication were required to change public perception and opinion. This transformation was obtained through sound science and hard data delivered from our monitoring project.

The population genetics research conducted between 2004 and 2008 was a logical and necessary next step for our research project and Parks Canada management objectives. As mentioned earlier, a recent review article concluded that there is no evidence that wildlife overpasses provide genetic connectivity (Corlatti et al. 2009). Although many thousands of individuals had been documented using the Banff crossings, there was a glaring need to evaluate whether populations were benefiting from the TCH crossing mitigation and whether these were repeat individuals or a few adult males using the wildlife crossings. The population-level study was initiated as part of the continuing monitoring and research project supported by private conservation foundations and WTI. Later Parks Canada provided support through the National Office of Ecological Integrity funding and formation of the BWCP partnership. The results from our DNA-based study assessing genetic connectivity and population benefits will be the first objective study investigating whether wildlife crossing structures can mitigate demographic fragmentation of grizzly bears by a major transportation corridor.

The previous discussion is relevant to future monitoring of the TCH Phase IIIB mitigation. Short-term and sporadic monitoring lacking scientific credibility will usurp many years of dedicated research to gain public and stakeholder support for the TCH mitigation. The TCH Phase IIIB Environmental Screening report (Golder Associates 2004) is not a strict guide that Parks Canada must follow. Nonetheless, there is an obligation on the part of Parks Canada to use the Environmental Screening report recommendations to determine what level of information and quality of assessment is necessary to meet the agency mandate of maintaining and preserving ecological integrity in the park ecosystem (Parks Canada 1997).

3.10. Rationale for further monitoring

3.10.1. Introduction

The BWCP, under various names and funding arrangements, has managed to monitor wildlife movement across the TCH for over 12 years. In the last four years, several publications, reports and presentations have been produced using the data collected from this monitoring effort (see Appendix A). Nonetheless, there are additional management needs that require research, and funding is invariably difficult to secure. Therefore, resource managers will question why monitoring should be continued. Here we outline several important considerations that justify why and how long-term monitoring of the wildlife crossing structures should continue in both Field Units.

3.10.2. Unique information on population trends

Information from annual or seasonal counts of wildlife movement at the crossing structures can be used to document changes in the distribution and abundance of wildlife. Currently, only two species of large mammal are reliably censused each year in Banff. Elk are systematically counted on a regular basis and wolf populations are compiled from a variety of formal and informal sources. Aside from the crossing structure data, there is no other database of large mammal population trends in Banff. Comparable databases include ungulate pellet counts and corridor snow transect monitoring. The ungulate pellet count data have been shown to be inconsistent with both wildlife crossing structure and corridor snow transect data, cannot readily distinguish between deer species, and are only conducted every other year. Similarly, the corridor snow transect effort is unable to distinguish between deer species, is dependent on weather, is only conducted near the Banff townsite, and is unable to reliably detect species whose movements are seasonally dependent (e.g., grizzly and black bears). Other possible data sources for population trend monitoring include the recent pilot testing of cameras in the backcountry (M. Gibeau, Parks Canada, personal communication), similar to those used at the wildlife crossing structures for the past four years. However, this effort is focused on few species (carnivores primarily), temporally limited to summer months, and spatially restricted to trails.

There is no viable alternative to the long-term monitoring of wildlife crossing data. Monitoring of the wildlife crossings can alleviate most of the shortcomings in the databases described above, as:

a) Deer species are identifiable (through cameras);

b) Minimal field work is required (one field visit every two to three weeks);

c) Sampling along the entire Bow Valley (45 km and growing);

d) Species detection occurs year-round;

e) Species detection is weather independent;

f) Probability of species detection is high within the wildlife crossing structures, unlike backcountry cameras where animal movement is less constricted.

3.10.3. Incidental benefits to other resource managers

When our monitoring and research project began in 1996, park managers were unable to realize the value of long-term monitoring other than assessing wildlife crossing structure performance. After several years of monitoring, it became apparent that the monitoring data was important management data for evaluating the restoration of predator-prey interactions and their movements throughout the Bow Valley. The consistent, year-round monitoring data proved to be valuable for natural resource managers as it provided the only information on species occurrence, movements, reproduction and species' interactions along a 45-km transect (see Sections 3.3 and 3.4, *Summary data…*). The database remains the most comprehensive and reliable long-term data in the Banff Field Unit for monitoring changes in species distribution and abundance over time. This was clearly evident at a recent Montane Science workshop where the long-term wildlife crossing structure monitoring data was used to inform and support resource management actions in the Banff Field Unit.

3.10.4. Valuable information for public safety and managing wildlife–human conflicts

With most human and wildlife activity located in the valley bottoms, having current, reliable and localized data on the movements of carnivores helps wildlife managers improve visitor and wildlife safety. Updates emailed from the BWCP are used by the Banff Field Unit's human–wildlife conflict specialist to obtain real-time data on the movements, location and direction of travel of species or individual animals of management concern. Typically, the earliest documented movements of bears after winter denning are obtained from crossing structure monitoring and the information is used to inform the public about being aware of bears while hiking.

3.10.5. Are high-elevation, localized species adapting to highway mitigation?

Monitoring the wildlife crossing structures has produced thousands of documented passages by species common to the Bow Valley montane ecosystem, such as deer, elk, wolves and bears. However, recent developments in monitoring technology have improved our species identification and detection probabilities. For species that use the valley bottoms less frequently, it can be easy to miss the detection of important but rare, sporadically occurring movements. Species such as mountain goats, bighorn sheep, hoary marmots and pika (*Ochotona princeps*) are narrow-endemic species often restricted to a small geographic range. Their populations are demographically independent and naturally fragmented by intervening matrix habitat and require dispersal to maintain their metapopulations (See Section 7, *Dispersal requirements…*). Unlike the use of track pads, camera-based monitoring of the crossing structures will provide more reliable information documenting the movements and direction of travel of species with localized distributions needing to disperse across the TCH and Bow Valley.

3.10.6. Use of non-invasive survey methods

With the growing emphasis on non-invasive methods of wildlife research in Parks Canada, and the availability of increasingly powerful analytical tools, monitoring wildlife at the wildlife crossing structures will have an important role in biodiversity data collection in both Field Units.

There is a trend among animal-care committees at education and research institutions to encourage research methods that minimize harm to animals. Remote cameras, snow tracking and hair/DNA snagging devices are tools that have been tested and proven successful through the BWCP. These methods are not unique to wildlife crossings, but are advantageous here because the constricted nature of the crossings on animal movement facilitates high rates of animal detection.

3.10.7. Maintaining methodological rigor for future analyses

It is not always possible to envision how large-scale, long-term databases can be used. By providing a similar approach to monitoring over the coming years will put Parks Canada and the BWCP in a better position to build upon the data gathered the last 12 years. These data are unique worldwide, as no other highway mitigation project has been so closely monitored for such a long period as the TCH in Banff.

3.10.8. Leveraging funding with partners

The BWCP has been a successful partnership, merging common interests of private foundations, an academic research institute and a governmental agency. Annual partnership funding, on average, consisted of a 1-to-1 to 2-to-1 match for every dollar of Parks Canada funding. The ability to leverage Parks Canada funds with partnering organizations provides significant cost-benefits carrying out research addressing the national park mandate. Many foundations and private entities have added their support to this project in the past four years, including: Woodcock Foundation, Wilburforce Foundation, Kendall Foundation, Calgary Foundation, Alberta Conservation Association, Mountain Equipment Cooperative and the National Fish and Wildlife Foundation. Without their support, much of the research, technical transfer, outreach and communications would not have been possible. For future funding, a broad constituency of support will also be needed.

3.10.9. Reducing the costs of monitoring

The main reason put forth for terminating TCH crossing structure monitoring in the Banff Field Unit (Phases I, II and IIIA) is based on cost. Reducing costs can improve the likelihood of finding financial and management support. However, reduction in monitoring efforts can compromise the quality of data collection.

There are a number of options for reducing the costs associated with monitoring the wildlife crossing structures:

- Institute camera-only monitoring
- Conduct site checks less frequently
- Employ a more fuel-efficient vehicle
- Make use of citizen scientists
- Conduct monitoring in alternating years

We recommend, and already adopted as of October 25, 2008, camera-based monitoring supplemented by track pads. This has enabled us to reduce costs as crossing structures now need to be visited only every two to three weeks to change batteries and download images. An additional task associated with camera-based monitoring that track-pad monitoring did not entail is the need to process images collected from the cameras. Image processing can take anywhere from 5 minutes to 1 hour per camera for each two- to three-week monitoring interval. Details on costs of camera-based monitoring are provided in the paper by Ford et al. (in press).

3.11. Future monitoring methods: Management options and recommendations

3.11.1. Introduction

For the past 12 years the BWCP has monitored wildlife crossings using track pads, which consist of sandy-loam substrate. There are two to seven track pads at each underpass and one large track pad at each overpass. Track pads were visited on average every two to four days for most of these 12 years. Inevitably, most track pads become windswept, flooded, covered with snow or washed out from rain. Each year most of the track pads need to be reconditioned, either by importing new material or by spending extra effort to loosen the local material at the crossings.

Over the 12 years, the BWCP has increasingly begun to supplement track pad data through the use of remote cameras. Remote infrared-operated 35mm cameras were initially used on the two wildlife overpasses as a means to improve species detection, since inclement weather would obliterate tracks in track pads. At first this enabled us to better understand animal behaviour, timing and group size as they used the overpasses. Later, as remote digital cameras came onto the market, we replaced the 35mm cameras on the overpasses and incrementally began placing cameras at select wildlife underpasses. Although we have no supporting data, we believe the use of remote digital cameras greatly improved the efficacy of species detection on the wildlife overpasses. It also became apparent that cameras were able to detect species movement from animals not detected on the track pad, generally due to poor quality tracking material or errors in track identification (i.e., wrong species). In 2007, additional cameras were deployed at wildlife crossings where hair/DNA sampling of bears took place. Cameras provided information on bear behaviour at the hair/DNA snagging devices and helped improve our hair/DNA snagging success rate as we learned how some bears avoided the barbed-wire. By examining detection rates of animals while using track pad and cameras simultaneously, we were able to better understand the characteristics that lead to detections by different species and crossing structure configurations (see Ford et al. in press). This methodological analysis has enabled us to provide empirically based recommendations for designing future monitoring studies along the TCH.

3.11.2. Management options

There are three basic approaches for monitoring wildlife crossings along the TCH: cameras, track pads, or both. Within these approaches it is possible to structure the data collection along a spectrum of sampling intensities. At one end of the spectrum, sampling intensities are low and monitoring is diffused over time or space. At the other end, crossing structures are monitored so as to minimize data loss with a visit to each site every other day. For example, during bear hair/DNA data collection, crossing structures were visited every other day to reduce the chances of missing a hair sample due to wind or rain events.

Ford et al. (in press) highlighted the benefits and limitations of each approach (Table 3.13). In general, cameras outperform track pads by most performance metrics. The only instances where track pads are preferred are at sites where security (e.g., high risk of theft or vandalism) is a concern. One of the most important factors limiting the use of track pads is the frequency of field visits required. Field visits need to occur in intervals of under four days to reduce the chances of data loss as tracks disappear from erosion. Furthermore, when more than six individuals use a single track pad, we found our detection accuracy dropped by approximately 50 percent. Thus, monitoring based on track pads also needs to keep the intervals short enough so as to minimize the number of track impressions that need to be interpreted. Increasing the frequency of visits to each site increases the cost of several project expenditures such as wages, fuel, and equipment repair.

If track-pad-only monitoring is to continue, there are few options available to reduce the number of visits to a site. Sampling could be performed on alternate years or at alternate sites within years. The alternate year option dramatically reduces our ability to detect changes over time. Data collection for analysis of factors influencing animal passage will be compromised by unequal sampling effort, thus reducing the strength of our inferences about how animals respond to crossing structures attributes and design. The alternating year option also reduces the benefits of monitoring for informing human–wildlife conflict specialists. The alternating sites option may incur cost savings by reducing sampling size, however, logistical requirements for the monitoring, such as a vehicle and field assistant, are still required. It takes about 10–20 min per crossing structure to collect all the data through both methods. By reducing the number of stops in the day without reducing the distance traveled, there will only be a cost savings of a few hours of an assistant's wage. This option will have the least effect on reducing cost savings while at the same time compromising data quality and integrity of the long-term monitoring effort.

Camera-based monitoring provides more options for sampling intensity, is cheaper over the long term, and produces more information about wildlife use of the crossing structures than track pads. The quality of camera data does not change with time or with the number of animals using the crossing structures. So long as the batteries are charged, the camera is as likely to detect the first of 100 elk as it is the last.

One of the main drawbacks to cameras, like any digital technology, is the consequences of device failure or malfunction. Compared to simply viewing and raking some sandy soil on track pads, the use of cameras has many more links in the procedural chain that need to be maintained. Properly recording an animal in the database depends on the following:

- Batteries need to be charged and installed correctly.
- Compact flash cards need to be installed correctly, and site and time data need to be programmed correctly on the camera.
- The camera needs to function in all weather.
- The lens cannot be obstructed.
- People cannot steal or vandalize the camera.
- The animal has to pass slowly enough and at the correct distance from the camera to be detected.
- Technicians need to properly file the raw camera images.
- Images need to be interpreted correctly by the technician performing the classification.

In our experience over the past two years using digital cameras, each of these requisites have been at issue at least once. The frequency of camera failure is decreasing however, as we learn how to place cameras in areas that will maximize recording of crossing events. One important consideration is the role of the field assistant in providing high quality data. The field assistant must sort through thousands of photos and have the patience and work ethic to consistently apply standardized image classification protocols. Additionally, the cost of image interpretation is directly linked to the number of individuals using the crossing structure over the two-week period, from a few seconds of processing when no animals were detected, to a few hours when herds of elk loitered beneath the underpass. Overall, camera-based monitoring is a more flexible and less expensive approach to detecting crossing events than track pads, but still can only provide an estimate of animal use under certain conditions.

3.11.3. Recommendation

The current approach to monitoring by the BWCP is the one recommended for future monitoring along the TCH Phase IIIB. Our primary method of monitoring is the use of remote cameras and we supplement these data with information from track pads.

We visit each camera every two weeks to download images, exchange batteries and check for tracks. Battery life in the older cameras that use AA cells is at least three weeks, but we found that changing them every two weeks provides a balance between efficiency and potential data loss from camera failure, particularly during the winter. We found that newer camera models that use C-cell batteries can operate during the winter for at least six weeks. One older camera has been converted from using 8 AA batteries to 8 C cells. This camera had its batteries changed in early December of 2008, and as of May 21, 2009, there was no indication that battery life had declined more than a few percent. We expect that battery life for all cameras will be even longer as the season warms, though more crossing events means that cameras will be taking more pictures and using more battery power.

We continue to monitor crossing structure use with track pads for two reasons. First, and most importantly, track pad data provides a safeguard against camera failure. Though an accurate count of individuals from an elk herd passing through an underpass over five days may be impossible to pick up without a functioning camera, a lone grizzly bear track is usually obvious. The second reason is that some sites we monitor (e.g., Five Mile bridge) receive too much human traffic to install a camera without using high levels of security. In this case, a track pad is still used to detect animal movement.

Table 3.13: Benefits and limitations of cameras and track pad methods for monitoring wildlife crossing structures.

Issue	Track pads	Cameras	Recommended method to address issue
Detections of coyotes and grizzly bears	Significantly higher probability of detection	Significantly lower probability of detection	Track pads
Detections of elk and deer	Significantly lower probability of detection	Significantly higher probability of detection	Cameras
Detections of black bears, cougars, wolf, bighorn sheep and moose.	Work slightly better for wolves, bighorn sheep, and moose	Work slightly better for black bears, and cougars	Either method
Monitoring interval	2–7 days	>2 weeks	Cameras
Disturbance to wildlife	Decreases inversely to duration of monitoring interval	Infrared camera flash may disturb wildlife at night	Cameras
Species identification	Limited by species groups and track pad condition	High confidence	Cameras
Temporal resolution of crossing events	Increases with number of visits to the site	Does not depend on the number of visits to the site	Cameras
Start up costs	Cheaper	More expensive	Track pads
Operational costs	More expensive	Cheaper	Cameras
Maintenance	Higher (at least once per year)	Lower	Cameras
Weather dependency	Wind, snow, rain and icing can negatively affect track pad conditions	Condensation or frost can cover the lens	Cameras for overpasses, track pads for underpasses
Security	No risk of theft and vandalism	Some risk of theft and vandalism	Track pads

4. GENETIC CONNECTIVITY OF GRIZZLY AND BLACK BEAR POPULATIONS ACROSS THE TCH

4.1. Introduction

Engineered wildlife crossings are increasingly used by transportation agencies to meet the needs of animals to cross roads with reduced hazard to motorists and wildlife (Clevenger and Waltho 2000; Gagnon et al. 2007). Studies have demonstrated that a broad range of species will use wildlife crossing structures (Foster and Humphrey 1995; Mata et al. 2005) and thus can lead to reduced road mortality for some species (Clevenger et al. 2003; Dodd et al. 2007; Huijser et al. 2007). One would intuitively expect these measures to enhance the viability of wildlife populations due to an increase in survival.

Until now, research has largely focused on the level of use that crossings receive from a range of wildlife species, with the assumption that the greater the use, the more successful the crossing structure. Questions remain, however, as to whether these measures actually improve population viability and which species might benefit from them. Previous studies have yet to go beyond showing that various species will use crossing structures. But use does not necessarily translate into the flow of genes, viable populations and maintenance of ecological processes that characterize functional connectivity (Crooks and Sanjayan 2006; Hilty et al. 2006; Kindlmann and Burel 2008). Investigation of these factors can provide evidence-based data on whether populations benefit from wildlife crossing mitigation, and thus whether support for the continued and growing implementation of wildlife crossings by transportation and resource management agencies is warranted. Research that addresses these unanswered questions will require new methods that allow assessment of connectivity for populations, communities and ecological processes.

Obtaining empirical data to evaluate population benefits for some species can be problematic. Population-level data can be difficult to obtain because wide-ranging, fragmentation-sensitive species such as bears, cougars and wolverine typically are elusive and occur in relatively low densities (Weaver et al. 1996). At present, the most reliable method involves live-trapping, marking and closely monitoring the movements of individuals within a population, but for logistical reasons this is impractical. Evaluate whether crossings provide population-level benefits (adult male and female movement across roads; juvenile dispersal, survival and reproduction of offspring) using telemetry studies would require a decade or more of intensively tracking animal movements. This is an inordinately long time for management to wait for answers from research.

Molecular techniques now make it possible to identify species, individuals, their genders, and genetic relatedness from hair samples collected through non-invasive genetic sampling (NGS) methods (Foran et al. 1997; Woods et al. 1999; Long et al. 2008). NGS techniques potentially enable the measurement and analysis of parameters related to the dispersal of individuals, viability of populations and ultimately the maintenance of local and regional biodiversity (Epps et al. 2005; Cushman et al. 2006; Schwartz et al. 2007). Compared to telemetry methods, this technique could provide an efficient, relatively inexpensive, and non-invasive way to acquire critical information regarding genetic interchange facilitated by crossings, in a relatively short period of time, without ever having to capture or see the animal (Kendall and McKelvey 2008). The development of a NGS method that more clearly defines the demographics and genetics of animal movement through wildlife crossings will significantly advance our knowledge of the conservation value of these measures and provide evidence-based support for their future implementation.

We describe a NGS method of obtaining information on potential population-level benefits of wildlife crossings in Banff. Our technique was focused on black bear and grizzly bear populations that were impacted by the TCH in the Banff-Bow Valley. Specifically we describe the study design and preliminary field data from the implementation of the NGS technique on black and grizzly bear populations using data collected at multiple wildlife crossings along the TCH and their populations in the surrounding landscape. Finally, we discuss the added value of non-invasively collected genetic data for conservation and management applications.

4.2. Methods

In 2006, the prototype hair-sampling system developed at the wildlife crossings (Clevenger and Sawaya, submitted) was incorporated into a three-year landscape-scale study in Banff. NGS methods were used to obtain information about the bear population that uses the wildlife crossings and occupies the study area. The goal of using these methods was to extract DNA from the hair samples for use in genetic analyses. These analyses would provide an estimate of the number of individual male and female grizzly and black bears that use the crossing structures and that occupy the Bow Valley. The genetic data would also be used to determine relatedness and relationships between individual bears of each species.

We used hair traps as described by Woods et al. (1999) and rub tree surveys following Boulanger et al. (2008) to collect DNA from the population of bears in the Bow Valley. We used the hair-sampling system that was described above to collect DNA from bears passing through the wildlife crossing structures (see Figure 4.1). A study area boundary was established by creating a 14-km buffer in all directions around the mitigated section of the TCH extending 45 km from the park’s east entrance to Castle Junction. Since hair traps for grizzly bear population estimates typically employ a 7 km x 7 km grid (Boulanger et al. 2008) to distribute effort across the region of interest, we chose a 14-km buffer so that we could have a grid that spanned the TCH and allowed for sampling up to two full grid cells away from the highway (Figure 4.1). The orientation of our grid location was chosen to make our grid continuous with a larger sampling effort to inventory grizzly bears in Alberta conducted by the Foothills Research Institute (G. Stenhouse, in preparation). By following these criteria, we created a sampling grid that straddled the TCH and contained equal numbers of 7 km x 7 km grid cells to the north and south of the highway. We surveyed all trails within the 14-km buffer for the presence of rub trees (Figure 4.2). We recorded the geographic coordinate of any rub trees located using a global positioning system unit (Garmin® 12XL, Garmin Ltd., Olathe, Kansas) and placed three 30-cm strands of barbed wire on them for future sampling (see Kendall et al. 2008).

Figure 4.1: Location of hair traps (“hair snares”) monitored for non-invasive genetic sampling of black and grizzly bear populations in Banff National Park during 2006 and 2008. Grid cells are 7 km x 7 km.

Figure 4.2: Location of rub trees monitored for non-invasive genetic sampling of black and grizzly bear populations in Banff National Park between 2006 and 2008.

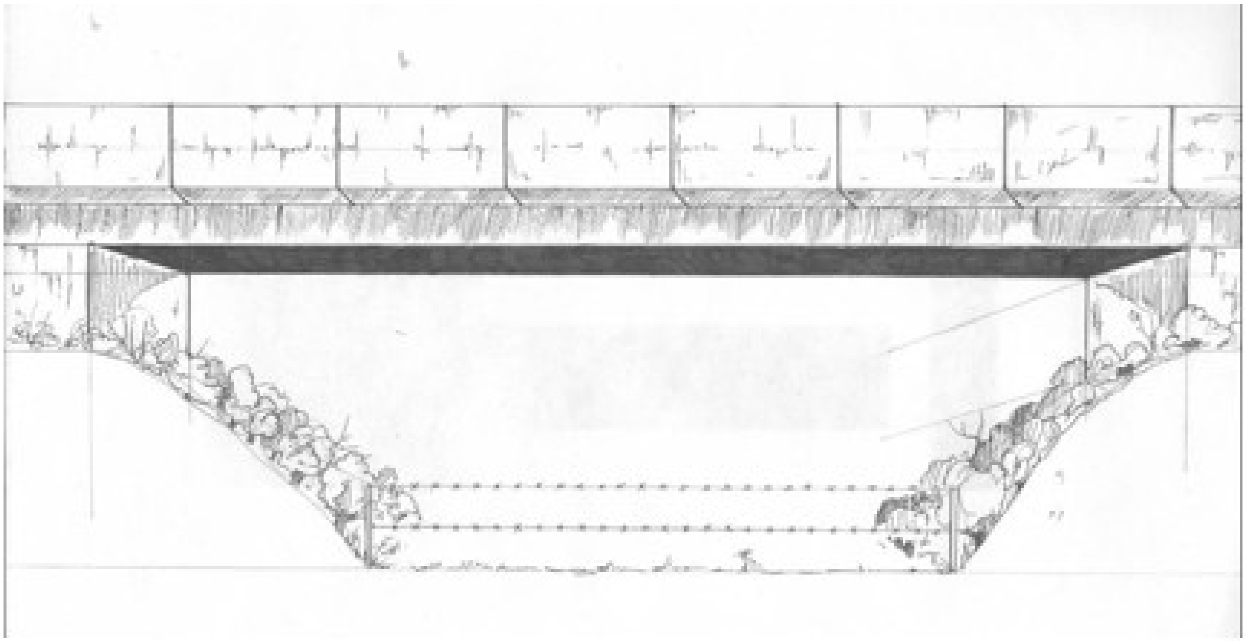

Figure 4.3: Illustration of hair-sampling system at wildlife underpass in Banff National Park (Illustration by S. Harrison).

