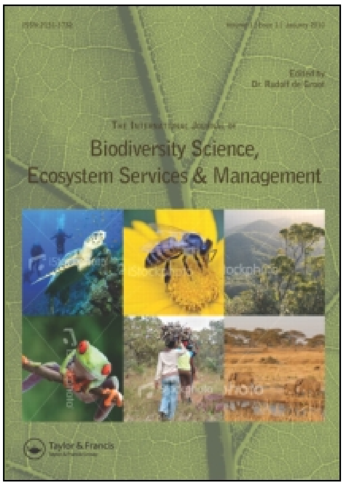


**International Journal of Biodiversity Science, Ecosystems Services & Management**
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t907405630

# Fostering ecosystem function through an international public-private partnership: a case study of wildlife mitigation measures along the Trans-Canada Highway in Banff National Park, Alberta, Canada

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Online publication date: 19 April 2010



**To link to this Article: DOI:** 10.1080/17451590903430153
**URL:** http://dx.doi.org/10.1080/17451590903430153

*International Journal of Biodiversity Science & Management*
Vol. 5, No. 4, December 2009, 181–189



# Fostering ecosystem function through an international public–private partnership: a case study of wildlife mitigation measures along the Trans-Canada Highway in Banff National Park, Alberta, Canada

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The establishment of protected areas is seen as one solution to preserve remaining components of natural ecosystems. However, the preservation role of protected areas may conflict with human activities such as industrial development and tourism. Canada's Banff National Park (BNP) hosts about 3 million visitors per year, has approximately 8000 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 BNP has highlighted the park's conflicting roles. The TCH in BNP has been subject to pioneering efforts to reduce its negative effects on wildlife mortality and movement. Over 12 years of monitoring, BNP's highway mitigation measures have made this stretch of road one of the most intensely studied in the world. Both adaptive management and flexible institutional arrangements made this effort possible. The results of monitoring studies are being shared with a broad audience, from transportation practitioners and ecologists to the general public and school children. By learning more about the success of highway mitigation, a community of informed citizens is taking shape and becoming active in their understanding of nature and science.

**Keywords:** wildlife crossings; fencing; connectivity; education; road ecology; monitoring; wildlife-vehicle collisions

## Introduction

Over the past 25 years, loss of biological diversity (biodiversity) has become recognized as one of the most significant environmental challenges of our time (Primack 2006). Biodiversity conservation is often linked with the establishment of protected areas or ecological reserves (IUCN 1994; Gaston et al. 2008). In Canada, federally designated protected areas (national parks) are managed by Parks Canada. The management of national parks in Canada has evolved from a multi-use (resource extraction, recreation, preservation) to a dual-use (recreation and preservation) mandate, with an increasing focus on restoring ecosystem processes (White and Fisher 2007). This newer paradigm relies upon the restoration and maintenance of what Parks Canada describes as ecological integrity (EI): 'An ecosystem has integrity when it is deemed characteristic for its natural region, including the composition and abundance of native species and biological communities, rates of change and supporting processes' (Canada National Parks Act 2000). In 2001, the Canada National Parks Act was amended to state that 'maintenance or restoration of ecological integrity . . . shall be the first priority . . .' in park management (Canada National Parks Act 2000).

The evolution of the ecological integrity paradigm within Parks Canada can be tracked through the development of the Trans-Canada Highway (TCH) within Banff National Park (BNP). Over the past 30 years, Parks Canada has adopted research, engineering and policy initiatives to mitigate the negative effects of the TCH on the BNP ecosystem. The purpose of this paper is to describe how the implementation of these initiatives has created one of the most intensely mitigated and studied stretches of highway in the world. We begin with an overview of the ways in which the TCH affects wildlife in BNP and then discuss how Parks Canada has responded to those impacts. Next, we examine management performance by reviewing research results derived from long-term monitoring of the TCH mitigation measures. Last, we describe the funding arrangements and outreach efforts that enabled long-term monitoring to occur.

## Study area

Banff is Canada's first national park, legally designated as such in 1885. Located in the Rocky Mountains on the western border of Alberta, BNP encompasses 6641 km$^2$ of glaciers, mountains, forest, lakes and rivers (Figure 1). The montane ecoregion, which covers less than 4% of the park, provides the most effective habitat for wildlife in this mountainous landscape (White and Fisher 2007). Two communities, the town of Banff (population 6700) and the village of Lake Louise (population 938), are located in this montane ecoregion, as is a 73-km section of the TCH, the Canadian Pacific Railway, and several secondary roads. Situated between the major population centres of Vancouver and Calgary, the TCH in BNP experiences significant through-traffic in addition to an estimated 3 million destination visitors a year. Traffic volumes average over 16,000 vehicles per day, peaking at over 35,000 vehicles per day during the summer months (Parks Canada,

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ISSN 1745-1590 print/ISSN 1745-1604 online