In 2006, we monitored 20 of the 23 wildlife crossings using our hair-sampling system. Of the three underpasses not monitored, two were excluded due to high levels of human use (Edith, Buffalo), and the third was excluded because it floods during the summer months (Cascade). Buffalo and Cascade underpasses are rarely used by bears because of their close proximity to the town of Banff (Clevenger and Waltho 2000; Clevenger et al. 2002). Between May 24 and August 11, we deployed hair traps in 37 grid cells during five, 14-day sampling periods. A total of 188 hair-trap sites were set and maintained. Between August 15 and October 15, we monitored 330 rub trees and conducted a minimum of three rub tree surveys per trail segment. Surveys were run on average once every three weeks.

In 2007, we monitored 20 of the 23 wildlife crossings using our hair-sampling system. We chose not to set and maintain any hair trap sites during our second field season due to the high cost and effort associated with running a hair trap grid and the greater potential for bears to avoid hair traps when sampling consecutive years. Between May and August of 2007, we expanded our rub tree monitoring and added an additional 167 rub trees. We monitored a total of 497 rub trees and surveyed every trail segment at least twice between May 25 and October 15.

In 2008, we continued to monitor the 20 wildlife crossings using our hair-sampling system and we also sampled the population using both hair traps and rub tree surveys, as in 2006. We set and maintained 210 hair trap sites between May 24 and August 19. We deployed 42 hair traps in a 7 km x 7 km grid for five, 14-day sampling periods. We monitored 497 rub trees between May 15 and October 15 and we conducted a minimum of three rub tree surveys per trail segment.

4.3. Results and discussion

4.3.1. Sampling success

In 2006, we collected 352 hair samples from the hair-sampling system at the wildlife crossings, 831 samples from 188 hair traps and 886 samples from 331 rub trees. In 2007, we collected 413 hair samples from the wildlife crossings and 2,795 samples from 497 rub trees (no samples were collected from hair traps since no hair traps were deployed). In 2008, we collected 553 samples from the wildlife crossings, 1,125 samples from 210 hair traps and 2,859 samples from 497 rub trees. The number of samples collected at the wildlife crossings included incidental hair collection from some non-target species such as deer and coyotes.

The percentage of bear crossing events for which we obtained hair samples (hair-sampling success rate) ranged from 47 percent for black bears to 63 percent for grizzly bears between 2006 and 2008 (Table 4.1). The rate of hair sampling for black bears remained relatively constant, while the rate for grizzly bears declined slightly during the three-year period. Although our hair-sampling system was not designed for cougars or wolves, hair-sampling rates for the two carnivores ranged from 17 percent to 56 percent.

Table 4.1: Hair-sampling success rate for large carnivores at Banff wildlife crossings.

2006	Crossing events	Number of events with >1 sample collected	Percent hair-sampling success
Grizzly bear	85	54	63%
Black bear	126	60	47%
Cougar	48	16	33%
Wolf	138	77	56%
2007			
Grizzly bear	78	39	50%
Black bear	60	29	48%
Cougar	54	9	17%
Wolf	185	73	39%
2008			
Grizzly bear	148	83	56%
Black bear	74	37	50%
Cougar	98	21	21%
Wolf	332	96	29%

Rub trees were more likely to provide hair samples than hair traps (Table 4.2). During the three-year period an average of 72 percent of the rub trees yielded at least one hair sample, while 48 percent and 49 percent of the hair traps produced samples during 2006 and 2008, respectively. The percentages were calculated as number of sampling units yielding at least one hair sample divided by total number of sampling units.

Table 4.2: Hair-sampling success rate at hair traps and rub trees in Banff, 2006–2008.

	Percent hair trap success (N)	Percent rub tree success (N)
2006	48% (188)	67% (331)
2007	N/A	76% (497)
2008	49% (210)	70% (497)
Total	49% (398)	72% (1,325)

4.3.2. Summary of genetic analysis and methodology

The DNA amplification success rate varied between 55 percent and 82 percent for black and grizzly bear samples obtained at the wildlife crossings (Table 4.3). In 2006, 11 black bears (five females, six males) and 11 grizzly bears (four females, seven males) were identified using the wildlife crossings. In 2007, eight black bears (four females, four males) and 12 grizzly bears (six females, six males) were sampled using the wildlife crossings. These are considered minimum estimates of individuals and genders using the crossings as we were unable to sample hair from all individuals and not all samples were adequate for genetic analysis. Samples collected in 2008 are awaiting analysis. Amplification success rates of hair samples from cougars and wolves ranged from 39 percent to 81 percent. In 2006, three wolves (one female, two males) and one cougar (male) were identified, whereas in 2007 a total of five wolves (four females, one male) and three cougars (males) were identified using the crossings.

Table 4.3: Results of non-invasive genetic sampling of large carnivores using wildlife crossing structures in 2006 and 2007. These numbers are minimum counts as not all individuals left adequate samples for genetic analysis. Samples from 2008 are pending analysis.

2006	Number of samples collected	Number of samples to individual[1]	DNA amplification success rate	Total number of individuals	Number of females	Number of males
Black bear	94	64	68%	11	5	6
Grizzly bear	110	69	63%	11	4	7
Cougar	23	9	39%	1	0	1
Wolf	92	40	43%	3	1	2
2007						
Black bear	55	45	82%	8	4	4
Grizzly bear	198	109	55%	12	6	6
Cougar	16	13	81%	3	0	3
Wolf	107	65	61%	6	4	1

[1] Total number of samples that could be identified to an individual.

In 2006, 29 grizzlies and 40 black bears were identified from the hair trap samples and 53 grizzlies and four black bears were identified from the rub tree samples. The total number of individuals identified at the crossings, hair traps and rub trees combined (there was substantial overlap among sampling methods) was 66 grizzlies and 43 black bears. A total of 17 percent (n=11) of all grizzly bears and 25 percent (n=11) of all black bears were identified using the crossings with our hair-sampling system. The 2007 data are not readily comparable to 2006 data and not summarized since no hair traps were deployed in 2007 and the size of the sampling area changed slightly between years.

Our hair-sampling system using two strands of barbed wire was effective at obtaining hair samples from not only our target bear species, but also cougars and wolves. The preliminary results of our population-level study showed that we were able to extensively sample black and grizzly bears at the wildlife crossings (Figure 4.4) and the greater population (hair traps and rub trees) using NGS methods. Nearly 10,000 hair samples were collected during the three-year study (not all samples were sent to the genetics lab for analysis), demonstrating the efficacy of the methods at sampling the target populations. We did not analyze all the rub tree samples in 2007 and 2008 because the 2006 rub tree data showed that a high proportion of samples collected from a given tree were identified as the same individual. Kendall et al. (2008) found similar results at rub trees in Glacier National Park, Montana.

Figure 4.4: Grizzly bear passing through hair-sampling system on one of the wildlife overpasses in Banff.

We derived individual identifications and determined genders from samples collected from all three sampling methods. Although our hair-sampling success rate for grizzly and black bears was approximately 50 percent, our sampling success rates were also respectable for non-target cougars (33 percent) and wolves (56 percent). Hair-sampling success of grizzly bears at the wildlife crossings declined from 2006 to 2008, despite our efforts to maximize hair collection at each of the crossings. Our camera data showed that each successive season, grizzly bears, in particular, made increasing attempts to avoid the barbed wire. Such avoidance tactics included jumping over the wire and stepping on and pushing down the upper wire. Black bear hair capture success at the wildlife crossings was constant during the three-year period. The lower hair-sampling success rate for black bears is likely due to their smaller size and ability to avoid rubbing the wire. Among hair traps and rub trees, our results indicated that hair-sampling success was greater at rub trees compared to hair traps. In the only other study where hair traps and rub trees were sampled simultaneously, Kendall et al. (2008) found the opposite, that hair traps consistently yielded more samples than rub trees.

4.3.3. Spatial and temporal patterns of hair collection at wildlife crossing structures

Twelve years of monitoring at Banff's wildlife crossings has revealed a number of spatial and temporal patterns of use by a variety of large mammal species. An examination of spatial patterns is important to the understanding of the relationship between crossing structure types and crossing structure preferences, while an examination of temporal patterns of use (see Section 3.3, *Summary data…*) is important to the understanding of when and why animals cross the road. Since our track pad monitoring has revealed some interesting spatial and temporal patterns of use, we compared the detections from track pads to the detections from DNA analysis of hair samples to see whether those patterns are reflected in our hair sampling collection. A direct comparison of track pad data to hair sample data provides cross-validation between the methods and allows us to determine if the sample is representative in space and time for bears using the crossings.

Spatial pattern of hair sampling and track detections

Data from black bears were collected at the wildlife crossing structures using track pads and hair collection methods. During the 2006 and 2007 field seasons, we detected 178 black bear crossing events using track pads, and collected at least one hair sample from 71 (40 percent) of those crossings (Figure 4.5). For the two years of data that we have been able to analyze, black bear hair collection was highly correlated with the black bear track detections ($r^2=0.87$). The distribution of black bear hair sample collection was strikingly similar to distribution of black bear track detections. Black bear track detections occurred at 15 wildlife crossing structures, while hair samples were obtained from 14 crossing structures. The majority of track detections and hair samples were obtained at the Duthil (DH) wildlife underpass. Track detections were highest at Duthil and Powerhouse (PH) underpass. Like track detections, hair samples were obtained from a wide geographic range of wildlife crossings, from the east gate almost to Castle Junction (Copper) and covering nearly 45 km.

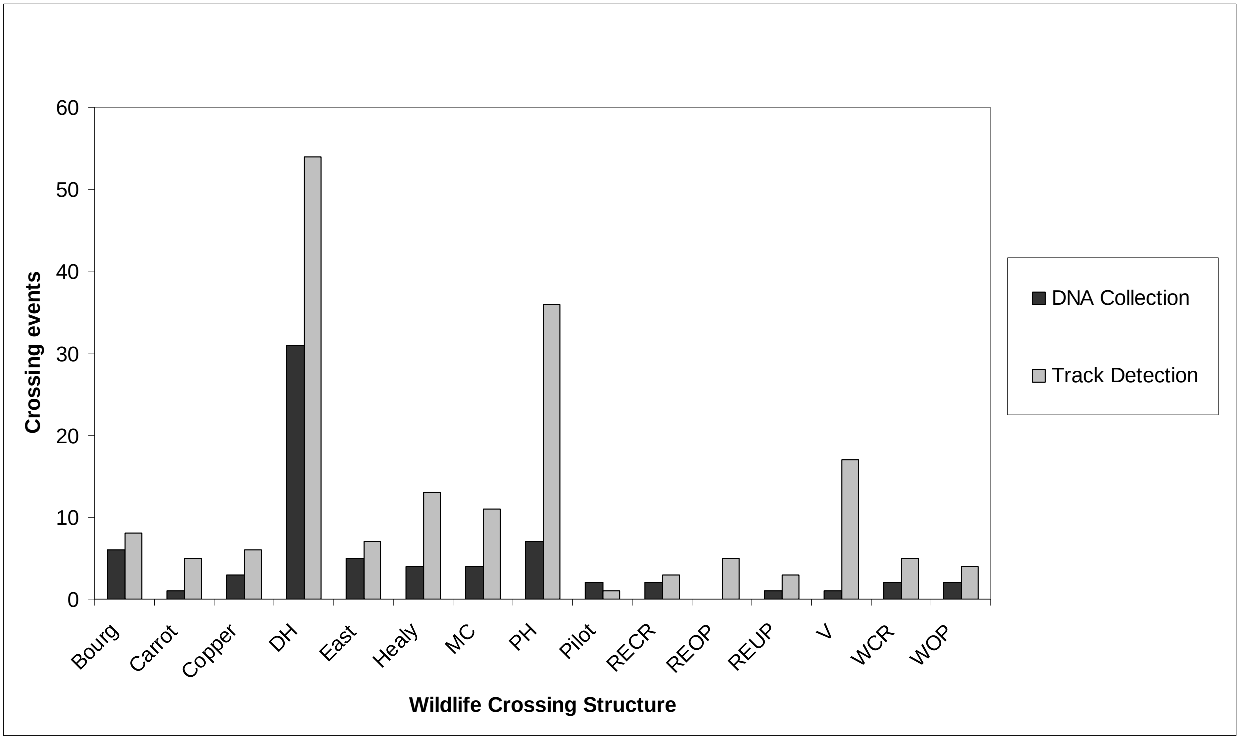

Figure 4.5: Correlation of black bear detections from tracks and collection of hair samples with black bear DNA at wildlife crossing structures, 2006–2007. Only crossing events that produced species identification and individual identification from hair samples were included in results. Many crossing events resulted in the collection of multiple samples from the same individual and some individuals were detected at the same wildlife crossing on multiple occasions.

Similar to black bears, grizzly bear hair collection was highly correlated with grizzly bear track detections (r^2=0.99). During 2006 and 2007, we detected 211 grizzly bear crossings and collected at least one hair sample from 86 (41 percent) of those crossings (Figure 4.6). The distribution of grizzly bear hair samples was strongly correlated to the distribution of grizzly bear track detections (Figure 4.6). Grizzly bear track detections occurred at 13 wildlife crossing structures, while hair samples were obtained from only four crossing structures. The majority of track detections and hair samples came from three crossing structures: Redearth overpass (REOP), Wolverine overpass (WOP) and the Healy wildlife underpass. Track detections were highest at these three crossing structures, as were grizzly bear hair sampling events. Unlike track detections that were obtained from a wide geographic range of wildlife crossings, hair samples were obtained from a limited number of wildlife crossings.

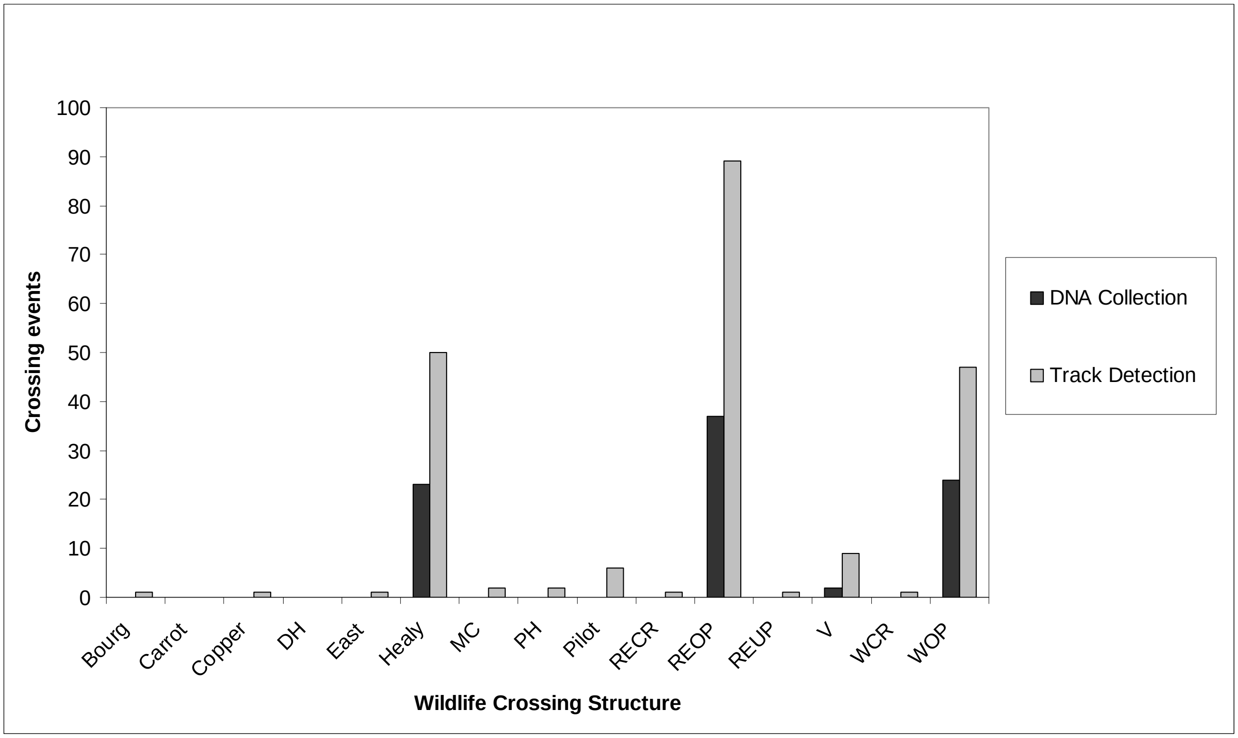

Figure 4.6: Correlation of grizzly bear detections from tracks and collection of hair samples with grizzly bear DNA in 2006–2007. Only crossing events where hair samples produced species identification and individual identification were included in results. Many crossing events produced more than one sample that assigned to the same individual and some individuals were detected at the same wildlife crossing on different dates.

Temporal pattern of hair sample collections

The collection of hair samples from bears using the wildlife crossings was strongly associated with the month of the year (Figure 4.7). Hair sampling occurred from May to October. We analyzed hair collection data from 2006 and 2007. The temporal pattern of black bear and grizzly bear hair collection was strikingly similar. The peak of black bear and grizzly bear hair collection occurred in June and July. The similarity between species and timing of the peak could be explained by the fact that bears are searching widely for both food and mates during these months of the year. The mating season for grizzly and black bears occurs between June and July and high-quality forage and spring foods are most abundant in the valley bottom montane habitat during these months. As summer progresses bears tend to leave the valley bottom habitats and move higher up in the mountains to forage on newly emergent vegetation. We suspect that as bears spend more time in the valley bottom habitat there is greater likelihood that they will also need to cross the TCH via wildlife crossing structures.

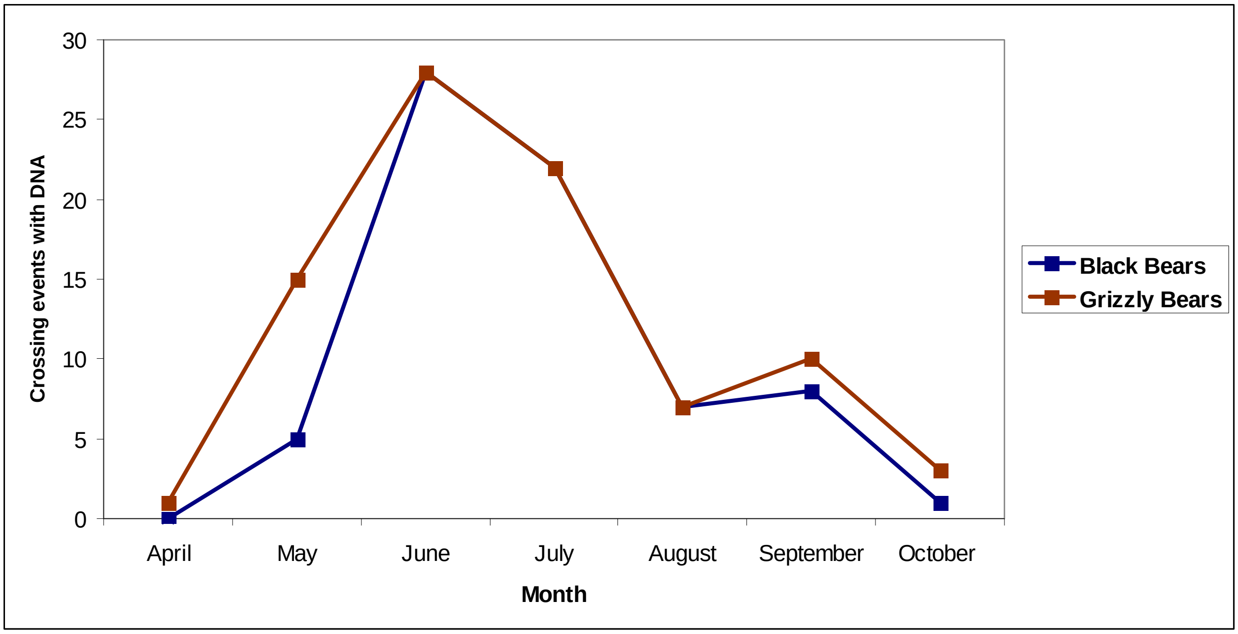

Figure 4.7: Number of crossing events per month with collection of bear DNA at hair sampling system at wildlife crossings in Banff during 2006–2007. Only crossing events where hair samples produced species identification and individual identification were included in results. Many crossing events produced more than one sample that assigned to the same individual and some individuals were detected at the same wildlife crossing on different dates.

4.3.4. Individual use of wildlife crossing structures

Twelve years of monitoring at Banff's wildlife crossings has revealed a number of spatial and temporal patterns of use by a variety of large mammal species, but a deeper understanding of individual use is necessary to interpret what these patterns really mean for individuals and populations. We must quantify the variability and distribution of use between individuals in order to fully assess the merits of different crossing structure types.

The mean number of bear crossings per individual identified through DNA analysis was 5.46 for black bears and 6.14 for grizzly bears (Table 4.4). There was more variability in the number of crossing events per grizzly bear individual than per black bear individual (range=1–17 vs. range=1–25, SE=1.73 vs. SE=1.53).

Table 4.4: Descriptive statistics for number of crossings per individual bear detected through DNA analysis of hair samples[1] collected at wildlife crossings during 2006–2007.

	Black bears	Grizzly bears
Mean	5.46	6.14
Standard Error	1.53	1.73
Median	4.00	3.50
Minimum	1	1
Maximum	17	25
Total crossings	71	86
Number of bears	13	14

[1] Hair samples produced individual ID and gender information.

The frequency of bear crossings by individual males and females detected from hair samples helps explain how many individuals contributed to the total number of crossing events. It is of interest to know how that frequency is distributed between gender classes. Among black bears, two individuals were detected in a high proportion of crossing events (Figure 4.8). Since DNA collection was highly correlated with track detection, we can speculate that one male and one female black bear were responsible for the majority of wildlife crossings detected by DNA analysis. Since it is impossible to obtain age information from DNA, we cannot infer too much about the distribution of individual bear use at crossings until we correlate the DNA data with the remote camera data to determine age classes of individuals. Bear use of crossings may be a function of age, or social and reproductive status, and without knowing the age of an animal, we are unable to know about the other conditions. Cubs of the year are small, which should make them more difficult to detect with our hair sampling system, thus resulting in underestimating their use of crossing structures.

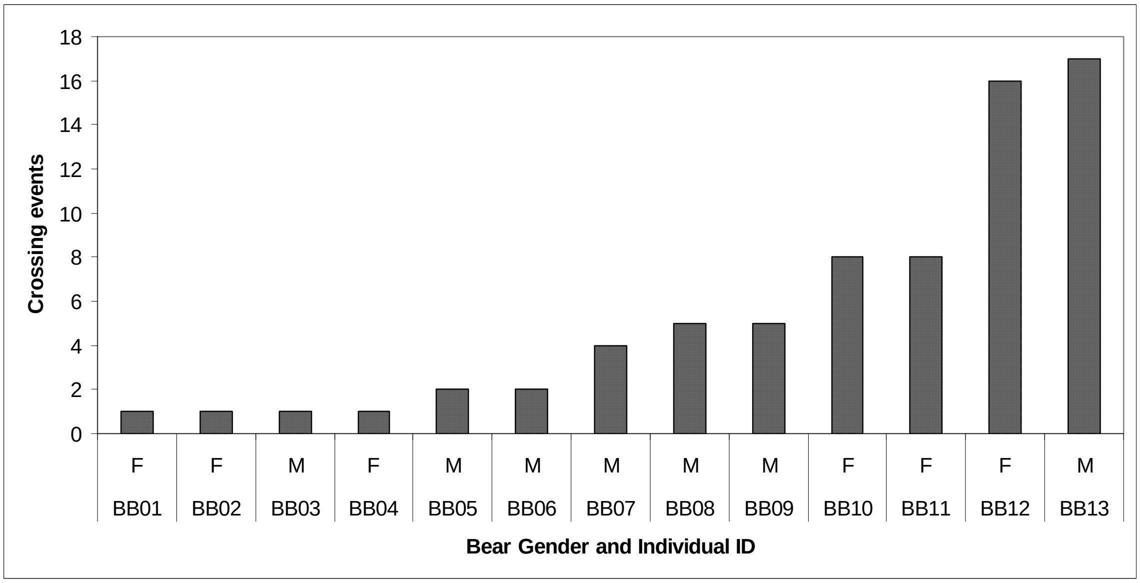

Figure 4.8: Frequency of black bear passages by each male (M) and female (F) individual detected from hair samples collected at wildlife crossings in Banff during 2006–2007.

Among black bears, two individuals were detected in a high proportion of crossing events (Figure 4.8). Since hair collection was highly correlated with track detection, we can speculate that one male and one female black bear were responsible for the majority of wildlife crossings detected by DNA analysis.

One male individual was detected in a high proportion of grizzly crossing events (Figure 4.9). Because hair collection was highly correlated with track detections, we can speculate that one male grizzly bear was responsible for the majority of wildlife crossings detected by DNA analysis. As was the case with black bears, at this point we cannot infer too much about the distribution of individual grizzly bear use at crossings until we correlate the DNA data with the remote camera data to determine age classes of individuals. Similar to black bears, grizzly bear cubs of the year are small, making them more difficult to detect with our hair sampling system, which could result in underestimating their use of crossing structures.

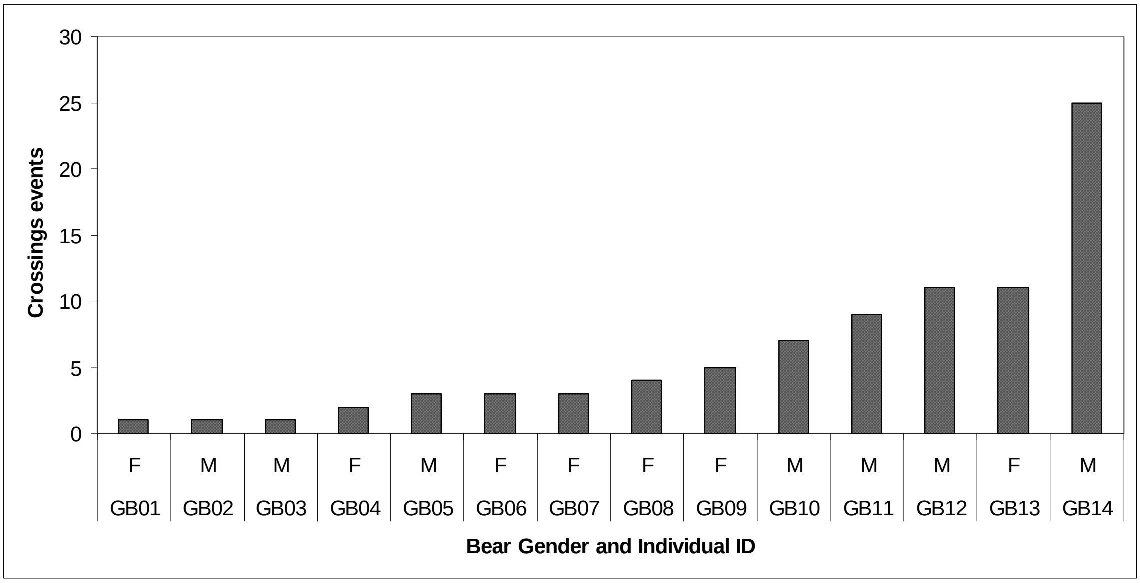

Figure 4.9: Frequency of grizzly bear passages by each male (M) and female (F) individual detected from hair samples collected at the wildlife crossings in Banff during 2006–2007.

4.3.5. Future direction

Completing genetic analysis of field data

In 2009, we will continue to analyze the 2006 and 2007 data and also pursue funding for genetic analysis of the hair samples collected in 2008. All of the 553 samples collected from the wildlife crossings in 2008 have been extracted and genotyped. Many of the 2,895 rub tree samples have been extracted and analyzed following the sub-selection criteria employed in 2007. Many samples that were collected in the core of the study area have not been extracted or genotyped, including 478 rub tree samples and 1,125 hair trap samples. The estimated cost to analyze these samples is $30,049.

Comparison of non-invasive sampling methods

Once we have the complete 2008 genetic dataset, we will work with Dr. Mike Gibeau, carnivore biologist for Parks Canada, to compare three noninvasive genetic sampling methods (hair traps, rub tree surveys and scat detection dogs) for monitoring grizzly bears in the mountain parks. This comparison will result in a technical report coauthored by M. Sawaya and M. Gibeau providing detailed recommendations for monitoring grizzly and black bear populations in the Canadian Rocky Mountain National Parks. This report could be extremely useful for planning proposed bear population surveys along Phase IIIB of the TCH and Highway 93-South in Kootenay.

Data analyses and research questions

While awaiting the genetic results from 2008, we will continue to examine the data that has already been collected and analyzed. We will evaluate whether the TCH is a barrier to gene flow by calculating the magnitude of genetic differentiation (Fst) across the TCH and performing partial Mantel tests to determine the cause of differentiation if found. We will use landscape genetics to compare the relative magnitude of genetic differentiation across the TCH with other potential barriers to movement. Our collaboration with Dr. Guillaume Chapron, which is described in the following chapter, provides a unique opportunity to develop a genetic-based population viability analysis (PVA) model. We will parameterize Dr. Chapron's individual-based, spatially explicit model using our genetic data (population size, movement rates, etc.) and use the model to explore the relationship between wildlife crossings and gene flow. The combination of landscape genetic analysis and PVA will give us a better understanding of the link between highway mitigation measures, gene flow and population viability. Data analysis and publication of results is underway and should be completed by December 2010, although the completion date is dependent upon the continuation of graduate student support and securing funding for the genetic analysis of the hair samples collected in 2008.

4.3.6. Applications

The genetic data gathered from our hair-sampling system has added greatly to our knowledge of the number and gender of individual bears, cougars and wolves that use the Banff wildlife crossings to move across the TCH. However, the potential applications for management have yet to be realized. The genetic data collected from the three hair-sampling methods we employed could have other applications for the conservation and management of wildlife populations. The data could be used to monitor and estimate population size (Banks et al. 2003; Piggot and Taylor 2003; Pearse and Crandall 2004), develop species occupancy models (MacKenzie et al. 2006; Pearce and Boyce 2006; Long et al. 2008), calculate migration rates (Manel et al. 2005; Dixon et al. 2006) and quantify the degree of genetic population structure (Pearse and Crandall 2004; Proctor et al. 2005; Millions and Swanson 2007). This information could then be used to parameterize population viability and genetics models (Beissinger and McCullough 2002; Hanski and Gaggiotti 2004). Because each hair sample is associated with a geographic coordinate, then crude home range maps can be constructed in cases where the same individual is sampled repeatedly (Taberlet et al. 2003).

Our study examines a non-invasive approach to assess the efficacy of a suite of wildlife crossing structures in restoring demographic and genetic connectivity of black and grizzly bear populations. Similar research questions for management can be addressed at different spatial scales and for different taxonomic classes. Amphibian tunnels and small culverts are often used by transportation agencies to mitigate road effects on herpetiles and small- and medium-sized mammals (Langton 1989; Dodd et al. 2004). These tunnels and culverts are assumed to benefit target populations by reducing mortality and enhancing population connectivity. Many of these species have special habitat requirements, localized populations, and are strongly impacted by road-related mortality (Fahrig et al. 1995, Gibbs and Shriver 2002, Rondini and Doncaster 2002). Obtaining empirical data demonstrating population-level benefits of crossing structures for these species can be less problematic and challenging than for the large, wide-ranging species in our study. We encourage others to test the protocols that we have developed in Banff for similar large-sized mammals or with other taxa that should benefit from the investment of crossing structures.

5. DEVELOPMENT OF A SPATIALLY EXPLICIT GRIZZLY BEAR POPULATION VIABILITY ANALYSIS

During the last 25 years Banff has minimized ecological impacts of the Trans-Canada Highway (TCH) through an innovative approach to highway construction utilizing fencing in combination with a variety of wildlife crossings. More than a decade of monitoring these crossings demonstrates a high level and regularity of use by 11 species of large mammals, which have used them over 100,000 times. It is critical for managers from Parks Canada and the Highway Service Centre to know whether these wildlife crossing structures contribute to maintaining viable populations. Healthy functioning ecosystems require viable wildlife populations.

Models are excellent tools that can provide a framework for evaluating a range of performance criteria and management options more easily and quickly than can be done in the field. This can be done by explicitly modeling performance scenarios or management strategies. Spatially explicit models can be developed to provide scenarios of varying highway (wildlife crossing structure) permeability, aid in assessing the conservation value of crossing structures, and provide a range of connectivity (permeability) values that are needed to maintain viable populations in Banff and the greater mountain park ecosystem.

The goal of this work is to investigate the desired performance criteria (viable populations) by building spatially explicit, individual-based models that rely on empirical data rather than extrapolation from published literature and research conducted elsewhere. These local-scale models linking connectivity and population viability will account for variable landscape conditions (resource selection functions), include accurate species demographic parameters, and be based on more than 12 years of field data on species crossing frequencies and their specific response to different crossing structure configurations.

We are using demographic simulation models to investigate what are the consequences (if any) of fencing and crossing structures on the grizzly bear population dynamics. Two demographic mechanisms explaining how fencing and crossing structures may act can be identified: (1) an increase of demographic parameters by reducing road-induced mortality through fencing, and (2) an increase of virtual population size by restoring connectivity through crossing structures. What we want to investigate is whether the mitigation measures provide a significant improvement of the demographic viability of the grizzly bear population in and around Banff.

For this, we are developing specially enabled demographic Individual-Based Models for grizzly bears, parameterized with datasets from Banff and other North American areas. Models are written in Objective C language, which can be described as C with an object extension and is perfectly suited for ecological modeling since it originates from SmallTalk language. Each individual is described as an “object” and characterized by its biological “patterns” (age, sub-population, etc.). Because the model is based on individual rules, the population dynamics are an emerging property of events at the individual level and not predefined by equations as in more traditional population models. This allows consideration of more explicit biological realities. Individual-Based Models are time and memory consuming, however, because they follow the birth, life, death and interactions of each individual within a population. To run simulations in a reasonable amount of time, we are using a cluster of workstations.

One of the most appealing features of Individual-Based Models is their ability to simulate the positions and movements of individuals in space. This is particularly important because the outcome of models can differ depending on whether spatial components are accounted for. Our current model is spatially implicit—that is, we have a bear population that has been structured into two sub-populations separated by a highway. Bears have the possibility to move between sub-populations using crossing structures, according to a given crossing probability p. We are computing the extinction rate of this population with no highway present (p=1), with a fenced highway without a crossing (p=0), and with possibilities of crossing ($0<p<1$). This analysis will show how probable crossing p must be (i.e., how much use should the crossing structures get) to reduce the extinction rate to an acceptable level.

We then can compare the simulated minimum value of the probability to cross (required to have a viable population) with the *achieved* probability to cross, computed from the Banff telemetry dataset. If we find that this achieved value is larger than the simulated minimum value, then we can infer that the crossing structures are an effective means of mitigating effects of fenced roads. Conversely, if the value is smaller, the crossing structures may be insufficient for maintaining demographic viability.

Simulations performed so far indicate that whether restoring connectivity has an effect on population viability depends highly on modeling assumptions. The Banff grizzly bear population is part of the larger Rocky Mountain population, and is separated in two parts by the TCH. Each of these sub-populations remains large enough to be viable by themselves. The demographic viability is shaped by particular assumptions such as catastrophic events (or different mortality rates) in one of the sub-populations but not the other, or that the Bow Valley grizzly bear population has a small carrying capacity and is isolated from other bears in the Rocky Mountains.

While the demographic effects on the bear population viability of restoring connectivity may be too diffuse to assess, the genetics effects are important as gene flow could be enhanced by the crossing structures. Increasing connectivity and reducing road-related mortality through fencing and crossing structures, however, should affect population viability. The models we have developed are designed to be flexible enough to incorporate aspects other than demography, making it possible to investigate the genetic effects of restoring connectivity. This modeling analysis will be completed during 2009.

Population modeling work is being conducted by Dr. Guillaume Chapron, Assistant Professor at the Swedish Agricultural University, Grimsö Wildlife Research Station (http://www.apple.com/uk/education/hed/arts/swedish/index.html).

6. ROAD-RELATED MORTALITY OF WILDLIFE IN THE MOUNTAIN PARKS

6.1. Introduction

Roads represent a source of mortality to wildlife populations in addition to their usual causes of mortality such as predation and disease. For many years it has been a problem in both Field Units and a cause for concern among park managers and transportation planners (Damas and Smith 1982; Woods 1990; Banff-Bow Valley Study 1996; Woods et al. 1996). The long-term trend and prospects are for increasing traffic volumes on the TCH and other primary roads in the parks. Development of practical highway mitigation will rely on an understanding of patterns and processes that result from highway accidents involving elk and other wildlife.

6.2. Methods

Road mortality data are collected by Parks Canada personnel from the Warden Service and the Highway Service Center. Public reports are also checked and verified by Parks Canada for field sign, if available. In most cases, GPS-derived spatial locations are provided along with the sex, age and species of animal. Necropsies may also be performed to determine health status. We focus our analysis on the start of the fiscal year for the reporting period (April 1, 2005) and finish where mortality records have been most recently cleaned and updated (December 31, 2008).

6.3. Large mammal mortality along the TCH

Large mammal mortalities along the TCH provide important data for evaluating the effectiveness of mitigation measures designed to prevent animal movement into the right-of-way (ROW), reduce wildlife–vehicle collisions and sustain viable populations of wildlife. The most informative means of determining how road mortality changes over time and place is to measure the size of the wildlife population in the surrounding landscape, and then calculate the per capita mortality. Most wildlife populations near the TCH do not have accurate population estimates available, with the exception of wolves and elk. For these and the remainder of the large mammal species in Banff, we summarize the amount of annual road-kill for mitigated (Phases I, II and IIIA) and unmitigated (Phase IIIB and the TCH in Yoho National Park) sections as a comparison of how road-kill rates changed over time. Additionally, we provide per capita mortality rates for elk and wolves.

6.3.1. Results and discussion

Road mortality rates were lower for large carnivores along the mitigated section of the TCH (Table 6.1), with the exception of wolves and grizzly bears. Three large carnivore events contributed to all of the large carnivore mortalities along Phases I, II and IIIA: two orphaned grizzly bear cubs killed together (2005), one putative alpha female wolf from the Bow Valley pack (2008), and one male wolf from the Bow Valley pack a few weeks later. Black bear mortalities were relatively scarce along the mitigated section of the TCH, but averaged two to three individuals per 100 km per year on the unmitigated TCH west of Castle Junction.

Table 6.1: Mortality rate for large mammals along mitigated and unmitigated portions of the Trans-Canada Highway between Banff National Park's east gate and Yoho National Park's western boundary. Data are from April 1, 2005 to December 31, 2008.

Species	Mitigated	Unmitigated		
	Phases I, II, IIIA (Kills/100km/year)	Phase IIIB (Kills/100km/year)	Yoho (Kills/100km/year)	Total Kills (n)
Unknown Bear spp.	0	0.8	0	1
Black bear	0	3	1.9	7
Grizzly bear	4.2	0	0	2
Cougar	0	0	0.6	1
Wolf	1.7	0.8	1.3	6
All large carnivores	**2.8**	**4.6**	**3.8**	**17**
Coyotes	10	4.6	3.2	29
Lynx	0	0	1.3	2
All medium carnivores	**10**	**2.6**	**4.4**	**31**
Unknown. Deer spp.	0	1.5	3.8	8
Mule deer	2.8	6.9	7.0	25
White-tail Deer	5.6	5.3	12.7	37
Elk	2.2	6.9	8.9	27
Moose	0	4.6	7.6	18
Sheep	0	0	0	0
Goats	0	0	2.5	4
All ungulates	**10.6**	**25.1**	**42.5**	**119**
All species	**23.3**	**34.3**	**50.8**	**167**

Medium-sized carnivores, primarily coyotes, have much higher mortality rates within the fenced mitigated section of the TCH compared to farther west on the unmitigated TCH (Table 6.2). At least two factors can explain this phenomenon: 1) fencing was generally not designed to prevent animals coyote-sized and smaller from accessing the ROW; and 2) there are more coyotes in the eastern, mitigated portion of the Bow Valley.

In the first case, coyotes can access the ROW at cattle guards, gaps below the fence and through gaps in many of the swing gates. Phase IIIA includes a buried chain-link fence apron to reduce animal intrusions onto the ROW, but this effort was not included on the earlier Phase I and II sections. Further analysis will be performed to determine if patterns in road-killed carnivores follow the buried and unburied fence sections. In a previous study, Clevenger et al. (2002) found that buried fencing on Phase IIIA was significantly more effective at reducing carnivore intrusions onto the ROW than unburied fencing on Phase I and II.

Table 6.2: Proportion of species groups represented in road mortality records within each mitigation phase along the Trans-Canada Highway between Banff National Park's east gate and Yoho National Park's western boundary. Data are from April 1, 2005, to December 31, 2008.

Species group	Phases I, II, IIIA (road mortality)	Phases I, II, IIIA (use of wildlife crossings)	Phase IIIB* (road mortality)	Yoho* (road mortality)
Large carnivores	12%	4%	13%	8%
Medium carnivores	43%	3%	13%	9%
Ungulates	45%	94%	73%	84%
Total kills (n)	42	n/a	45	80

*Wildlife crossing data unavailable

Ungulate mortality was two to four times lower on the mitigated section of the TCH (Table 6.2). This was driven primarily by lower rates of mule deer, elk and moose mortalities. White-tailed deer mortalities were still slightly higher along Phases I, II and IIIA than on Phase IIIB. Again, these patterns could be explained by species distributions along the Bow Valley, with more moose and mule deer farther west of Banff and more elk and white-tailed deer in the eastern part of the study area. Moose mortality rates are substantially higher along Phase IIIB and in Yoho National Park than farther east. Although habitat distribution plays a role in where moose mortalities occur (with presumably better habitat west of Phase IIIA), we detected 139 moose crossings at the wildlife crossing structures in the past eight years. The number of moose crossings per year is relatively low (<20 crossings per year). Moose numbers are believed to be low in the mitigated section, however, they use wildlife overpasses nearly exclusively and exhibit strong selection for wildlife crossing design (see Section 3.3 and 3.4 *Summary data…*). Mitigation fencing on Phase IIIB will be highly effective at reducing moose–vehicle collisions, however rigorous long-term monitoring is needed to adequately assess whether the mitigation efforts improve the permeability of the TCH for moose and provide for the long-term sustainability of their populations in the area.

The high rates of mortality of medium-sized carnivores and ungulates along the fenced section of the TCH point to several areas where the efficacy of the fencing has been compromised. Further analysis will focus the spatial resolution of road-kill distributions on mitigated highway sections to determine if there are predictable patterns or hotspots in road-kill and what biophysical or infrastructure-related factors might be associated with these hotspots. For instance, are mortalities and fence intrusions along the mitigated section of the TCH associated with swing gates or cattle guards? This information can then be used to highlight where management needs to improve the fence design and/or install escape ramps.

The proportion of mortality among certain species groups (i.e., large carnivores vs. medium carnivores vs. ungulates) was not consistent with the proportion of these species' movement rates through the wildlife crossings (Table 6.2). Ungulates, for instance, accounted for 94 percent of the movements through the wildlife crossings, yet only represent 45 percent of the mortalities along the mitigated section of the TCH. However, on the unmitigated section of highway, ungulates were 73–84 percent of the mortalities. This appears to be driven by the high numbers of medium-sized-carnivore mortalities along the mitigated section of the TCH. Overall, mortalities were lower along the mitigated section of highway and the rate appears to be decreasing (Figure 6.1), while there was little change to the overall rate of mortality along the unmitigated sections.

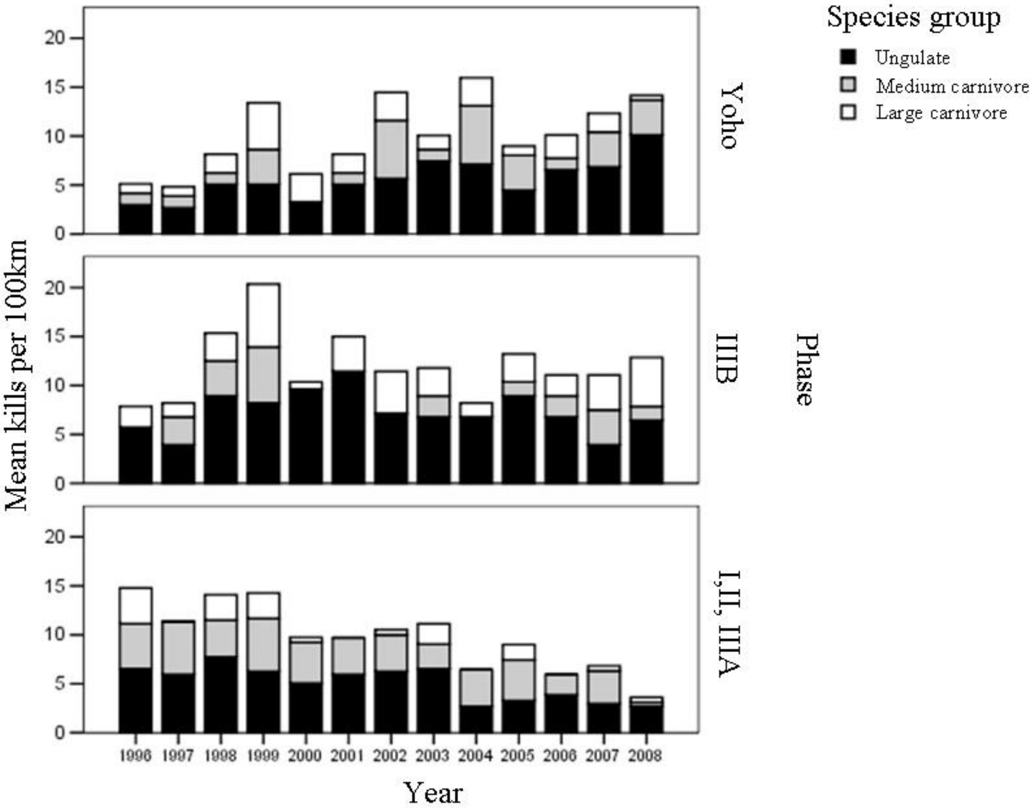

Figure 6.1: Annual mortality rates among species groups by phase on the Trans-Canada Highway, 1996–2008.

Large-carnivore mortalities along the mitigated section of the TCH were much lower than along the unmitigated sections (Figure 6.2). There were some sporadic black bear mortalities in the late 1990s and in 2003 along the mitigated section. However, there is a recent but fairly dramatic upward trend in black bear road mortalities along Phase IIIB. Cougars and grizzly bears were rarely detected as road-kill along any of the sections. Wolf mortalities remain low, and their mortality rates are relatively stable (see below).

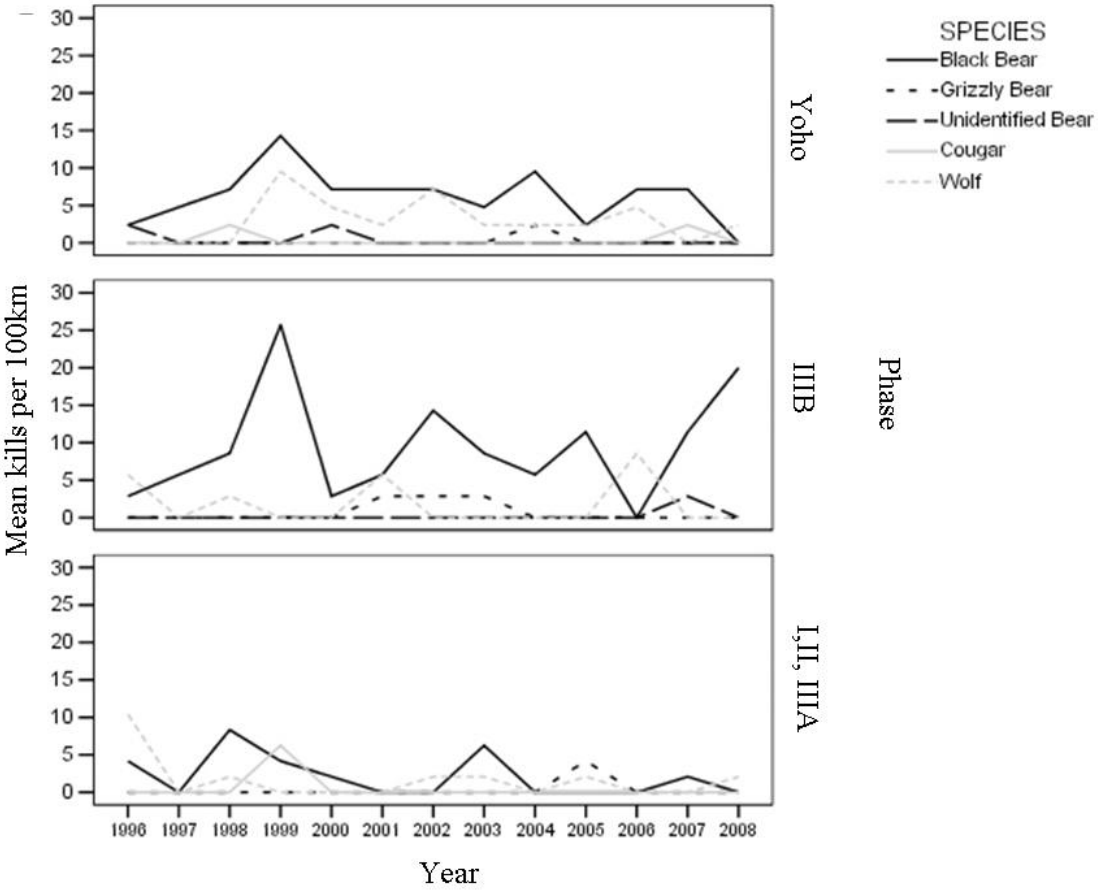

Figure 6.2: Annual mortality rates, by mitigation phase, among large carnivores on the Trans-Canada Highway, 1996–2008.

Medium-sized-carnivore mortalities were dominated by coyotes along all three sections (Figure 6.3). Though the mortality rate was highest along the mitigated section, the trend has declined since 1996 from 23 kills/100km/year to 5 kills/100km/year. Conversely, both Phase IIIB and the TCH in Yoho showed an increasing trend recently in coyote mortalities.

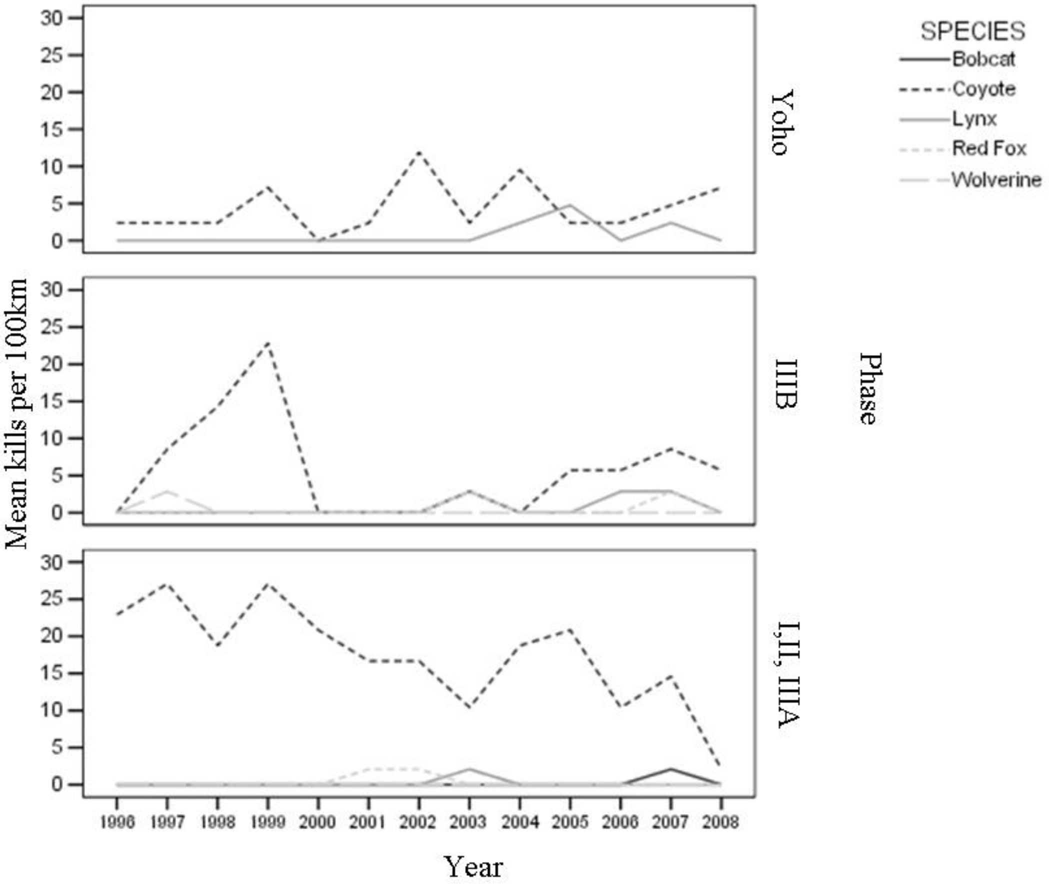

Figure 6.3: Annual mortality rates, by mitigation phase, among medium-sized carnivores on the Trans-Canada Highway, 1996–2008.

Trends in ungulate mortalities were fairly stable among all highway sections and for most species (Figure 6.4). Elk, however, have been steadily declining in road mortality rates along all TCH sections, while moose appear to be increasing along Phase IIIB. Bighorn sheep and mountain goats are rarely killed along the TCH.

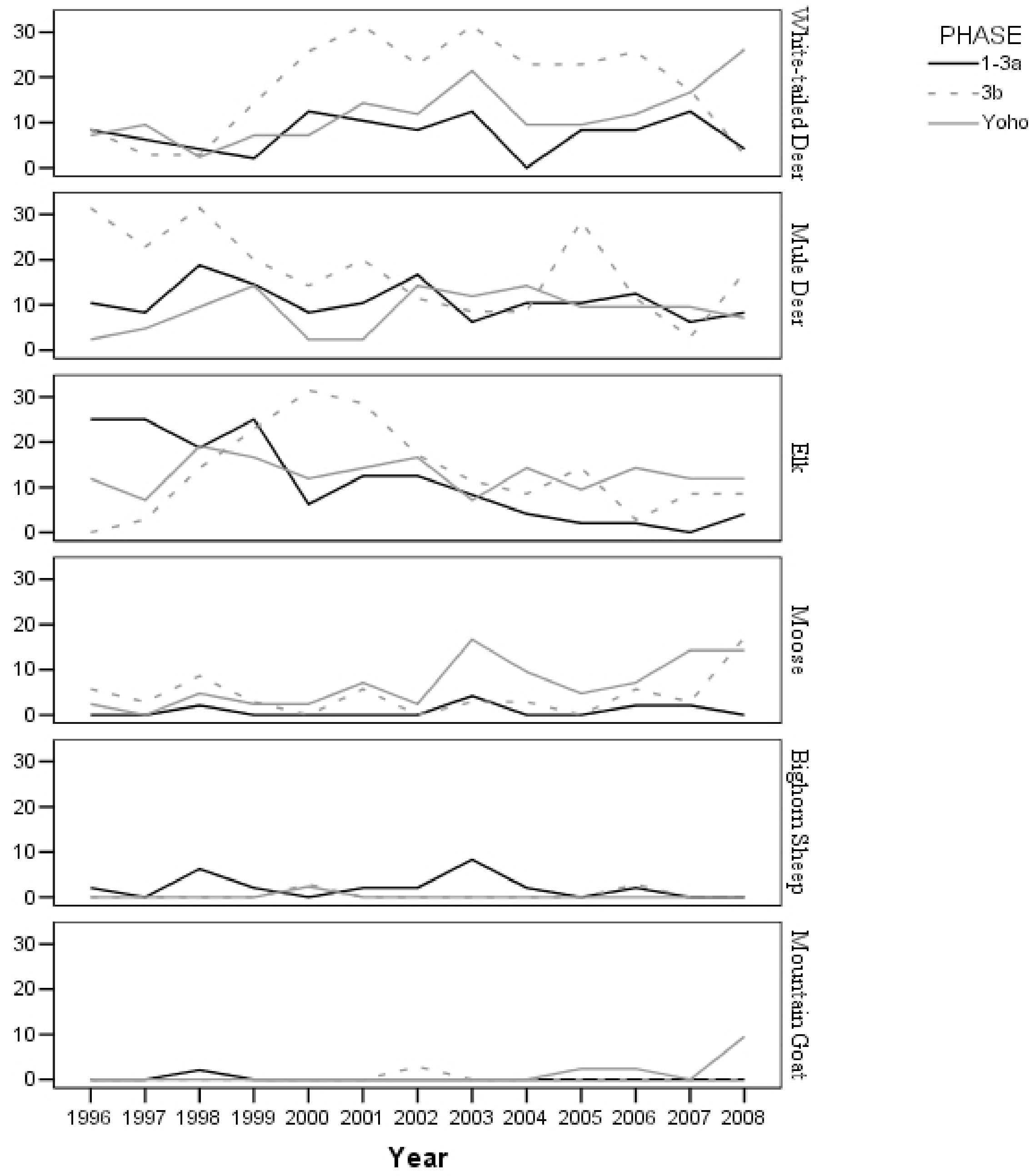

Figure 6.4: Annual mortality rates, by mitigation phase, among ungulates on the Trans-Canada Highway, 1996–2008.

There was a very strong, positive relationship between elk population size and mortality rate along the fenced section of the TCH (Figure 6.5). However, even after controlling for population size, year had a significant negative effect on road mortality rate. The R^2 for the model is 0.585, with the predicted coefficients from an analysis of variance (ANOVA):

Number of elk road kills = [7965.0] – [0.038 * (Population size)] – [3.970 * (Year)]

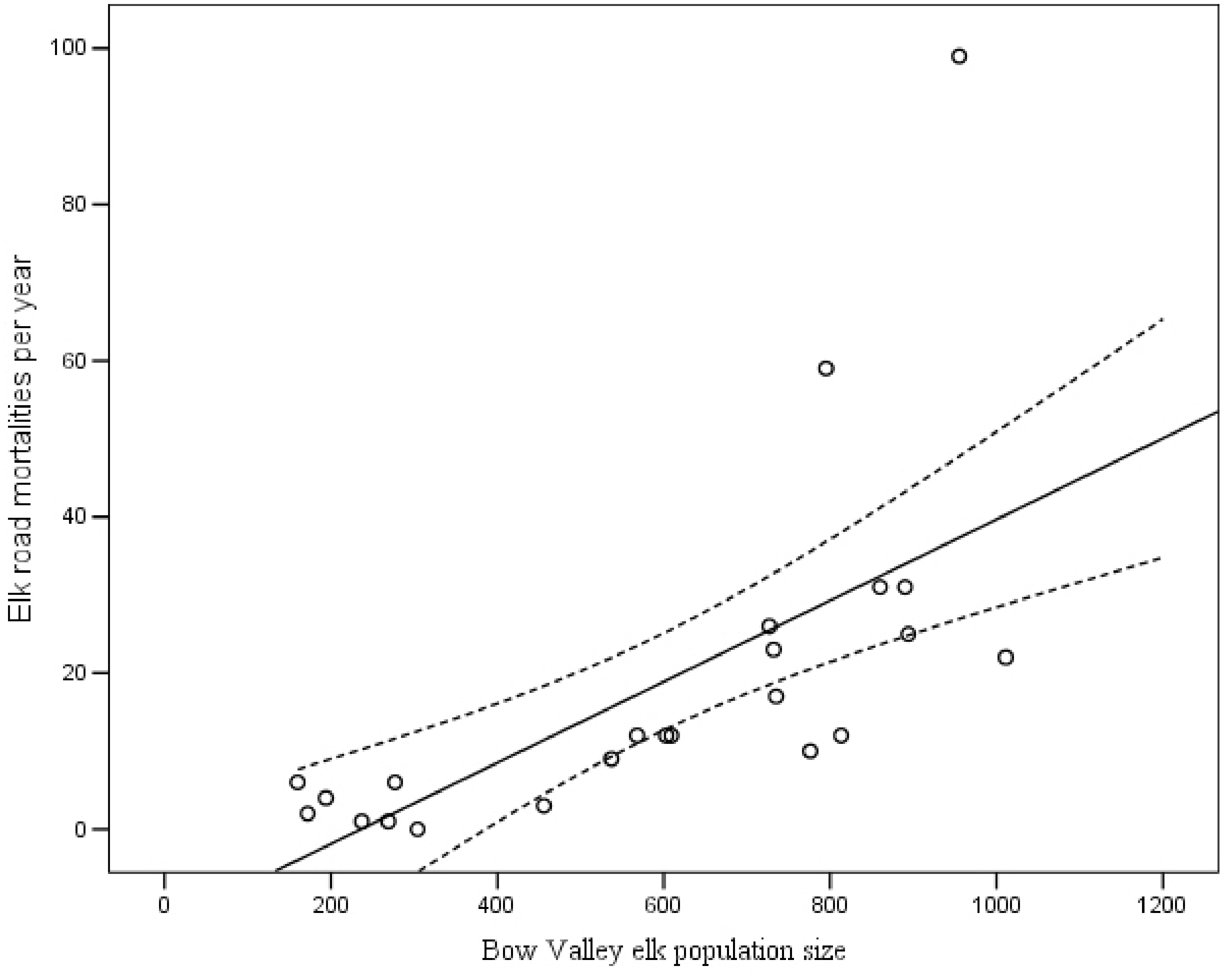

Figure 6.5: Relationship between elk population size and elk mortality rate along the fenced section of the Trans-Canada Highway.

Consistent with the overall elk mortality rate per kilometer, the mortality rate per capita is declining as well (Figure 6.6). There was a spike in mortalities in 2002, though it is unclear what precipitated this increase. When looking at the long-term mortality rate, declines in per capita road-kills were substantial following the completion of Phase II (Figure 6.7). Phase IIIA had a less dramatic effect, likely because fewer elk use this area of the Bow Valley. Still, the overall trend in road mortality rates for elk indicates that mitigation is quickly moving them towards zero along the mitigated section of highway. Further analysis will incorporate traffic volumes and more spatially precise relationships between population estimates and mortality locations (see Clevenger et al. 2002).

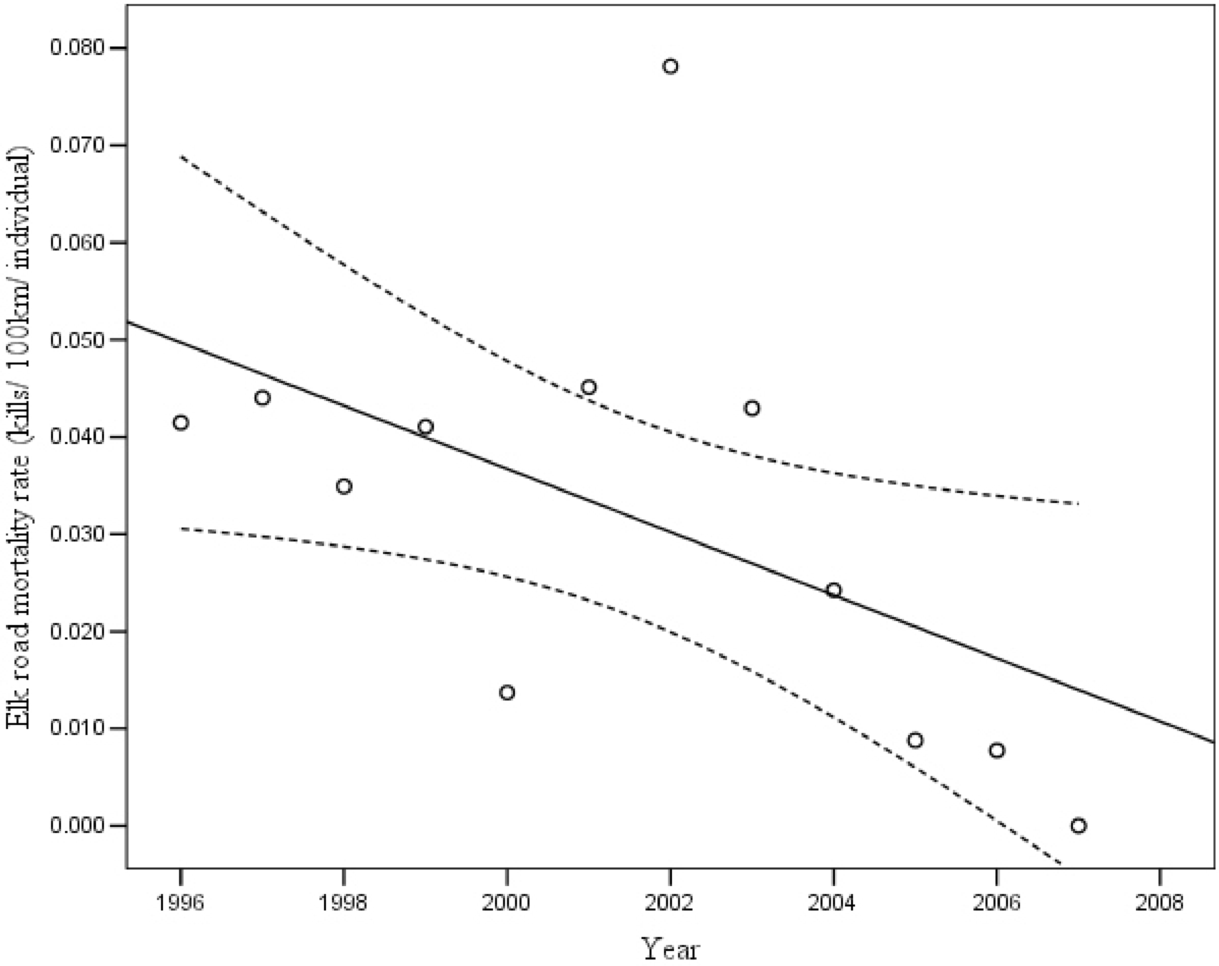

Figure 6.6: Elk mortality rate per kilometer per capita on the Trans-Canada Highway as a function of time, 1996–2008.

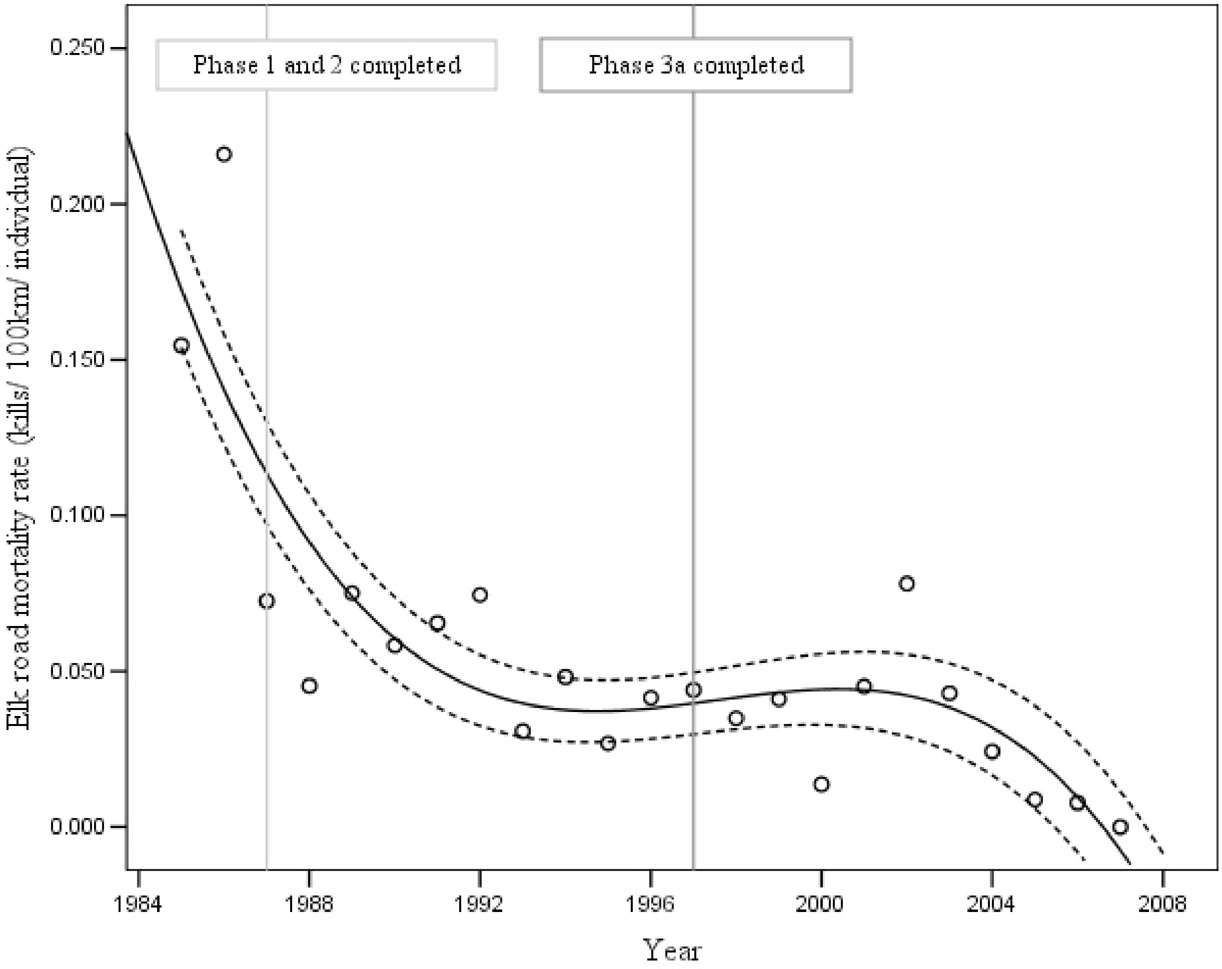

Figure 6.7: Elk mortality rate per kilometer per capita on the Trans-Canada Highway from 1996 to 2008.

Wolf per capita mortality rate was far less predictable than the rate for elk. Wolf mortalities showed no relationship (R^2 = 0.027) with population size (Figure 6.8). We did not perform an ANOVA because there were not enough individuals killed or estimated in the population to meet the assumptions of the statistical test. Not surprisingly, the per capita mortality rate fluctuated with no clear trend over recent years (Figure 6.9) or the long term (Figure 6.10). However, during the 12-year study period, there have only been six years with at least one wolf mortality on the TCH. Over the long term, wolves suffered several mortalities after Phase I and II were completed, though this may have occurred along the unmitigated sections. Two of the nine years in which no wolves were killed on the highway were prior to the mitigation of Phase IIIA. Between the mitigation of Phases I and II and the completion of Phase IIIA, the average annual mortality rate for wolves was 0.289 kills/individual/100km (n=10 years). This rate of mortality occurred while there were between four and nineteen wolves using the Bow Valley (Huggard 1993; Paquet et al. 1996). Conversely, the wolf road-kill rate following the completion of Phase IIIA was 0.095 kills/individual/100km (n=11 years), or roughly a three-fold decline. During this latter period there were between six and fifteen wolves using the Bow Valley (Duke et al. 2001; Hebblewhite et al. 2002).

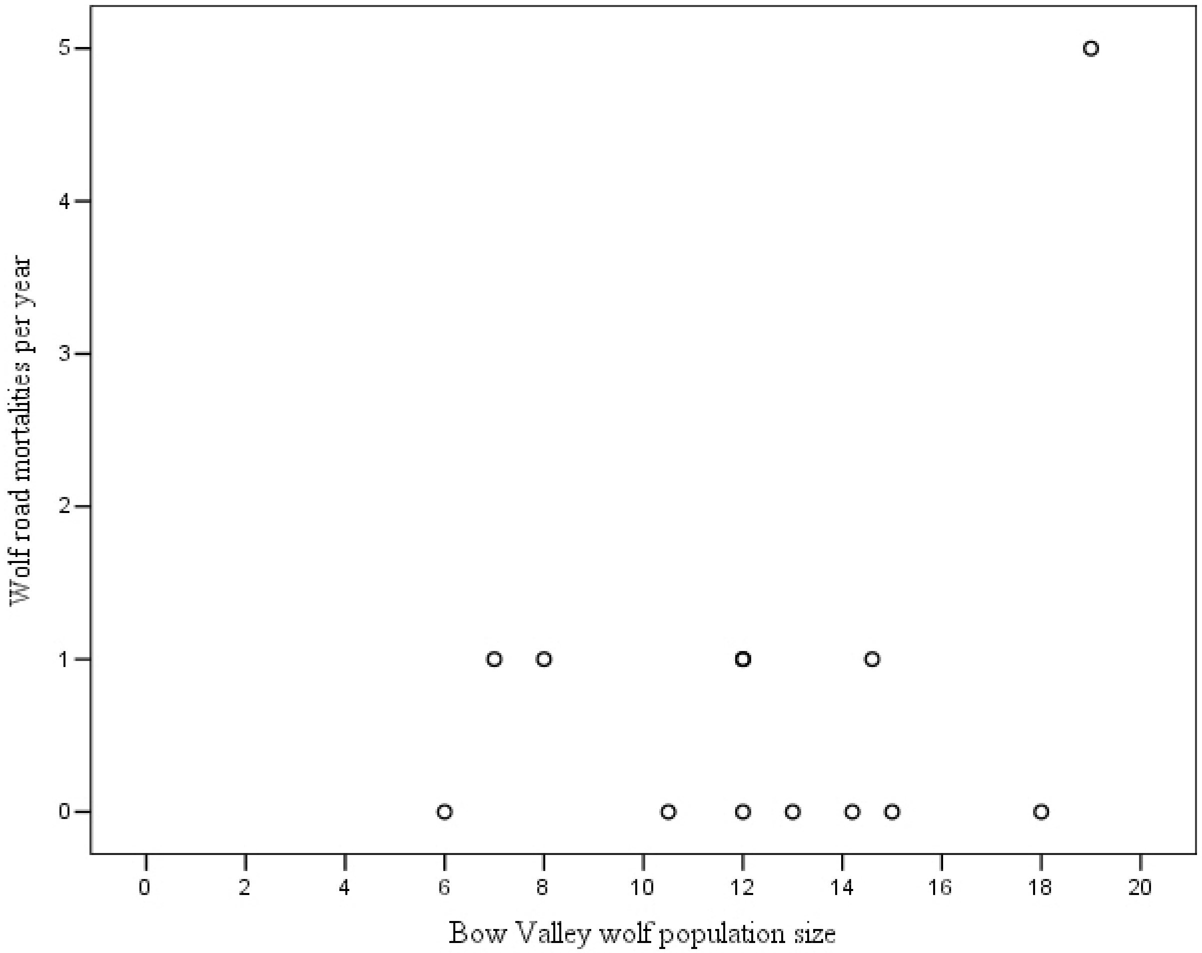

Figure 6.8: Rate of Bow Valley pack wolf mortalities per year on the Trans-Canada Highway as a function of pack size, 1996–2008.

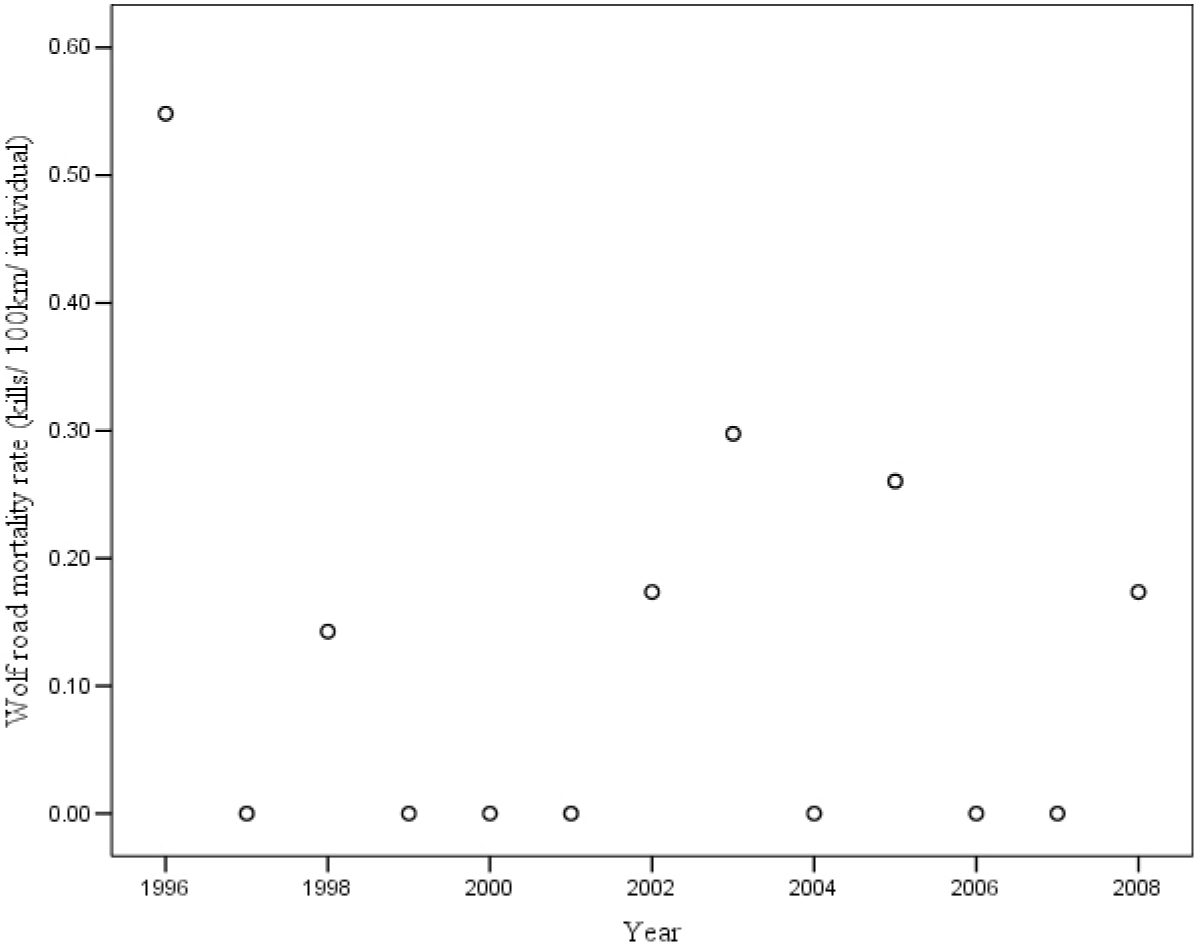

Figure 6.9: Wolf mortality rate per kilometer per capita on the Trans-Canada Highway as a function of time, 1996–2008.

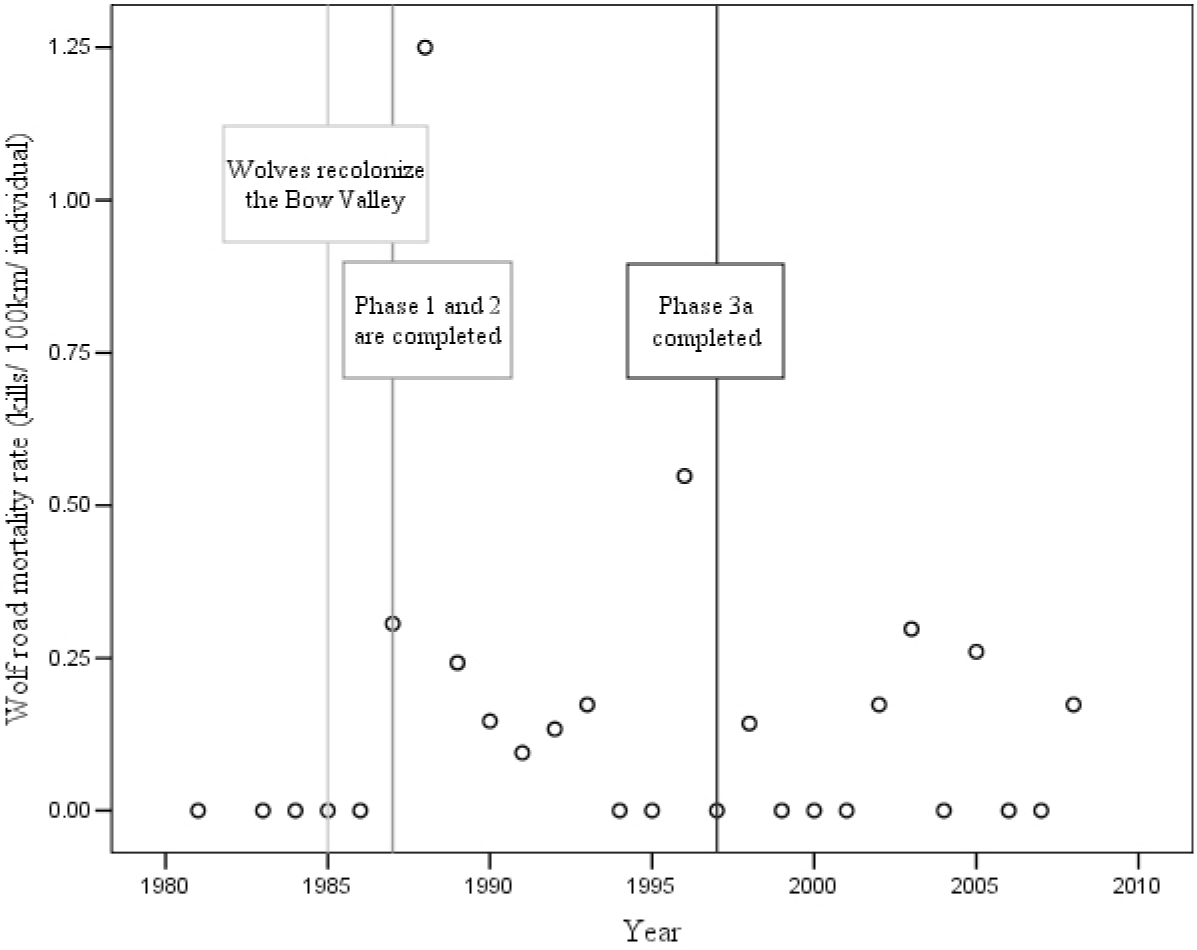

Figure 6.10: Wolf mortality rate per kilometer per capita on the Trans-Canada Highway from 1996 to 2008.

Clear patterns emerged from the trends in per capita mortality rates among elk and wolves using the Bow Valley over the past three decades. Mitigation is clearly improving motorist safety and reducing elk–vehicle collisions. While wolf mortalities continue to occur along the mitigated section of highway, there is far less mortality per capita following mitigation of Phase IIIA.

The results in this section highlight the importance of habitat in determining mitigation effectiveness. Namely, elk mortalities changed little with twinning and mitigation of Phase IIIA, but mortalities were substantially reduced after Phase I and II were completed. This pattern strongly parallels the distribution of elk within the Bow Valley, which is concentrated near the town of Banff. Next, wolf mortalities were substantially reduced following mitigation in their preferred area of the Bow Valley, Phase IIIA. Though both species continue to be killed within the mitigated fenced section of the TCH, there are options available to reduce the amount of road mortality—e.g., better fence inspections and timely repairs, more effective cattle guards, and adequate ROW escape mechanisms.

For elk, future declines in the size of the elk herd from management actions such as culling and increasing predator access to elk during the winter (T. Hurd, Parks Canada, personal communication) will help reduce the likelihood of road-kills. Our model estimates that once the elk population reaches the management target of 150 individuals within the Bow Valley, there should be very little chance of a road mortality occurring.

For wolves, developing a more robust model can be helpful in determining the factors leading to road mortalities. However, it can be inferred that access points and gaps in the fencing most likely lead to intrusions into the ROW. Direct management of wolves that have entered the ROW have been successful, with credit going to the Warden Service for herding animals back across the fence and controlling nearby traffic. Though it is not clear from the data available to our research project how many times wardens have performed this task, there is no doubt that any loss of capability to quickly respond to fence intrusions could increase the risk of mortality and have negative consequences on the viability of the wolf population. A long-term and sustainable approach would be to develop a less permeable fencing system.

6.3.2. Summary data for road-related wildlife mortality on roads in Banff and KYLL Field Units

Wildlife mortality along highways within the Banff and KYLL Field Units continues to be an issue of high concern for management and environmental stakeholder groups. Since 2005, there have been 57 large carnivore mortalities, 45 medium-sized carnivore mortalities and 428 ungulate mortalities on roads in the two Field Units (Table 6.3). Details of mortality trends along the TCH are discussed above in Section 6.3. Highway 93-South remains the deadliest section for large carnivores, with black bears the most commonly killed species in this group. Likewise, among the known locations of ungulate mortalities, most (46 percent) occur along Highway 93-South. Among both known and unreported mortality locations, white-tailed deer are the most commonly occurring (48 percent) of all ungulate mortalities in the study area. Among medium-sized carnivores, the mitigated section of the TCH is the most deadly road in the study area. Coyotes represented 84 percent of all known and unreported medium-sized carnivore mortalities in the study area. When looking at reported mortality locations only, ungulate collisions are more common (59 percent) on low traffic volume parkways and secondary highways than on the TCH. Taken together, these results indicate that for many species, the lower traffic volume roads (e.g., parkways, Highway 93-South) are a greater source of mortality than the high traffic volume TCH. However, to identify the true risk of wildlife–vehicle collisions for each highway requires additional data on wildlife population size, traffic volume and road length.

Over the past 11 years, more than 1500 mortalities have been recorded along the highways in the Banff and KYLL Field Units (Table 6.4). Ungulates made up 77 percent of these mortalities, with Highway 93-South having the largest proportion of ungulate kills (32 percent of all ungulate mortalities), followed by the TCH in Yoho (17 percent) and the TCH in Banff (13 percent). The TCH in Yoho had the most large carnivore road-kills—25 percent of all mortalities within this species group—followed by Highway 93-South (22 percent) and Highway 93-North (14 percent). Black bears (68 percent) and wolves (21 percent) made up the vast majority of mortalities for the four large carnivore species. Among medium-sized carnivores, coyotes represented over 90 percent of all mortalities. Medium-sized carnivores were most likely to be killed along the busier TCH (77 percent of known mortality locations) than on smaller highways.

Since 1997, the proportion of road-related mortalities of large carnivores, medium-sized carnivores and ungulates on all park roads was 12 percent, 11 percent and 76 percent, respectively. However, during the past five years this proportion was 11 percent, 9 percent, and

81 percent. This slight change suggests that ungulate mortalities are a growing problem, with most of this mortality occurring along unmitigated roads in the study area.

Table 6.3: Wildlife mortality records for the Banff and KYLL Field Units from April 1, 2005, until December 31, 2008.

	Banff Field Unit		KYLL: BNP			KYLL: KNP		KYLL: YNP	Unknown road	Total
Species	TCH	Other	TCH	93N	Other	93S	Other	TCH		
Unknown bear spp.	0	0	1	0	0	0	0	0	0	1
Black bear	0	1	4	6	2	7	0	3	12	35
Grizzly bear	2	0	0	0	0	2	0	0	1	5
Wolf	3	0	1	1	0	4	0	2	3	14
Cougar	0	0	0	0	0	0	0	1	0	1
Total large carnivore	**5**	**1**	**6**	**7**	**2**	**13**	**0**	**6**	**16**	**57**
Bobcat	0	1	0	0	0	0	0	0	0	1
Coyote	18	2	6	1	0	1	0	5	5	38
Lynx	0	0	0	1	0	0	0	2	1	4
Red fox	0	0	0	1	0	0	0	0	1	2
Total medium carnivore	**18**	**3**	**6**	**3**	**0**	**1**	**0**	**7**	**7**	**45**
Unknown ungulate	0	0	0	0	0	0	0	0	1	1
Unknown deer spp.	0	2	2	2	0	11	0	6	13	36
Elk	4	0	9	1	0	4	0	14	11	43
Mountain goat	0	0	0	0	0	0	0	4	1	5
Moose	0	0	6	0	0	21	0	12	17	56
Mule deer	5	13	9	6	0	11	0	11	17	72
Sheep	0	0	0	0	0	4	0	0	4	8
White-tailed deer	10	6	7	3	2	83	1	20	75	207
Total ungulate	**19**	**21**	**33**	**12**	**2**	**134**	**1**	**67**	**139**	**428**
Total	**42**	**25**	**45**	**22**	**4**	**148**	**1**	**80**	**162**	**5530**

TCH: Trans-Canada Highway; 93N: Highway 93-North; 93S: Highway 93-South.
Other roads: Highway 11, parkways and access roads.
Unknown road: Database records do not indicate which road; plotting UTM coordinates can be used in the future to complete these records.

Table 6.4: Wildlife mortality records for Banff and KYLL Field Units from January 1, 1997, until December 31, 2008.

	Banff Field Unit		KYLL: BNP			KYLL: YNP		KYLL: KNP		Unknown road	Total
Species	TCH	Other	TCH	93N	Other	TCH	Other	93S	Other		
Unknown bear spp.	0	0	1	0	0	1	0	0	0	0	2
Black bear	7	4	14	20	2	26	0	25	0	20	118
Grizzly bear	2	0	2	1	0	1	0	3	0	1	10
Cougar	3	0	0	0	0	2	0	0	0	0	5
Wolf	5	1	2	3	0	14	0	10	0	3	37
Total large carnivore	**17**	**5**	**19**	**24**	**2**	**44**	**0**	**38**	**0**	**24**	**173**
Bobcat	0	1	0	0	0	0	0	1	0	0	2
Lynx	1	0	1	1	0	4	0	1	0	1	9
Coyote	85	12	20	2	2	20	0	17	0	7	165
Red fox	2	0	0	2	0	0	0	0	0	1	5
Wolverine	0	0	1	0	0	0	0	0	0	0	1
Total medium carnivore	**88**	**13**	**22**	**5**	**2**	**24**	**0**	**19**	**0**	**9**	**182**
Unknown deer spp.	8	9	8	8	0	12	1	18	0	16	80
Mule deer	17	45	44	17	1	40	0	29	0	22	215
White-tailed deer	20	21	40	17	6	53	1	222	2	96	478
Elk	28	27	44	11	3	53	2	24	0	18	210
Mountain goat	0	1	0	1	0	5	0	2	0	2	11
Moose	1	0	10	5	0	27	1	53	0	27	124
Bighorn Sheep	0	10	1	0	0	1	0	23	0	5	40
Unknown ungulate	0	0	0	0	0	1	0	0	0	1	2
Total ungulate	**74**	**113**	**147**	**59**	**10**	**192**	**5**	**371**	**2**	**187**	**1160**
Total	**178**	**131**	**188**	**88**	**14**	**260**	**5**	**428**	**2**	**220**	**1515**

TCH: Trans-Canada Highway; 93N: Highway 93-North; 93S: Highway 93-South.
Other roads: Highway 11, parkways and access roads.
Unknown road: database records do not indicate which road; plotting UTM coordinates can be used in the future to complete these records.

7. DISPERSAL REQUIREMENTS OF HIGH-ELEVATION SPECIES WITH LOCALIZED POPULATIONS: A REVIEW

7.1. Metapopulation processes

Metapopulations are patchily distributed networks of localized sub-populations. In most cases, individual subpopulations cannot survive on their own and are subject to extirpation or "winking out." Maintenance of subpopulations depends on the movement of individuals from "source" patches through the metapopulation network (Hanski 1999). Metapopulation theory predicts that the dispersal corridors linking the network are absolutely critical to the long-term survival of the species (Gustafson and Gardner 1996; Hanski and Gaggiotti 2004). Historically, these corridors have likely been shaped by landscape factors such as elevation, slope, and land cover. In addition to these factors, anthropogenic changes to the Canadian Rocky Mountain landscape that have occurred over the past several decades may be imposing additional constraints on dispersal. If this new landscape lowers dispersal success, the current metapopulation framework may not be functioning in a way that would support historic numbers of wildlife and their populations (Lacy 1997). In particular, increased recreation, a growing web of transportation infrastructure and even logging outside the mountain parks all have the potential to limit dispersal across the matrix between habitat patches and thereby fragment and isolate wildlife populations (Harrison and Bruna 1999).

Alpine habitat is patchily distributed throughout the Canadian Rocky Mountains in an archipelago of high elevation islands. Mountain goats, bighorn sheep, hoary marmots and pikas (*Ochotona princeps*) are a few examples of high-elevation, localized species (HELS) living in these islands that form metapopulations, or basically a network of populations linked by dispersal (Hanski 1999). Loss of connectivity between populations can accelerate the loss of genetic diversity because of genetic drift (Hedrick 2005). These populations are demographically independent and naturally fragmented by intervening matrix habitat. Often resources are variable and local extinctions common. Nonetheless, some connectivity in the form of exchange of individuals among populations is presumed essential to maintain regional metapopulations.

In a study of habitat fragmentation and gene flow within a desert bighorn sheep (*O. c. nelsoni*) metapopulation, Epps et al. (2005) found that geographical distance was the prevailing natural barrier to gene flow and the whole metapopulation. They also found that human-made barriers (highways, canals, developed areas) might greatly reduce stability of the metapopulations by eliminating gene flow. Some HELS make seasonal altitudinal movements, which may affect how anthropogenic barriers and disturbance may influence gene flow and connectivity among populations (Rice 2008). Currently there is evidence that many marmot populations are disappearing from historically occupied areas, and few recolonizations have been detected (Griffin et al. 2008). Low connectivity and rates of dispersal among marmot populations have been identified as among the most important factors limiting recolonization and allowing at least occasional gene flow among isolated colonies. The effects of climate change on HELS and seasonal migrants are unclear (Inouye et al. 2000).

If metapopulation recovery and the recolonization of vacant habitat is impeded by either natural or anthropogenic factors that reduce gene flow and dispersal success, two management approaches might reverse this trend. First, it may be possible to restore severed connections between metapopulation patches through changes in land management. Currently, the locations of landscape corridors linking HELS habitat in the Canadian Rockies are not well known or understood, nor have the historic and anthropogenic landscape factors that may limit dispersal between patches been clearly identified. Dispersal dynamics are likely to differ between male and female mountain goats (Hutchins and Geist 1987). Many mountain ungulates have sex-biased dispersal: males are much more likely to travel long distances between populations, while females are probably the limiting factor in colonization events. Because recolonization of vacant habitat requires both sexes, understanding how gender affects dispersal would be a critical aspect to consider in park management plans. An assessment of the genetic structure and health of HELS within the mountain parks would also be useful in understanding the scope of the problem and help to focus limited available resources on populations that are threatened by loss of connectivity and anthropogenic fragmentation of habitat.

7.2. Status and knowledge of current distributions in the mountain parks

Currently the status and distribution of HELS is poorly understood in the mountain parks, and their genetic structure and health is even more ambiguous. Numerous natural and anthropogenic barriers may limit movement and metapopulation function. Therefore, park management should strive to obtain baseline population genetic information and determine how landscape features influence gene flow and exchange of individuals among populations.

7.2.1. Current distribution and occurrence

We extracted records from the Parks Canada Observation Master Database between 1978 and 2008 for the Banff and KYLL Field Units. We plotted the records of species occurrence for entries with UTM coordinates, including records with an estimated spatial error of 1 km or less. To minimize the effect of spatial error we overlaid species occurrence records with 1-ha-sized hexagons, and summed the total number of species occurrences for each hexagon.

Mountain goats. The occurrence data indicated there are six clusters with elevated numbers of observations (Figure 7.1). The clusters and all other observations were distributed relatively uniformly throughout the two Field Units. From north to south, light clustering of mountain goat observations was found in the Cataract Creek–Drummond Glacier area. South and to the east, more clustering of observations was found in the Flints Peak and Palliser Range, with higher density of observations in the latter area. Not surprisingly, a high number of observations and a large cluster occurred in the Lake O’Hara area. Similarly, a large cluster of mountain goat observations was found adjacent to Highway 93-South near Hector Gorge. Last, a small cluster of observations occurred in the Marvel Lake area. A total of 3,552 records were in the database, however, only approximately 200 were accurate to less than 500 m.

Bighorn sheep. The occurrence data suggested there are three main areas where a high number of bighorn sheep observations are made (Figure 7.2). Unlike the distribution of mountain goat observations, bighorn sheep records lie primarily along the northeastern edge of the Banff Field Unit, along the northern border of the Bow Valley watershed from Baker Creek to Cory Pass, and in a southwest–northeast axis between the Sunshine Ski Resort and Lake Minnewanka. High observation clusters were found in the Panther–Dormer Mountain area, the Stoney Pass and Cascade Valley area, and the Lake Minnewanka and Vermilion area. Noteworthy were large sections of the two Field Units with no or scarce observations recorded—the entire Yoho National Park, much of Kootenay National Park save the southern entrance and some sections along Highway 93-South, and the northern part of Banff. A total of 5,579 records were in the database, however, only approximately 200 were accurate to within 500 m.

<u>Hoary marmot</u>. Banfield (1974) describes the habitat of the hoary marmot as “so remote that very little has been written concerning its life history.” Along with Gadd (1995) they detail their habitat as the alpine tundra zone beyond treeline and as far as the limit of vegetation, between 6,800 and 8,000 ft in elevation. They may occasionally be found at lower elevations on the forest edge where rock piles and clearings may provide proper food and cover.

The hoary marmot observations are dispersed throughout the two Field Units, however, the actual number recorded is significantly lower than mountain goats and bighorn sheep (Figure 7.3). Marmot clustering was found in the Yoho Pass area, to the north near Helen and Fish Lakes, on the Lake Louise Ski Hill and in the area of Lake Louise. Numerous observations were made near Goodsir Pass, Redearth Pass and Egypt Lake, and near Stanley Glacier. A total of 107 records were in the database, however, only approximately 40 were accurate to within 500 m.

<u>Pika</u>. Few observation records were available for pika occurrence in the two Field Units. Only a handful of scattered observation locations were recorded: the Lake Louise Ski Hill, Goodsir Pass, Kaufmann Lake, and Vermilion Pass–Stanley Glacier area (Figure 7.4). A total of 20 records were in the database, however, only one record was accurate to within 500 m.

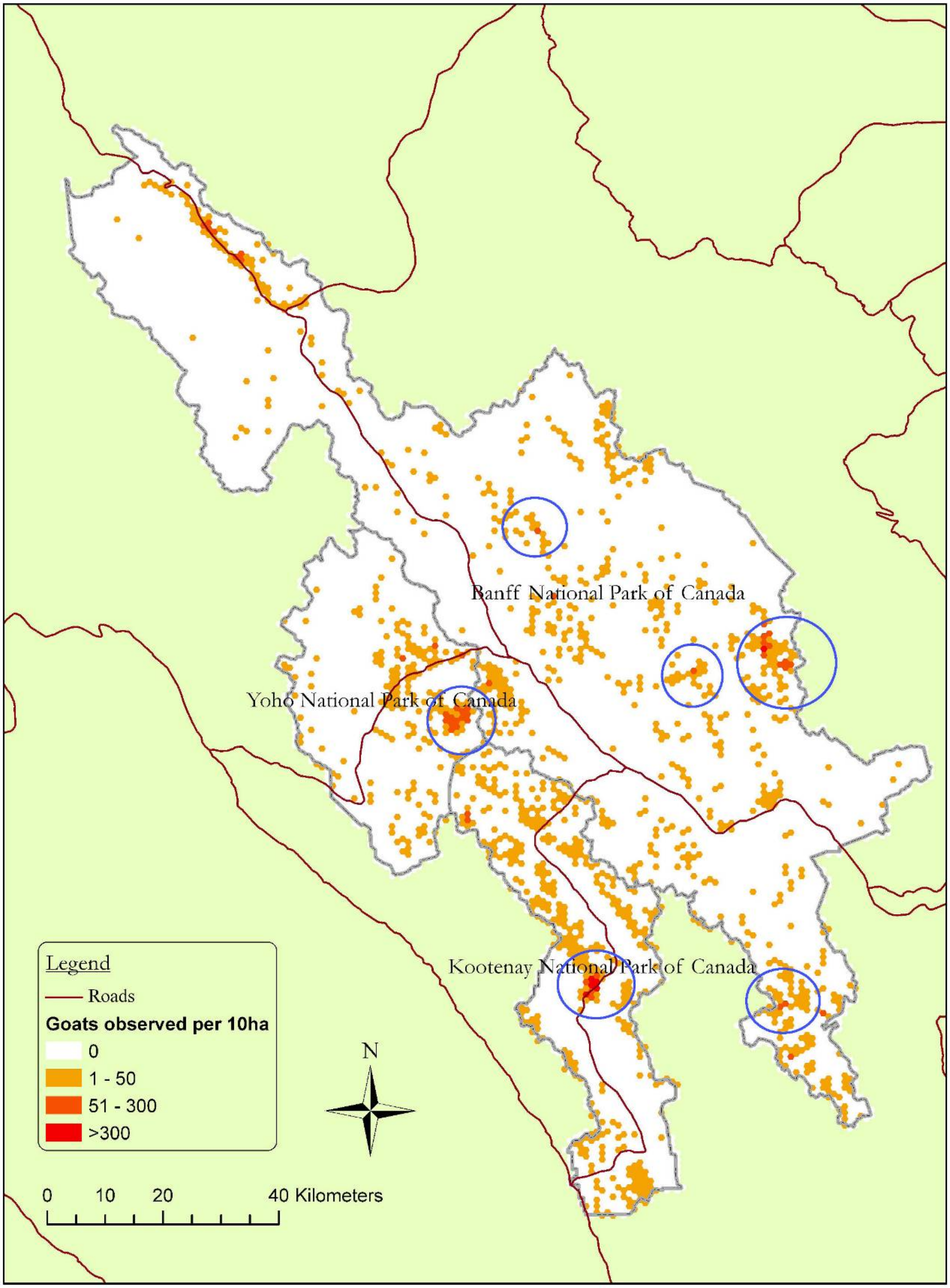

Figure 7.1: Species occurrence records for mountain goats in Banff and KYLL Field Units, 1978–2008.

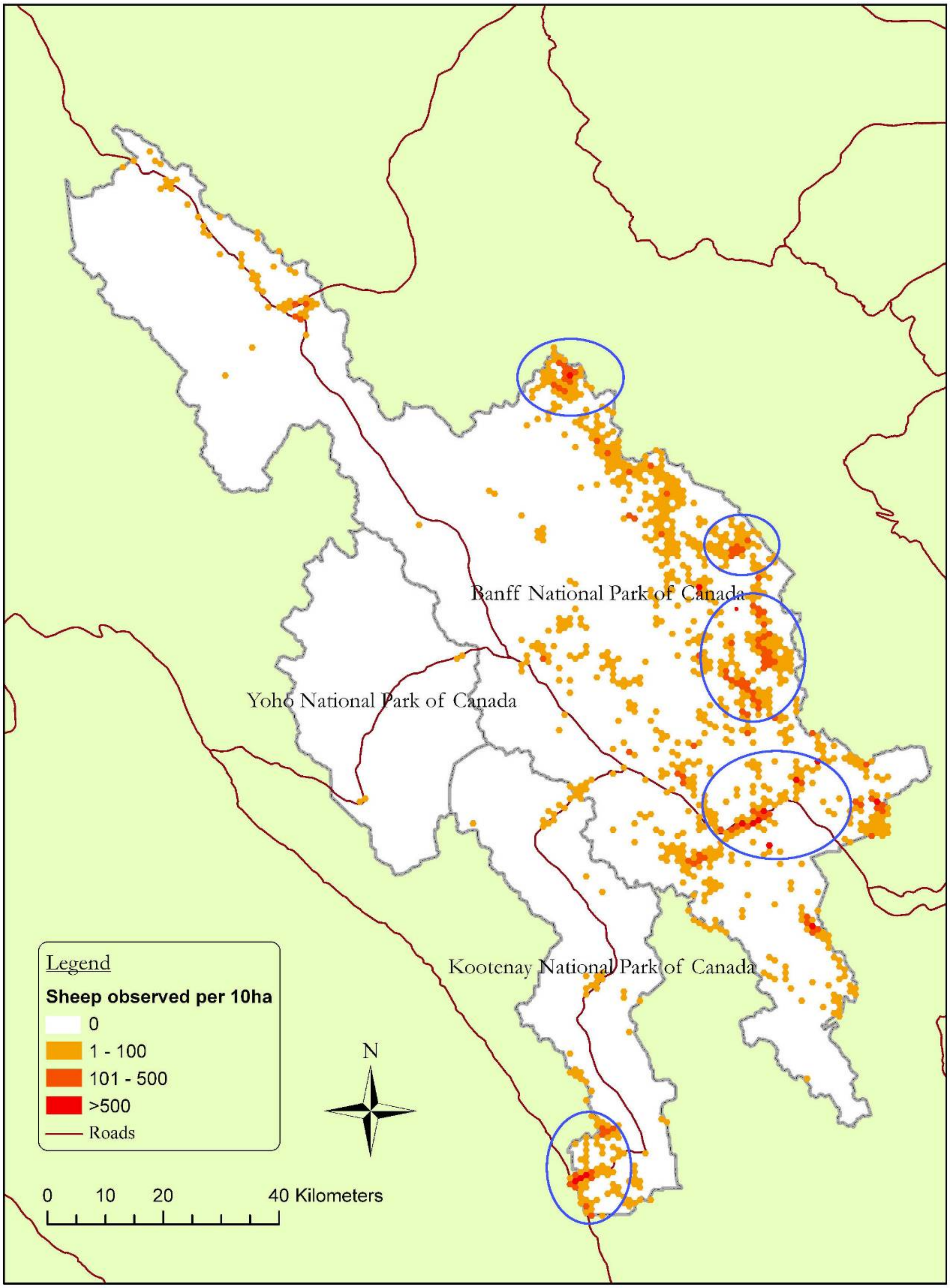

Figure 7.2: Species occurrence records for bighorn sheep in Banff and KYLL Field Units, 1978–2008.

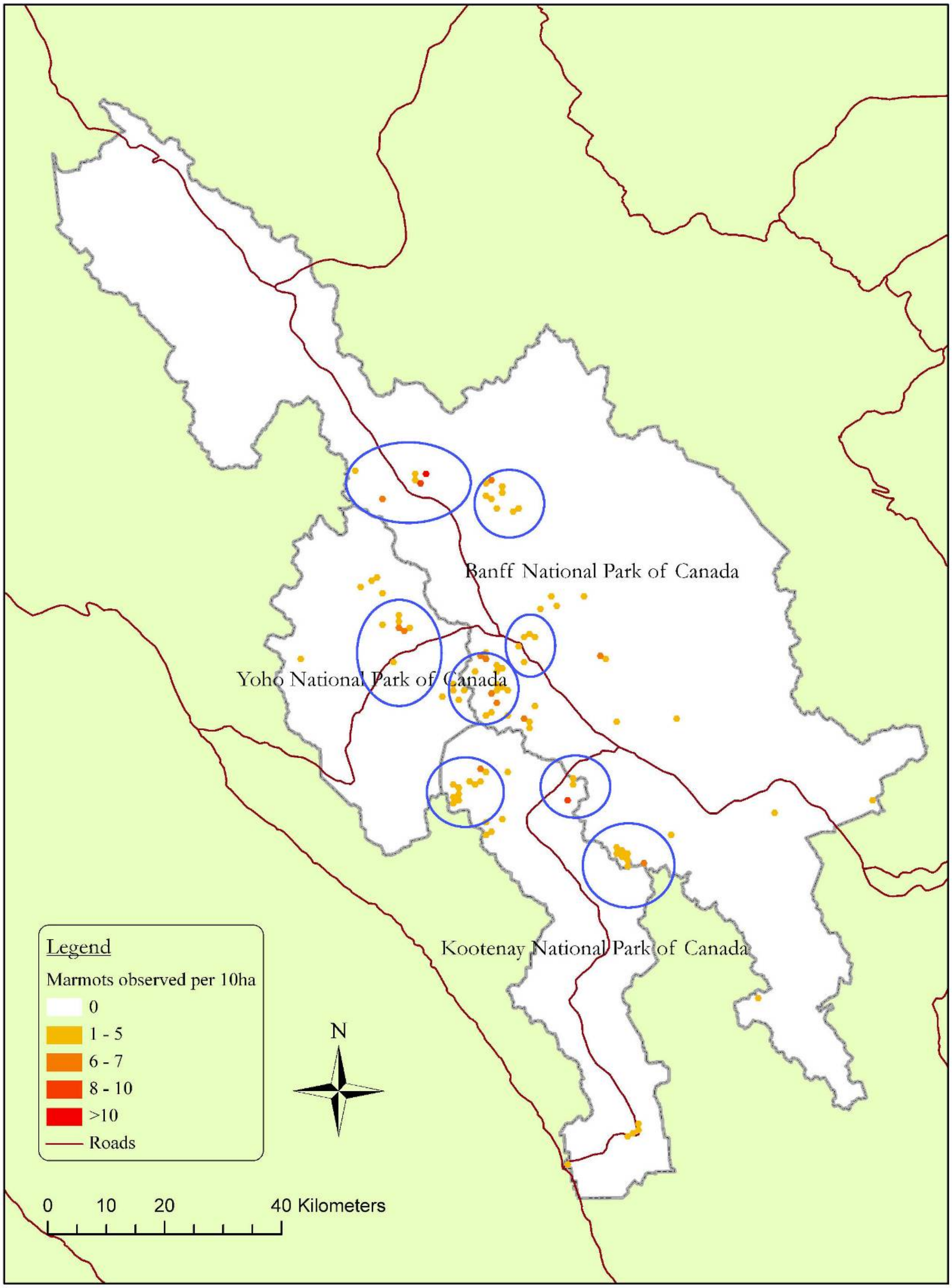

Figure 7.3: Species occurrence records for hoary marmots in Banff and KYLL Field Units, 1978–2008.

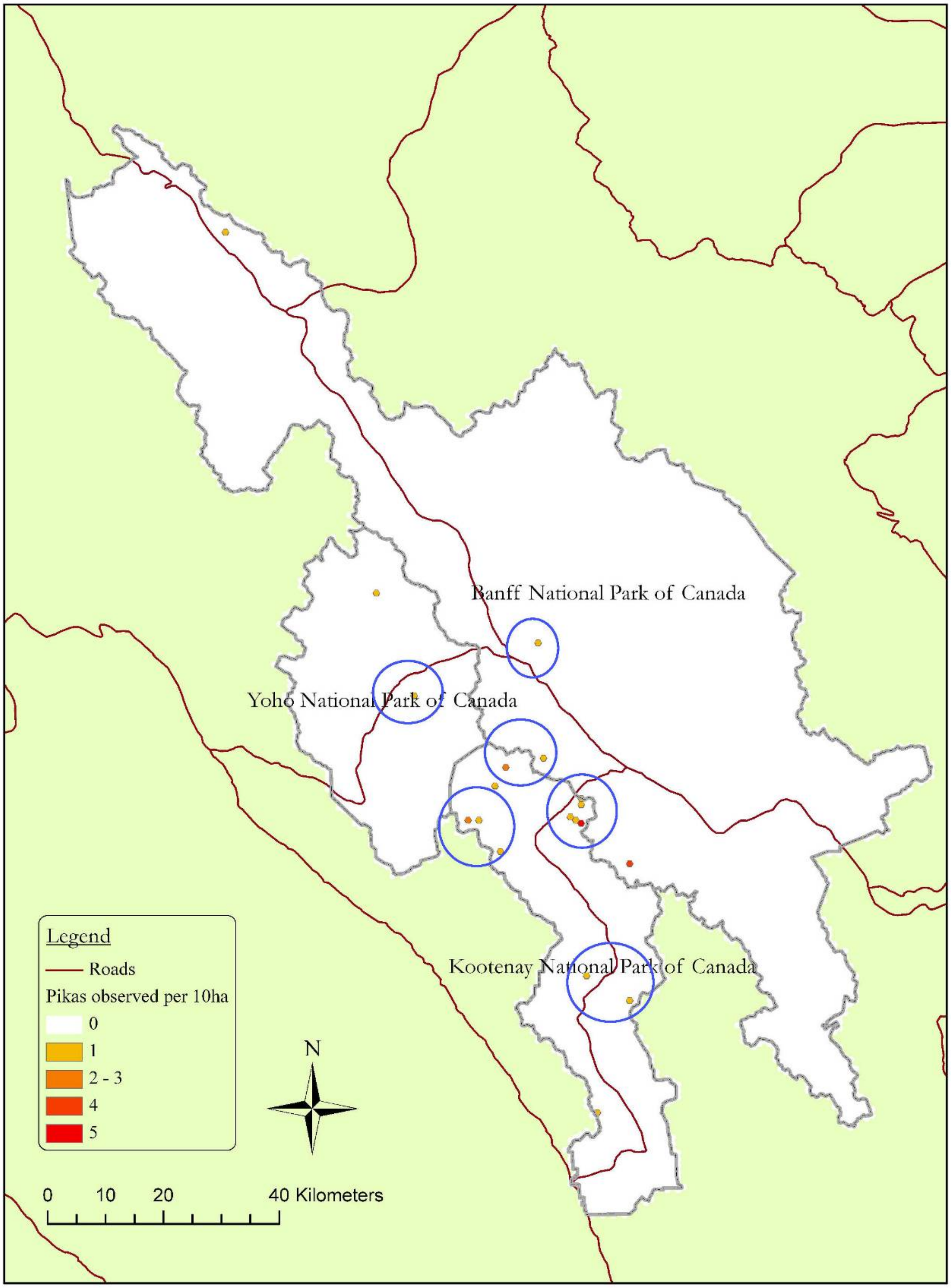

Figure 7.4: Species occurrence records for pikas in Banff and KYLL Field Units, 1978–2008.

7.2.2. Suggested target species for metapopulation assessment

The spatial pattern of recorded occurrences of mountain goats, bighorn sheep and hoary marmots suggests that populations are within distances that dispersal and exchange of individuals within the metapopulation is possible. The data for pika are too few to comment on at this point and, because of a probable lack of reporting, likely do not represent their actual status and distribution in the mountain parks.

The mountain goat and hoary marmot populations appear to be the most promising target species for obtaining baseline population genetic information to evaluate how landscape features influence gene flow and exchange of individuals among populations. Their populations are widely distributed throughout the two Field Units and dissected by the TCH and Highways 93-North and 93-South. There is no evidence to date that mountain goats have used the Banff wildlife crossings. However, their tracks can be easily confused with deer and bighorn sheep tracks and thus are not readily identifiable. Hoary marmots are of interest due to their recent colonization of the Redearth wildlife overpass in 2007 and 2008. Further, very little is known about the status, distribution and life history requirements of either mammal in the mountain parks. Should there be other Parks Canada data on the occurrence of these species not currently recorded in the Observation Master Database, then that data should be used to reassess whether bighorn sheep or pika may be more suitable than the other two species.

7.3. Conservation concerns related to highways

7.3.1. Policy framework

A strategic goal of the Banff National Park Management Plan is to maintain and restore habitat connectivity for large carnivores, ungulates and other wildlife in the park and on surrounding lands (Parks Canada 1997). Studying the effects of habitat fragmentation on particular species affected by human disturbance, such as highway infrastructure, and measures to restore essential movements between populations are recognized as key actions in the plan.

Populations of HELS in the two Field Units are demographically isolated and naturally fragmented by intervening habitat not optimal for dispersal and population exchange. The loss of connectivity between populations and the potential loss of genetic diversity because of inbreeding and genetic drift are a concern for the conservation and management of the ecological integrity of the park ecosystem. Previous environmental assessments of the impacts of twinning the TCH through Banff have not indicated that any of the HELS would be affected (Anonymous 1995; Golder Associates 2004). Valued ecosystem components (VECs) were identified as a focus in the TCH Phase IIIB Environmental Screening process (Golder Associates 2004). The wildlife species selected as VECs for the assessment were elk, deer, moose, grizzly bear, black bear, wolf, lynx, wolverine, harlequin duck (*Histrionicus histrionicus*) and boreal toad. In addition, two general classes of wildlife were also considered: small- to medium-sized mammals and passerines (songbirds).

Mountain goats and bighorn sheep were species considered, but not selected as VECs because habitats for these species are not present close to the TCH, or individuals are not known to cross the TCH frequently enough to warrant their inclusion (Golder Associates 2004). The screening report did recognize the importance of occasional movements in maintaining genetic variation within and between populations.

7.3.2. Road-related mortality

The TCH Phase IIIB Environmental Screening report (Golder Associates 2004) indicated that Flaa (1989) reported there were no mountain goats or bighorn sheep killed in collisions with vehicles on this highway section between 1977 and 1987. However, our query of the mortality database for both Field Units indicated that between 1982 and 2007 there were seven mountain goats killed in accidents with vehicles: three on the TCH in Yoho National Park, two on Highway 93-South in Kootenay National Park, and two in Banff (Sunshine Road and Highway 93-North). No bighorn sheep or pika road-kill records were found in the database, however, six hoary marmots were recorded as road-killed. One marmot was killed at an unknown highway location in Kootenay National Park and five were killed in Yoho National Park (three on the TCH, one on the Yoho Valley Road, and one on an unknown highway).

7.3.3. Wildlife crossing structure use

Although on none of the TCH phases were wildlife crossing structures in Banff designed for improving connectivity for HELS (Anonymous 1995), monitoring since 1996 has shown that bighorn sheep have used the crossing structures 4,592 times (see Table 3.3). Nearly all (>99 percent) detected bighorn sheep crossings occurred on Phases I and II. Bighorn sheep are relatively abundant above Vermilion Lakes from Mount Norquay to Cory Pass. Bighorn sheep have been detected 29 times using the Healy wildlife underpass, which represents the western limit of the main area of movement across the TCH Phase II. To the west of Healy wildlife underpass, one bighorn sheep was detected using the Wolverine wildlife overpass and 26 were observed using Redearth Creek and 8 were used Copper. These records and our analyses suggest that open-span bridge underpasses like those on Phases I and II are suitable for bighorn sheep. Mountain goats and pikas have not been recorded using any of the TCH wildlife crossing structures to date. In 2007, we witnessed hoary marmots colonizing the Redearth wildlife overpass structure. During the summers of 2007 and 2008 marmots were photographed on top of the overpass as well as creating burrows in the rock structure on both headwalls.

Like previous phases of the TCH twinning project, wildlife crossing structures planned for Phase IIIB were not designed for HELS (Golder Associates 2004). Nevertheless, the wildlife crossings are on average larger and more open than underpasses on previous phases. Several large wildlife overpasses (60 m wide) are planned on this 30-km section of highway. Larger and more open structures on Phase IIIB would likely provide for more suitable passage of HELS, provided there is sufficient escape terrain nearby for mountain goats and bighorn sheep and protective cover for hoary marmot and pika (Singer and Doherty 1985). It is uncertain whether the Phase IIIB crossings will improve connectivity and allow for exchange of individuals among populations should dispersal take place. The effect of a changing climate on the metapopulation structure of these HELS is in question as there are reports that climate change has affected other high-elevation species, including the yellow-bellied marmot (*M. flaviventris*; Inouye et al. 2000). Despite HELS receiving scant attention in the Phase IIIB environmental screening, maintenance of their metapopulations in the mountain parks is critical for the long-term ecological integrity of the regional park ecosystem. Research on HELS is highly recommended in order to monitor population status, trends and metapopulation persistence through dispersal and gene flow.

7.3.4. Recommendations

Below we outline a step-wise data collection and analytical process with the aim of providing the needed baseline information to survey HELS populations, analyze genetic health, and model dispersal corridors for exchange of individuals in metapopulations. Step 1 is described in detail below and provides the initial baseline population distribution data. Steps 2–4 should be conducted as part of assessments of the Phase IIIB mitigation to increase connectivity of VECs (Golder Associates 2004) across the TCH. Assessments need not be targeted at all four HELS but select species that will provide the greatest information on mitigation performance and regional metapopulation persistence.

1. *Current distribution and occurrence of HELS*
    a. Describe species occurrence in Field Units from Master Database records
    b. Identify regional metapopulations and their local populations
    c. Select populations for genetic sampling to determine genetic structure and relatedness
2. *Survey populations and collect genetic samples (fecal)*
3. *Conduct genetic analysis to determine population genetic structure and relatedness*
4. *Model dispersal and corridors for exchange using landscape genetics*
    a. Assess how natural and anthropogenic barriers affect connectivity among populations
    b. Identify priority areas for mitigation and assessment of adequacy of Phase IIIB mitigation for increasing connectivity and dispersal among populations

A rigorous, long-term (≥5 years) monitoring program should be designed to assess the impacts of the TCH Phase IIIB on HELS and determine whether mitigation improves connectivity and exchange of individuals among populations. Steps 2 and 3 should be conducted during Year 1 and repeated at Year 5 to examine changes in metapopulation structure and integrity with mitigation measures in place.

8. OUT OF BANFF: DATA NEEDS FOR HIGHWAY MITIGATION PLANNING IN KYLL

Until now a large part of our research has been situated in the Banff Field Unit as the mitigated sections of the TCH lie entirely within that management district. Apart from the TCH, other highways in both Field Units also have significant impacts on wildlife populations. Highway 93-South, the TCH in Yoho National Park, and to a lesser extent Highway 93-North historically have been major locations for wildlife mortality and continue to be today (Poll 1989; Clevenger et al. 2002; Caryl 2003).

Highway 93-South is of particular concern to management because mitigation from a highway twinning project is unlikely within the next 20 years. Increasing traffic volumes, partly associated with Calgary-driven development in the Columbia Valley, and a rapidly changing landscape are two factors that create an unsustainable situation for wildlife in Kootenay National Park. Therefore, in the short term management must devise a mitigation strategy that will be relatively low-cost and effective in protecting wildlife populations from growing transportation impacts.

The TCH in Yoho National Park has lower traffic volumes than the sections in Banff, but has had consistently high mortality rates for wildlife in the last decade (Parks Canada, unpublished data). From 1981 to 2002, there were on average 0.4 large mammal road-kills per km, the same mortality rate as on Highway 93-South (Clevenger et al. 2002). The government of British Columbia is twinning the TCH up to the west boundary of Yoho National Park. Therefore, the TCH in Yoho National Park is the next staging area for highway twinning in the Mountain Parks.

Because of the imminent conflicts between transportation and wildlife conservation, Highway 93-South and the TCH in Yoho National Park are emerging to the forefront of environmental stakeholder and KYLL resource management concerns. We provide discussion about the significance of these highways at the scale of the larger study area we have been working in. We also provide recommendations for future monitoring and research on these highways so Parks Canada management is able to make informed decisions regarding forthcoming research, planning and conservation actions.

8.1. Highway 93-South

Based on recommendations from Huijser et al. (2008) short-term, site-specific mitigation is planned as part of a Parks Canada-funded "Action on the Ground" project. Pre-mitigation baseline information will need to be collected for three monitoring objectives: demographics, movement and mortality. Baseline information from these objectives can be compared with post-mitigation data to accurately measure the impact of mitigation and change in the values of the three parameters.

Baseline demographic information is needed on population distribution and relative abundance of target species in the section of highway planned for mitigation. Information can be obtained from transects or grid-based species occupancy surveys (Long et al. 2008). Species occupancy data are obtained by surveys (single species or multiple species) that detect presence or absence of a focal species. While the presence of a species can be confirmed at a location, it is generally impossible to confirm species' absence. Analytical methods are available today that account for detection probability and model species distribution (MacKenzie et al. 2006).

Movement data on select focal species will be important to measure their rate of highway crossing prior to mitigation and identify the location of key crossing zones. Information on the crossing zones will be helpful to guide the design of mitigation planned on Highway 93-South. Movement data are best obtained by either snowtracking or radio/satellite telemetry-based monitoring of movements.

Last, mortality data from large mammals in the study area need to be collected prior to mitigation to be able to assess changes in rates of mortality after mitigation. Studies of road mitigation measure performance have typically had low inferential strength due to the lack of pre- and post-mitigation study design (Roedenbeck et al. 2007). The collection of road-kill data needs to be systematic and sampling effort and intensity consistent between years.

During the post-mitigation period, the same data on demographics, movement, and mortality need to be collected over at least the same period as pre-mitigation, and preferably over a longer period, to rigorously assess the impact (positive or negative) that mitigation has had on the target wildlife populations.

8.2. Kootenay grizzly bear monitoring

During the summer of 2008, vehicles on Highway 93-South struck and killed two grizzly bears. In the last 20 years only on one occasion was a grizzly bear killed on Highway 93-South—in late 1999 approximately 2 km north of Vermilion Pass in the Bow Valley watershed. The increasing traffic volumes on Highway 93-South, combined with the fact that much of the Kootenay and Vermilion Valleys are transforming into excellent bear habitat due to the 2001 and 2003 fires, will only exacerbate conflicts between bears (and other wildlife) and transportation.

There is no doubt that habitat conditions for wildlife in the Kootenay and Vermilion valleys are going to improve over time. However, little is known about the local grizzly bear population in terms of numbers, distribution and movement between neighbouring watersheds, such as the Bow Valley. Currently the Kootenay Valley is one of the few areas in the Canadian Rocky Mountains where grizzly bear data are lacking. If data were available they would seamlessly fit into a surrounding matrix of extensive grizzly bear genetics data obtained during the last 10 years (Proctor 2003; Stenhouse et al. 2005; Clevenger and Sawaya submitted). Given the pace at which landscape change will occur in this region over the next 20 years, it will be important for management to understand early on the demographics of the grizzly bears in Kootenay National Park. We strongly recommend that baseline information start to be collected on grizzly bear distribution and minimum population size as soon as possible. As part of this work, a critical component would be the development of a monitoring scheme to assess population trend using non-invasive methods. Results from the DNA-based bear research in Banff will be of great value in designing a research plan to sample the grizzly bear population. What we have learned from the efficacy of different sampling techniques in Banff can be applied to the Kootenay situation. Relatively cost-efficient means of sampling the grizzly bear population can be planned including methods to conduct the field sampling using rub trees checked by volunteers or citizen scientists. It will be of great interest for management to know what movement and exchange occurs between the Kootenay/Vermilion Valleys and the Bow Valley watershed. Genetic data from the three-year bear DNA sampling effort in Banff can be used to examine movement between the two watersheds.

8.3. TCH in Yoho National Park

The next phase of TCH twinning will occur in Yoho National Park. This is an area where data has been collected assiduously the last 10–15 years on incidence of wildlife road-kill, winter road crossings and their locations (Parks Canada, unpublished data) and to some extent animal movements (Paquet et al. 1999). To properly plan for impending TCH twinning in Yoho National Park it will be important to continue collecting mortality data with the same intensity and effort as in the past. Current data collection by the Warden Service should suffice. Winter road surveys should be re-initiated in order to obtain data on road crossings by wildlife, particularly large carnivores. The winter season is long and winter tracking conditions excellent in Yoho National Park, thus enabling good data collection and sample sizes from rare carnivores like wolverine and lynx. Protocols for winter road surveys are in place. This work should be part of the TCH Phase IIIB wildlife monitoring plan currently being prepared.

Identifying movement zones on the TCH will be difficult without radiotelemetry. The winter road surveys will assist with this type of data, however, they will be limited to winter movements. There are empirical data available from numerous radiotelemetry studies conducted in the Banff and KYLL Field Units that may be used to generate resource selection function maps for use in modeling least-cost paths of animal movement (Crooks and Sanjayan 2006). Data obtained from wildlife mortalities and winter road crossings on the TCH in Yoho can be used to validate least-cost path model results (see Clevenger and Wierzchowski 2006 as an example). Validation of model results is critical, however, independent data often are not available to assess the accuracy of most models (Rykiel 1996). These regional movement models should also form part of the upcoming TCH Phase IIIB wildlife monitoring plan.

These data form a solid starting point for initiating work toward recommendations for future TCH mitigation measures in Yoho National Park. Once potential mitigation sites are identified, site inspections in the field are conducted to better assess wildlife movement potential in each area, make fine-scale adjustments of mitigation placement, and discuss specific design concepts.

8.4. Future research activities in Banff and KYLL Field Units

As part of the current twinning of the TCH Phase IIIB a wildlife monitoring and research plan is being prepared. The proposed monitoring plan will guide evaluations of the newly constructed mitigation measures between 2009 and 2014. At the time of writing, the monitoring plan has not been finalized but the main components of the monitoring and research are shown in Table 8.1.

Table 8.1: Proposed monitoring of Trans-Canada Highway Phase IIIB mitigation measures to meet transportation and resource conservation management objectives.

No.	Management objective	Monitoring question	Methods	Target species
1	**Reduce wildlife–vehicle collisions (WVCs)**	Has mitigation reduced mortality of wildlife on the TCH? Are there fewer WVCs after mitigation compared to before?	**WVC data reporting & collection** PCA warden service MIR–WTI personnel	Elk, Deer Black bear
2a	**Restore population-level movements across the TCH** Improve habitat connectivity and genetic interchange for key species	Are the wildlife crossings (WCs) being used? How many individuals are using the WCs? And are males and females using the WCs?	**DNA/Hair sampling for both spp.** Bears using WCs : Barbed wire Bears in local population: Rub trees Lynx using WCs: Backtrack in snow lynx found using WCs Lynx in local population: Snow transects adjacent to WCs	Bears (grizzly & black bear) Lynx
2b	**Identify key wildlife crossing design criteria** What are the factors associated with WC that facilitate passage of different wildlife species?	How do we design WCs for different large mammals? Is WC size important? Is nearby habitat important? Is amount of human use a factor affecting use? How do we design WCs for wolverine & lynx?	**WC monitoring data used in multivariate analysis** Observed use: Remote cameras Expected use: Species occurrence surveys (local-level)	All large mammals coyote-sized and larger

2c	**Evaluate whether wildlife use new or modified culverts and their configurations (medians)** Do wildlife (small and medium-sized mammals) use newly installed or modified culverts?	Are there culvert design deficiencies? What are they? Do new culverts pass more wildlife than existing culverts? Do wildlife use culverts that open in centre median? How do we best design culverts for passage of small and medium-sized wildlife?	**Culvert monitoring data used in multivariate analysis** Observed use: Track plates (sooted) in culverts Expected use: Snow transect adjacent to culverts	Small and medium-sized mammals (coyote-size and smaller)
3	**Increase the distribution and area used by wildlife adjacent to IIIB corridor and in the larger landscape** What species are present and what is their relative abundance in areas adjacent to WC and in the larger landscape	Does mitigation result changing species distributions and habitat occupancy? Are species using more of the Bow Valley and occupying more of their potential habitat after mitigation?	**Technique varies by species groups** Species occurrence surveys determining presence–absence in local-level (see 2b) and larger landscape	Local level: All large mammals using WC Landscape: Wolverine & lynx
4	**Reduce fence intrusions into TCH right-of-way by fencing and Texas gates** How effective are fencing and Texas gates for different wildlife in project area?	Does fencing and Texas gates keep animals off roadway and from being killed?	**Fence intrusion data reporting and collection** PCA warden service MIR–WTI personnel	Large mammals coyote-sized and larger

5	**Restore harlequin duck movements across TCH Phase IIIB** Are harlequin ducks (including adult females and broods) able to move freely between Bow River and tributary streams where nesting/hatching occurs?	Does mitigation (Moraine Creek bridge) allow ducks to cross the TCH?	**Passive Integrated Transponder (PIT) technology** Capture and PIT implant breeding females; PIT antenna monitors movements across the TCH and on the tributary/breeding streams.	Harlequin ducks
6	**Evaluate TCH effects on population genetics of localized wildlife populations (sheep, goats)** Is the TCH a significant factor affecting genetics of high-elevation localized species?	Has the TCH caused the genetic integrity of populations to degrade and become more isolated?	**DNA/Pellet sampling** Pellet collection among select subpopulations	Mountain goat Bighorn sheep
7	**Identify potential sites for WCs. Prioritize sites by ecological importance (1°, 2°, 3°)** Where are the key conflict areas for wildlife movement across the TCH in Kicking Horse Canyon?	Where do we locate WCs in Kicking Horse Canyon and what should the WCs look like (dimensions, configuration etc)?	**Modeling animal movement** Develop empirically based animal movement models (as done for Phase IIIA); Validate models with independent field data from (1) road-kill locations, and (2) winter road survey data of snow tracking movements across TCH; Site visits to locations identified by model to develop conceptual design plans.	Large mammals (Bears, wolves, elk, sheep, goats)

In addition to research and evaluation of the Phase IIIB mitigation there are a number of research activities that the BWCP is pursuing. These activities are in various stages of development, from early phases of study design, pilot testing, in progress, and completed. These activities are shown below in Table 8.2. Many of the research activities in Table 8.1 and Table 8.2 could be conducted as graduate research projects.

Table 8.2: Future research activities as part of continuing long-term research in the Banff and KYLL Field Units.

Research question	Field component required?	Data collection status	Highway or TCH Phase
Does variable-dimension fencing deter small mammals from accessing the right-of-way?	yes	complete	IIIA IIIB
Do overpasses improve landscape connectivity for: (a) forest songbirds? (b) small mammals?	yes	pilot testing (a)	IIIA IIIB
Do predators exploit highway mitigation measures for prey capture?	no	complete	I, II, IIIA
Does human use of wildlife crossing structures affect wildlife movements?	no	complete	I, II, IIIA
How do wildlife crossing structures facilitate population-level movements of territorial species such as martens? Does "corridor plugging" for territorial species occur at wildlife crossings?	yes	pilot testing	I, II, IIIA, IIIB
How do wildlife crossing structures facilitate movement of lynx?	yes	pilot testing	IIIB
Fragmentation effects of the TCH and restoration of habitat connectivity for wolverine using predictive occurrence modeling	yes	In preparation	IIIB
What is the optimal design for mitigation fencing along Highway 93-South?	no	complete	93-South
What is the optimal spacing of wildlife crossing structures during simulated foraging, dispersal and migratory movements?	no	pilot testing	n/a

Do wildlife crossings facilitate seed dispersal by mammalian frugivores (e.g., martens)?	yes	pilot testing	IIIA, IIIB
How does traffic affect wildlife use of crossing structures?	no	complete	I, II, IIIA
How do animals respond to wildlife crossings over time?	yes	in progress	I, II, IIIA
How are wildlife crossing events clustered in space and time for each species?	no	complete	I, II, IIIA
Do highways affect gene flow and genetic structure of low-mobility and semi-arboreal vertebrates?	yes	in preparation	I, II, IIIA, IIIB
Do median barriers affect movement of mammals across roadway?	yes	in preparation	IIIA
Does Trans-Canada Highway mitigation fencing reduce mortality of ungulates and carnivores in Banff National Park and the province of Alberta?	no	in progress	IIIA, TCH-Canmore
Do Texas gates prevent fence intrusions by wildlife?	yes	in preparation	I, II, IIIA, IIIB

9. TECHNOLOGY TRANSFER

9.1. Workshops and professional development activities

2008

Organized a two-day workshop titled *Strategies to Reduce Animal–Vehicle Collisions in Alberta,* which took place in Calgary, 26–27 June, 2008. The workshop was organized by Red Deer College (Sandra MacDougall) and WTI (T. Clevenger, A. Ford) and funded by Alberta Transportation.

The BWCP is continuing to provide guidelines from the planning, design, monitoring and research of 24 planned wildlife crossing structures along 15 miles of Interstate 90 expansion in the Snoqualmie Pass in Washington.

The Southern Rockies Ecosystem Project (in conjunction with the Colorado Department of Transportation) continues to collaborate with T. Clevenger regarding field studies, data requirements, placement and design of a vegetated wildlife overpass on Interstate 70 on Vail Pass in Colorado.

A wildlife–vehicle collision and crossing mitigation plan was prepared for Highway 93-South in Kootenay and Banff National Parks. Dr Marcel Huijser of WTI led the report preparation and was assisted by the BWCP staff.

2007

Parks Canada created its second poster of wildlife crossings and the species that use them along the Trans-Canada Highway in Banff National Park. These are used for K–12 educational outreach to educate students as well as the general public on the findings of T. Clevenger's 10 years of research on Banff's 24 wildlife crossings.

The BWCP provides guidelines from the planning, design, monitoring and research of 24 planned wildlife crossing structures along 15 miles of Interstate 90 expansion in the Snoqualmie Pass in Washington.

The Southern Rockies Ecosystem Project (in conjunction with the Colorado Department of Transportation) establishes collaboration with T. Clevenger regarding field studies, data requirements, placement and design of a vegetated wildlife overpass on Interstate 70 on Vail Pass in Colorado.

2006

Organized a training course for Canadian transportation engineers, *Mitigating Transportation Impacts on Wildlife and Fisheries.* The two-day course covered the principles and techniques for mitigating highways for wildlife and fisheries. It was held on 12–13 October, 2006, at the Banff Centre. A total of 23 transportation engineers, primarily from Canada, took part. It included a field trip to several Banff wildlife crossings and current Trans-Canada Highway expansion (Phase IIIB) near Lake Louise.

The editorial board of *TR News*, the full-color magazine of the Transportation Research Board of the National Academies of Science, accepted an eight-page article for publication (including photos) on the BWCP for its Spring 2007 issue.

T. Clevenger led a group of 18 students and four course instructors to the Vermilion wildlife underpass (Trans-Canada Highway) and discussed the long-term research on the Banff wildlife crossings. The group was part of a Jay Ingram's intensive two-week course at the Banff Centre on "Science Communications." The course provides professional development for scientists, journalists, public and private sector communications professionals, and educators responsible for communicating about science.

The Whyte Museum of the Canadian Rockies in Banff hosted "*Wildlife Crossings,*" an exhibit of the BWCP that included videos, maps, photographs and interactive games. The exhibit ran from April to October and throughout the tourist season. Over 19,000 visitors attended the exhibit and many signed the register at the exhibit. The Whyte exhibit was nominated for and awarded a "Banff Tourism Heritage Award" for *Most Innovative Commitment to National Park and World Heritage Site Awareness.*

Directors of Calgary's Glenbow Museum visited the Whyte Museum "*Wildlife Crossings*" exhibit in September 2006. The Glenbow Museum expressed interest in housing the exhibit, however following the museum's change in administration, plans for its "Van Horne" exhibit on transportation in the West, which *Wildlife Crossings* would have been a part of, were dropped.

Parks Canada created its first poster of wildlife crossings and the species that use them along the Trans-Canada Highway in Banff National Park. These were used for K–12 educational outreach to educate students as well as the general public on the findings of T. Clevenger's 10 years of research on Banff's 24 wildlife crossings.

The American Museum of Natural History in New York City opened a special display on the Yellowstone to Yukon Conservation Initiative. It includes some of Tony Clevenger's photos of the Banff Wildlife Crossings Project.

The Montana State University's Renne Library hosted an author's reception of MSU faculty. T. Clevenger submitted a book he co-authored, "*Assessing and Managing the Ecological Impacts of Paved Roads*," published for the U.S. National Research Council by the National Academies Press in Washington D.C.

An article on T. Clevenger's research on wildlife crossings of the Trans-Canada Highway in Banff National Park was selected by the international conservation group "The Wildlands Project" for its Spring 2006 newsletter, and the Yellowstone-to-Yukon Conservation Initiative Winter 2006 newsletter.

The Yellowstone-to-Yukon Conservation Initiative's Board of Directors and staff were given a tour of several of the wildlife crossings, an overview of the findings of the project, and a visit to the Whyte Museum's display.

A group of students and instructors from Jay Ingram's two-week course Banff Centre course called "Science Communications" was taken to a wildlife underpass and visited the Whyte Museum's display. The course provided professional development for scientists, journalists, public and private sector communications professionals, and educators responsible for communicating about science.

A four-page colour brochure titled *The Banff Wildlife Crossings Project—Lessons from highway wildlife crossings in a North American protected area* was produced as a handout for potential funders and visitors to the Banff project, and for professional meetings.

9.2. Science and management conference presentations

2009

International Workshop for Stream Corridor Restoration, Seoul, South Korea, 26–28 February 2009.

Keynote address: “Lessons learned from long-term research on road mitigation measures for wildlife in Banff National Park, Alberta, Canada: Implications for river restoration in Korea" (T. Clevenger).

Symposium presentation: “Planning, design and performance evaluation of mitigation measures for wildlife populations” (T. Clevenger).

2008

Pacific Northwest Wildlife Connections Conference, Portland, OR, 19–20 Oct 2008. *Keynote address*: “The changing landscape of transportation: Designing roads for wildlife conservation” (T. Clevenger). *Symposium presentation*: “Mitigating fragmented landscapes” (T. Clevenger).

American Association of State Highway Transportation Officials (AASHTO), Technical Committee on Environmental Design meeting, Coeur d’Alene, Idaho, 23 Sept. 2008. *Presentation*: “A road runs through it: Mitigating road impacts in wildlife habitat” (T. Clevenger)

Alberta Transportation Workshop: Strategies to Reduce Animal–Vehicle Collisions in Alberta, Calgary, 26–27 June 2008. *Presentation*: “Case study: Research results of wildlife crossing mitigation in Banff National Park, Alberta” (T. Clevenger); “Mitigation: The Old and New of Collision Reduction Techniques (P. McGowen, WTI).”

Curso-Taller: Impactos de la Infraestructura sobre la Vida Silvestre del Área de Conservación Guanacaste, Parque Nacional Santa Rosa, Costa Rica. 17–20 June 2008. *Presentations: 1*. “Road ecology: basic concepts and applications.” *2*. “Mitigation strategies on the Trans-Canada Highway in Banff National Park, Alberta.” *3*. “Planning considerations for wildlife crossing mitigation” (T. Clevenger).

Ontario road ecology group symposium, Toronto Zoo, 23–24 April 2008. *Keynote address*: “The successes of road ecology mitigation in western North America” (T. Clevenger); *Presentation*: “Habitat linkage assessments: methods and considerations” (A. Ford).

Seminar on linear infrastructure impacts on large carnivores, Lamego, Portugal, 18 April 2008. *Presentation*: “Long-term monitoring and DNA-based approaches for restoring landscape connectivity across transportation corridors in the Canadian Rocky Mountains” (T. Clevenger).

Seminar on Road Ecology, Universidade de Lisboa, Portugal, 15 April 2008. *Presentations: 1*. "Road ecology: Concepts and applications for integrating ecology into sustainable transportation systems." *2*. "Long-term monitoring and DNA-based approaches for restoring landscape connectivity across transportation corridors in the Canadian Rocky Mountains" (T. Clevenger).

Highway 3 Transportation Corridor Workshop, Fernie, BC, 28–29 Jan. 2008. *Presentation:* "Management tools for communities and landscapes: Mitigating road impacts for wildlife" (T. Clevenger).

California Department of Transportation Road Ecology Meeting, Asilomar, CA, 16 Jan 2008. *Keynote address:* "The changing landscape of transportation: Designing roads for wildlife conservation" (T. Clevenger).

2007

Managing Environmental Impacts of Linear Corridors and Infrastructure, Revelstoke, BC, 7–8 November 2007. *Presentation*: "Banff's Highway Mitigation: Effectiveness and Future Development" (M. Sawaya, T. Clevenger, T. McGuire).

Universidad de Complutense, Madrid, Spain, "Cursos de Verano," El Escorial, 16–20 July 2007. *Presentation*: "Restauración de hábitat en el entorno de infraestructuras: soluciones para grandes mamíferos" (Habitat Restoration around Linear Infrastructure: Solutions for Large Mammals) (T. Clevenger).

International Conference on Ecology and Transportation, Little Rock, AR, 21–25 May 2007. *Presentation*: "Applications of local-scale research for planning and evaluating measures designed to restore regional landscape connectivity" (T. Clevenger). *Title (poster):* "Measuring Gene Flow Across the Trans-Canada Highway and Population-Level Benefits of Road Crossing Structures for Grizzly and Black Bears in Banff National Park, Alberta" (Sawaya, Clevenger, Kalinowski).

Non-profit Conservationists and Transportation: New Intersections, Workshop and Training Course, Bozeman, MT, 29–30 March 2007. *Presentation*: "Mitigating highways for landscape connectivity" (T. Clevenger).

2006

Transportation Research Board, Annual Meeting. "Wildlife and Highways workshop," Washington DC, 22 January 2006. *Presentation*: "Lessons from long-term monitoring, 1996–2006, Canadian Rocky Mountain Parks" (T. Clevenger).

Future Landscapes in the Canadian Rockies: Integrating Human Dimensions with Ecosystem Management, Central Rockies Ecosystem Interagency Liaison Group (CREILG), Canmore, Alberta, 14 November 2006. *Presentation*: "Management tools for landscapes: Mitigating road impacts for wildlife" (T. Clevenger).

9.3. Scientific publications

9.3.1. In press or published

Gunson, K., A. P. Clevenger, A. T. Ford, J. Bissonette and A. Hardy. In press. A comparison of data sets varying in spatial accuracy used to predict the occurrence of wildlife–vehicle collisions. *Environmental Management.*

Ford, A. T., A. P. Clevenger and A. Bennett. In press. Comparison of methods for monitoring wildlife crossing structures. *Journal of Wildlife Management*.

Rettie, K., A. P. Clevenger and A. T. Ford. In press. Innovative approaches for managing conservation and use challenges in the national parks: An example from Canada. In: *Handbook of Tourism Studies*. Editors: T. Jamal and M. Robinson. Sage Publications Inc.

Ament, R., A. P. Clevenger, O Yu and A. Hardy. 2008. An assessment of road impacts on wildlife populations in U.S. National Parks. *Environmental Management* 42:480–496.

Clevenger, A. P. and 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.

Huijser, M. P. and A. P. Clevenger. 2006. Habitat and corridor function of rights-of-ways. Pages 233–254. In: *The ecology of transportation: managing mobility for the environment.* J. Davenport & J. L. Davenport (eds). Springer, London, UK.

Gunderson, L., A. Clevenger, A. Cooper, V. Dale, L. Evans, G. Evink, L Fahrig, K. Haynes, W. Kober, S. Lester, K. Redford, M. Strand, P. Wagner, J. Yowell. 2005. *Assessing and managing the ecological impacts of paved roads.* National Research Council, The National Academies Press, Washington, DC.

Hansen, M. and A. P. Clevenger. 2005. The influence of disturbance and habitat on the frequency of non-native plant species along transportation corridors. *Biological Conservation* 125:249–259.

Clevenger, A. P. 2005. Conservation value of wildlife crossings: measures of performance and research directions. *GAIA* 14:124–129 (www.oekom.de/gaia).

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

9.3.2. Submitted for publication

Clevenger A. P. and A. T. Ford. Submitted. Terrestrial mitigation: Wildlife crossing structures, fencing and other highway design considerations. Chapter 2 *in:* Jon P. Beckmann, Tony Clevenger, Marcel Huijser, and Jodi Hilty (eds.) *Safe Passages: Highways, Wildlife and Habitat Connectivity.* Island Press, Washington DC.

Ford A. T., A. P. Clevenger and K. Rettie. Submitted. Banff Wildlife Crossings Project, Trans-Canada Highway, Alberta—A public–private partnership. Chapter 7 *in:* Jon P. Beckmann, Tony Clevenger, Marcel Huijser, and Jodi Hilty (eds.) *Safe Passages: Highways, Wildlife and Habitat Connectivity*. Island Press, Washington DC.

Clevenger, A. P. and M. Sawaya. Submitted. A non-invasive genetic sampling method for measuring population-level benefits of wildlife crossings for bears in Banff National Park, Alberta, Canada. *Ecology and Society (online).*

Huijser, M. P, J. W. Duffield, A. P. Clevenger, R. J. Ament and P. T. McGowen. Submitted. Cost–benefit analyses of mitigation measures aimed at reducing collisions with large ungulates in North America; a decision support tool. *Ecology and Society (online).*

Ford, A. T., K. Rettie and A. P. Clevenger. Submitted. Fostering biodiversity conservation through an international public–private partnership: mitigating the Trans-Canada Highway in Banff National Park, Alberta, Canada. *International Journal of Biodiversity Science and Management*.

Ford, A. T., A. P. Clevenger, M. P. Huisjer and A. Dibb. Submitted. Planning and prioritization strategies for phased highway mitigation using wildlife–vehicle collision data. *Wildlife Biology*.

10. OUTREACH AND EDUCATION

10.1. Public presentations

K–12 school presentations of "Banff Wildlife Crossings." One hundred eighty school presentations to over 5,000 students and teachers in the Bow Valley, Columbia Valley, Crowsnest Pass and Calgary Area (since November 2006).

Wildlife Crossings Structure Art Contest. Students who participated in the K–12 presentations in Calgary and Bow Valley submitted writing and art pieces about the crossing structures. Fourteen winners were awarded and their artwork was displayed on the Parks Canada website (September 2007 and 2008).

Red Deer River Naturalists. Cathy Gill presented to ~45 naturalists at the Kerry Wood Nature Centre in Red Deer, AB (27 November 2008).

Lake O'Hara speakes series. Tony Clevenger, Adam Ford and Cathy Gill each delivered presentations to ~200 guests and visitors at Lake O'Hara (Summers of 2006–2008).

Calgary Field Naturalist Annual Banquet 2007. Tony Clevenger was invited keynote speaker to 125 members (3 November 2007).

Banff Mountain Film Festival 2007. Cathy Gill gave a presentation to visitors at the festival (November 2007).

Bow Valley Naturalists. Mike Sawaya gave a presentation of his research at a monthly meeting in Banff (26 October 2007).

Town Council, Crowsnest Pass, Alberta Presentation by T. Clevenger to Crowsnest Pass Town Council on Banff mitigation and research results, followed by Q&A (10–12 September 2007).

Blairmore, Alberta. Public Presentation by T. Clevenger at "Wildlife Crossings" public launch organized by Crowsnest Pass Conservation Society (September 2007).

Shad Valley, University of Calgary, Presentation by T. Clevenger as part of summer Youth Enrichment Programme (21 June 2006).

Parks Canada Research Updates, Banff, Alberta. Presentation by T. Clevenger "Highway research in the Mountain Parks, 1996–2006" (May 2006).

10.2. Exhibits and displays

Calgary Zoo

Developed an exhibit at Cequel Energy Lodge on "Banff Wildlife Crossings—Science in Action." This display includes: "Quick Facts," an interactive touch screen, and a five-minute looping video on the wildlife crossings in Banff (July 2008–present).

Banff National Park Information Centre, Banff, Alberta.

Stand alone display with touch-screen, tracks and text panels, >20,000 people contacted (2006–present).

Canada Place, Banff, Alberta.

Touch screen display and Fast Facts, ~9000 people contacted (2007–present).

Lake Louise Information Centre, Lake Louise, Alberta.

Standalone display with touch screen and text panels, ~10,000 people contacted (March 2008–present).

Kerry Wood Nature Centre, Red Deer, Alberta.

Interpretive panel with photos and text on the Banff Wildlife Crossings Project (October 2008–present).

Radium Hot Springs Hot Pools, Radium, British Columbia.

Interactive touch screen display and text panels (November 2008–present).

Crowsnest Pass, Blairmore, Alberta. "Banff Wildlife Crossings Exhibit" in the Crowsnest Pass, organized by Crowsnest Conservation Society and Banff Wildlife Crossings Project (September to November 2007).

Banff Mountain Film Festival, Banff, Alberta. Display on the BWCP that was manned by park interpreters, ~300 people contacted (November 2006 and 2007).

Mountain Equipment Coop, Calgary, Alberta. Eight weekends with display and educational materials (manned), three weeks (stand alone): ~636 people contacted (January–March 2007).

Calgary Snow Show. Part of the display showcased the BWCP and was manned by park interpreters, ~500 people contacted (November 2006).

10.3. Media and communications

The front and back covers of the textbook *Essentials of Conservation Biology* (4th edition), by Richard B. Primack, focused on the Banff Wildlife Crossings project. It is published by Sinauer Associates, Inc., and is the most widely used textbook for conservation biology courses at universities in North America.

Wild Magazine, the Canadian Wildlife Magazine for Kids, April 2008.

AMA Westworld Magazine, April 2008 issue, page 14.

Pique Newsmagazine, Whistler, BC, March 2008.

Wild Lands Advocate, Alberta Wilderness Association, April 2008.

Western Transportation Institute, Montana State University. Road Ecology Program website displaying video clips of wildlife using Banff Crossings, 350 hits on first day. Website (www.westerntransportationinstitute.org/research/roadecology/).

New Wildlife Crossings Poster, our second poster was designed to include recent data and photos.

Canadian Parks & Wilderness Society (CPAWS), Calgary–Banff Chapter, "Green Notes" bi-annual newsletter. T. Clevenger interviewed for upcoming article on Banff Crossings.

The Globe and Mail, Canada's leading national newspaper published an article on Mike Sawaya's DNA-based research (October 2007). Local newspapers (Calgary Herald, Rocky Mountain Outlook) followed with similar articles.

Transportation Research News (TR News), a magazine published by the National Academies of Science, article appeared in March–April 2007 issue No. 249, "Highways Through Habitats: Lessons from the Banff Wildlife Crossings Project." TR News reaches more than 40,000 transportation professionals worldwide.

Yellowstone-to-Yukon Newsletter (Winter 2006), "Wildlife Crossings—Crossing over to Safety."

Calgary Area Outdoor Council newsletter (May 2007). Article on Banff Wildlife Crossings: monitoring and research results.

Reporters for the *New York Times, National Public Radio, the Canadian Broadcasting Corporation (CBC)* and other media outlets were given a field trip to the Banff Wildlife Crossings Project as part of a science and communications project developed by the Woodcock Foundation.

The New York Times science editor, Cornelia Dean, did a major story on the Yellowstone-to-Yukon bioregion, *Home on the Range: A Corridor for Wildlife*, with a special focus on the Banff Wildlife Crossings on the Trans-Canada Highway. Quotes and photos were provided by Tony Clevenger. The story was picked up by the Montreal Gazette, Toronto Star and many other newspapers across North America.

The *CBC Radio1* broadcast a half-hour segment on the nationwide program "*The Current*" about the Yellowstone-to-Yukon Conservation Initiative with special attention paid to the Banff Wildlife Crossings Project.

A local newspaper, The *Rocky Mountain Outlook*, did a story on the newly constructed Deadman Flats wildlife underpass and its effectiveness, with quotes from Tony Clevenger.

Ronald Tobias, the director of Montana State University's graduate film program, Natural History and Science, committed to making five podcasts on road ecology issues targeted for children 10–15 years old. Filmmakers shot footage in Banff in October and the first podcast was slated for completion in January 2007.

11. GROWING THE PARTNERSHIP

- Parks Canada—grant proposal submitted for Parks Canada Agency "Action on the Ground" funding for highways and wildlife science and education, 2009–2014.
- Calgary Foundation—awarded $40,000 for project outreach (January 2008). Y2Y fiscal agent.
- Calgary Foundation—donor-advised fund. Funded joint proposal with Miistakis Institute to conduct science workshop in the Crowsnest Pass (January 2008).
- Mountain Equipment Co-op—awarded $20,000 for research and community awareness (April 2008). CPAWS fiscal agent.
- WTI–Montana State University, University Transportation Center funds—$125,000, October 2008.
- Woodcock Foundation 2009 grant application awarded December 2008, $45,000.
- Wilburforce Foundation 2009 grant application awarded December 2008.
- Alberta Ecotrust 2009 letter of intent planned summer 2009.
- Alberta Conservation Association–awarded $5,915 for genetic connectivity study through Grants in Biodiversity Program (January 2008).
- National Fish and Wildlife Foundation—awarded $10,000 for support of genetic connectivity study through Budweiser Conservation Scholarship (September 2007).

APPENDIX A: SCIENTIFIC PUBLICATIONS, 2006–2009 (ABSTRACTS)

Gunson, K, A. Clevenger, A. Ford, J. Bissonette and A. Hardy. In press. A comparison of data sets varying in spatial accuracy used to predict the occurrence of wildlife–vehicle collisions. Environmental Management.

Wildlife–vehicle collisions (WVCs) pose a significant safety and conservation concern in areas where high traffic roads are situated adjacent to wildlife habitat. Improving transportation safety, accurate planning of highway mitigation, and identifying key habitat linkage areas may all depend on the quality of WVC data collection. Two common approaches to describe the location of WVCs include spatially accurate data derived from global positioning system or vehicle odometer measurements, and less accurate road-marker data derived from reference points (e.g., mile markers or landmarks) along the roadside. In addition, there are two common variable types used to predict WVC locations: (1) field-derived, site-specific measurements and (2) geographic information system (GIS)-derived. It is unclear if these various approaches produce similar results when attempting to identify and explain the location of WVCs. Our first objective was to determine and compare the spatial error found in road-marker data (in our case the closest mile marker) and landmark-referenced data. Our second objective was to evaluate the performance of models explaining high- and low-probability WVC locations, using congruent, spatially accurate (<3 m) and road-marker (<800 m) response variables in combination with field- and GIS-derived explanatory variables. Our WVC data sets were comprised of ungulate collisions and were located along five major roads in the central Canadian Rocky Mountains. We found that spatial error (mean ± SD) was higher for WVC data referenced to nearby landmarks (516 ± 808 m) than those referenced to the closest mile-marker data (401 ± 219 m). The top performing model using the spatially accurate WVC locations contained all explanatory variable types, whereas GIS-derived variables were influential in the best road-marker model and the spatially accurate reduced model. Our study showed that spatial error and sample size, using road-marker data for ungulate species, are important to consider for model output interpretation, which will impact the appropriate scale to apply modeling results. Using road-marker references <1.6km or GPS-derived data locations may represent an optimal compromise between data acquisition costs and analytical performance.

Ford A. T., A. P. Clevenger and A. Bennett. In press. Comparison of Motion-activated Camera and Trackpad Methods of Monitoring Wildlife Crossing Structures on Highways. Journal of Wildlife Management.

Wildlife crossing structures (e.g., underpasses and overpasses) are used to mitigate deleterious effects of highways on wildlife populations. Evaluating the performance of mitigation measures depends on monitoring structures for wildlife use. We analyzed the efficacy of two non-invasive methods that are commonly used to monitor crossing structure use by large mammals: tracking and motion-activated cameras. We monitored 15 crossing structures every other day between 29 June 2007 and 24 October 2007 along the Trans-Canada Highway in Alberta, Canada. Our objectives were to determine how species-specific detection rates are biased by the detection method used, to determine factors contributing to crossing event detection, and to evaluate the most cost-effective approach to monitoring. We detected a total of 3,405 crossing events by tracks and 4,430 crossing events by camera for mammals coyote-sized and larger. Coyotes and grizzly bears were significantly more likely to be detected by track pads, while elk and deer were more likely to be detected by cameras. Crossing event detection was affected by species, track pad width, and the number of animals using the crossing structure. At the levels of animal activity observed in our study our economic analysis indicates that cameras are more cost-effective than track pads for study durations longer than one year. These results will help researchers efficiently design and budget projects aimed at monitoring wildlife crossing structures on highways.

Ament, R., A. P. Clevenger, O. Yu and A. Hardy. 2008. An assessment of road impacts on wildlife populations in U.S. National Parks. Environmental Management *42, 480–496.*

Current United States National Park Service (NPS) management is challenged to balance visitor use with the environmental and social consequences of automobile use. Wildlife populations in national parks are increasingly vulnerable to road impacts. Other than isolated reports on the incidence of road-related mortality, there is little knowledge of how roads might affect wildlife populations throughout the national park system. Researchers at the Western Transportation Institute synthesized information obtained from a system-wide survey of resource managers to assess the magnitude of their concerns on the impacts of roads on park wildlife. The results characterize current conditions and help identify wildlife–transportation conflicts. A total of 196 national park management units (NPS units) were contacted and 106 responded to our questionnaire. Park resource managers responded that over half of the NPS units' existing transportation systems were at or above capacity, with traffic volumes currently high or very high in one quarter of them and traffic expected to increase in the majority of units. Data is not generally collected systematically on road-related mortality to wildlife, yet nearly half of the respondents believed road-caused mortality significantly affected wildlife populations. Over one-half believed habitat fragmentation was affecting wildlife populations. Despite these expressed concerns, only 36 percent of the NPS units used some form of mitigation method to reduce road impacts on wildlife. Nearly half of the respondents expect that these impacts would only worsen in the next five years. Our results underscore the importance for a more systematic approach to address wildlife–roadway conflicts for a situation that is expected to increase in the next five to ten years.

Clevenger, A.P. and M. Sawaya. Submitted. A non-invasive genetic sampling method for measuring population-level benefits of wildlife crossings for bears in Banff National Park, Alberta, Canada. Ecology and Society (online).

Intuitively, one would expect wildlife crossing structures to enhance the viability of wildlife populations. Previous research has demonstrated that a broad range of species will use crossing structures, however questions remain as to whether these measures actually provide benefits to populations. Studies have yet to determine the number of individuals using crossings, their gender or genetic relationships. Obtaining empirical data to demonstrate these population-level benefits for some species can be problematic and challenging at best. Molecular techniques now make it possible to identify species, individuals, their genders, and genetic relatedness from hair samples collected through non-invasive genetic sampling (NGS). We describe a NGS method to assess potential population-level benefits of 20 wildlife crossings on the Trans-Canada Highway in Banff National Park, Alberta. In a pilot study we tested the efficacy of a prototype NGS system designed to sample hair from bears (*Ursus* sp.) at two trial wildlife underpasses. The piloted hair-sampling method did not deter animal use of the trial underpasses and was effective at sampling hair from a high proportion of bears using the two underpasses. As part of a three-year study, the prototype hair-sampling system was used at 20 of 23 wildlife crossings, whereas hair traps and rub trees were systematically surveyed to obtain genetic information on the bear population in the surrounding landscape. We derived individual identifications and determined genders from samples collected from all three sampling methods. Hair-sampling success rate for grizzly and black bears at the crossings was approximately 50 percent, while our sampling success rates were also respectable for non-target cougars (33 percent) and wolves (56 percent). DNA amplification success rates varied between 55 percent and 82 percent for black and grizzly bear samples obtained at the wildlife crossings. Eleven black bears (5 females, 6 males) and 11 grizzly bears (4 females, 7 males) were identified using the wildlife crossings in 2006, while eight black bears (4 females, 4 males) and 12 grizzly bears (6 females, 6 males) were identified in 2007. The total number of individuals identified at the crossings, hair traps and rub trees combined was 66 grizzlies and 43 black bears. A total of 17 percent (n=11) of all grizzly bears and 25 percent (n=11) of all black bears were identified using the crossings with our hair-sampling system. Preliminary data from our NGS suggests the methodology is sound and effective for assessing the population-level benefits of Banff wildlife crossings, however the completed research will confirm those findings. NGS can be an important tool for determining the conservation value of wildlife crossings for other taxa and we urge others to carry out evaluations of this emerging methodology.

Huijser, M. P, J. W. Duffield, A. P. Clevenger, R. J. Ament, and P. T. McGowen. Submitted. Cost–benefit analyses of mitigation measures aimed at reducing collisions with large ungulates in North America; a decision support tool. Ecology and Society (online).

Wildlife–vehicle collisions, especially with deer (*Odocoileus* spp.), elk (*Cervus elaphus*) and moose (*Alces alces*) are numerous and have shown an increasing trend over the last several decades in the United States and Canada. We calculated the costs associated with the typical collision involving deer, elk and moose, including vehicle repair costs, human injuries and fatalities, towing, accident attendance and investigation, monetary value to hunters of the animal killed in the collision, and cost of disposal of the animal carcass. In addition, we reviewed the effectiveness and costs of 13 mitigation measures considered effective in reducing collisions with large ungulates We conducted cost–benefit analyses over a 75-year period using discount rates of 1, 3 and 7 percent to identify the threshold values (in 2007 $) above which individual mitigation measures start generating benefits in excess of costs. These threshold values were translated into the number of deer–, elk–, or moose–vehicle collisions that need to occur per kilometer per year for a mitigation measure to start generating economic benefits in excess of costs. In addition, we calculated the costs associated with large ungulate–vehicle collisions on ten road sections throughout the United States and Canada and compared these to the threshold values. Finally, we conducted a more detailed cost analysis for one of these road sections to illustrate that even though the average costs for large ungulate–vehicle collisions per kilometer per year may not meet the thresholds of many of the mitigation measures, specific locations on a road section can still exceed thresholds. We believe the cost–benefit model presented in this paper can be a valuable decision support tool for determining mitigation measures to reduce ungulate–vehicle collisions.

Ford, A. T., A. P. Clevenger, M. P. Huisjer and A. Dibb. Submitted. Planning and prioritization strategies for phased highway mitigation using wildlife–vehicle collision data. Wildlife Biology.

Mitigation measures to reduce wildlife–vehicle collisions (WVCs) on highways are becoming an established practice in many industrialized countries. Most highway mitigation projects occur while roads are being upgraded or repaired for other reasons. Finding cost-effective ways to locate and prioritize stretches of highway for mitigation presents an engineering, management and ecological challenge. We present three metrics to assist in prioritizing the location of wildlife-proof fencing along a 94km stretch of road in one of Canada's national parks. We considered temporal consistency of WVC occurrences, conservation value (i.e., reduction in WVC rates), economic benefits (i.e., cost of mitigation versus benefits in WVC reduction) and a combined approach to prioritize management actions. We compared the efficacy of four different lengths of fencing (i.e., phase lengths) at meeting these criteria: 2km, 5km, 10km and 25km. We used 1244 WVC records from 1981 to 2005 to assess mitigation effectiveness. We found that longer fences best address conservation concerns, but all fencing sections, irrespective of length, rarely captured more than 50 percent of WVC locations by species. We found that shorter fences were more economically efficient, but also more variable in performance, than longer fences. Lastly, we found that longer fence lengths tend to produce the best results for the combined metric criteria. Phased highway mitigation should be considered a viable means of meeting some management goals.

Clevenger A. P. and A. T. Ford. Submitted. "Terrestrial mitigation: Wildlife crossing structures, fencing and other highway design considerations." Chapter 2 *in:* Jon P. Beckmann, Tony Clevenger, Marcel Huijser, and Jodi Hilty (eds.) Safe Passages: Highways, Wildlife and Habitat Connectivity. Island Press, Washington, DC.

Wildlife crossing structures are being designed and incorporated into road construction and expansion projects to help restore or maintain animal movements across roads. Engineered wildlife crossings are designed to meet the dual needs of allowing animals to cross roads with reduced hazard to motorists and wildlife. Typically crossing structures are combined with high fencing and together are proven measures to reduce road-related mortality of wildlife and to connect populations. An increasing number of crossings have been built in North America and worldwide in the last decade. Anticipated population growth and ongoing transportation infrastructure investments in most regions, coupled with the resounding concern for maintaining large-scale, landscape connectivity, are generating interest in wildlife crossings as conservation tools. As road networks continue to grow and expand throughout North America, transportation agencies, land managers and local decision makers need to know the most effective approaches to designing safe roadways for motorists and wildlife. In this chapter we review and synthesize current knowledge of North American wildlife crossing systems as it pertains to their design, monitoring and performance criteria. The chapter provides information on how to increase the effectiveness of established designs and recommends ways to design for particular species and species groups in different landscapes. These guidelines can be used for wildlife crossings on new or existing roads, highway expansions (e.g., two-lane to four-lane) and bridge reconstruction projects. The review is not meant be exhaustive but captures the most current literature, knowledge, and data with regard to the current practices in wildlife crossing mitigation.

Rettie, K., A. P. Clevenger and A. T. Ford. In press. Innovative approaches for managing conservation and use challenges in the national parks: An example from Canada. T. Jamal and M. Robinson (eds.). In: Handbook of Tourism Studies. Sage Publications Inc.

Ford A. T., Rettie, K. and A. P. Clevenger. Submitted. "Fostering biodiversity conservation through an international public–private partnership: mitigating the Trans-Canada Highway in Banff National Park, Alberta, Canada." International Journal of Biodiversity Science and Management

Ford A. T., A. P. Clevenger and K. Rettie. Submitted. "Banff Wildlife Crossings Project, Trans-Canada Highway, Alberta—A public–private partnership." Chapter 7 *in:* Jon P. Beckmann, Tony Clevenger, Marcel Huijser, and Jodi Hilty (eds.) Safe Passages: Highways, Wildlife and Habitat Connectivity. Island Press, Washington, DC.

(This abstract describes all three works)

The preservation of biological diversity (biodiversity) is recognized as one of the most significant environmental challenges of this century. The establishment of protected areas is seen as one solution to preserving remaining components of natural ecosystems. However, the preservation role of protected areas may conflict with human activities such as industrial development and tourism. Banff National Park (BNP) is Canada's flagship protected area, established in 1885. BNP sees about 2 million visitors per year, has approximately 9000 full-time residents and is bisected by nationally significant rail and road transportation routes. The upgrading of the Trans-Canada Highway (TCH) from two to four lanes within the park boundaries brought to light the conflicting roles that BNP serves. Consequently, the TCH in BNP has been subject to pioneering efforts to reduce the negative effects of the highway on local wildlife mortality and movement. With over 12 years of monitoring BNP's highway mitigation measures, this stretch of road is also one of the most intensely studied in the world. The role of adaptive management and flexible institutional arrangements made this effort possible. The results of the monitoring study are being shared with a broad audience, from transportation practitioners and ecologists to the general public and school classrooms. By learning more about the success of highway mitigation, a community of informed citizens is taking shape and becoming active in its understanding of nature and science.

APPENDIX B: NAMES AND ABBREVIATIONS OF WILDLIFE CROSSING STRUCTURES

Names and abbreviations of wildlife crossing structures as they are used in the text, and the construction phase where they are located.

Name	Design	Abbreviation	TCH Phase
Bourgeau	Metal culvert	Bourg	IIIA
Buffalo	Open span	Buff	II
Carrot Creek	Creek Bridge	CARROT	I
Castle Junction	Metal culvert	Castle	IIIA
Copper	Metal culvert	Copper	IIIA
Duthil	Open span	DH	I
East gate	Open span	East	I
Edith	Open span	EDITH	II
Healy	Open span	H	II
Johnston	Box culvert	John	IIIA
Massive	Metal culvert	MASS	IIIA
Morrison Coulee	Metal Culvert	MC	I
Pilot	Box culvert	PILOT	IIIA
Powerhouse	Open span	PH	I
Redearth Creek	Creek bridge	RECR	IIIA
Redearth wildlife overpass	Overpass	REOP	IIIA
Redearth wildlife underpass	Box culvert	REUP	IIIA
Sawback	Box culvert	Saw	IIIA
Vermilion	Open span	V	II
Wolverine Creek	Creek bridge	WCR	IIIA
Wolverine wildlife overpass	Overpass	WOP	IIIA
Wolverine wildlife underpass	Metal culvert	WUP	IIIA

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