DOI: 10.1080/17451590903430153
http://www.informaworld.com

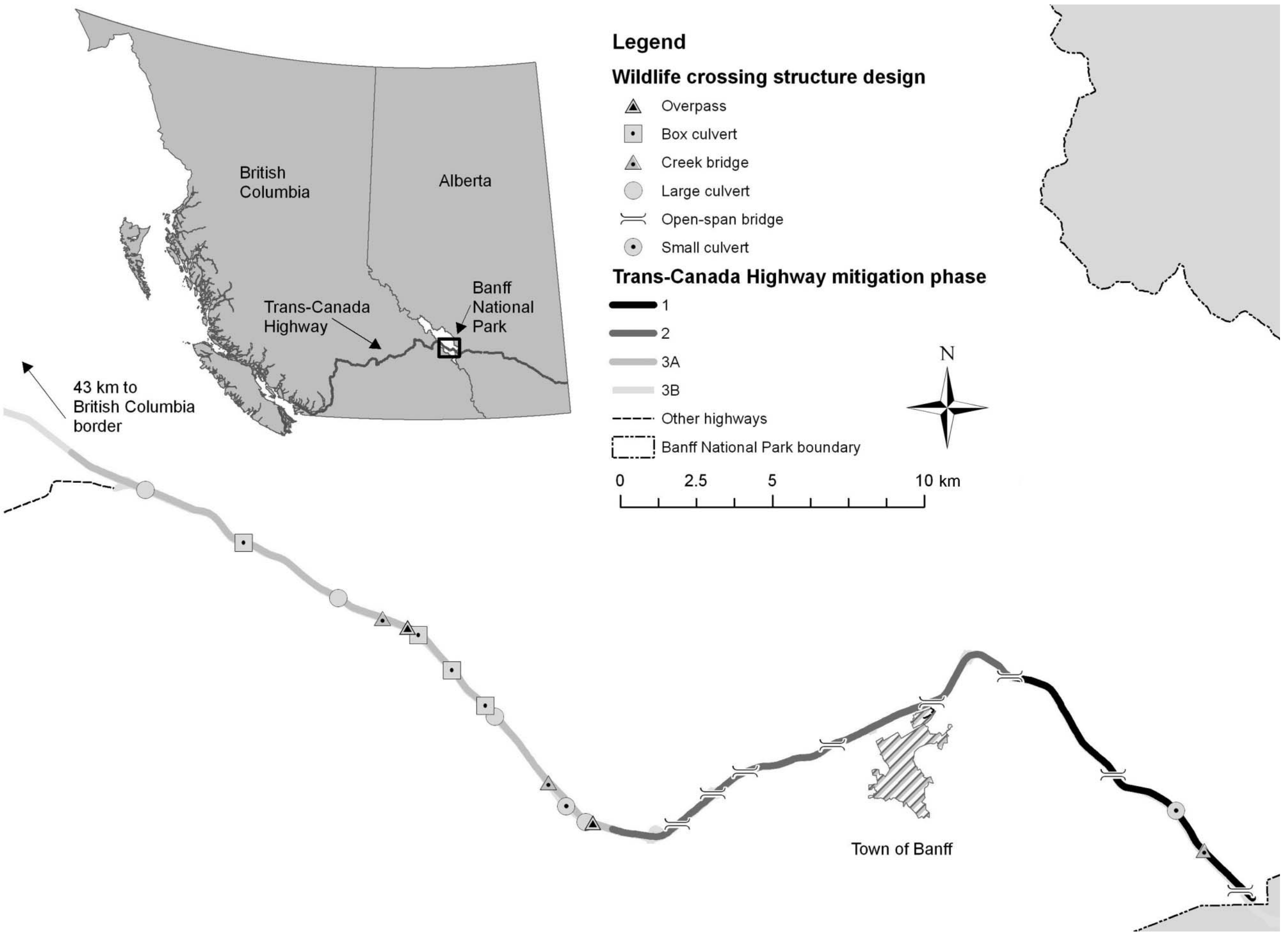


Figure 1. Map of the study area showing Trans-Canada Highway mitigation and twinning phases from the eastern boundary of Banff National Park to the British Columbia–Alberta border.

unpublished data). This concentration of human activity may be disrupting key ecological processes within the park, thereby contravening Parks Canada's EI mandate.

## Road effects on wildlife

Roads affect wildlife populations negatively by increasing mortality, creating a partial or complete barrier to movement, removing habitat from the landscape, and facilitating the spread of invasive species (Forman et al. 2003). The most obvious effect of roads on wildlife is mortality due to wildlife-vehicle collisions (WVCs). WVCs are a threat to human safety and property (Conover et al. 1995; Morrall 2004). In some cases, rates of WVCs may be high enough to cause wildlife populations to decline. For example, the 1990 elk (*Cervus canadensis*) population in the Banff-Bow Valley was estimated at 800 individuals and was predicted to fall to fewer than 175 individuals by 2010, largely due to WVCs along the TCH (Woods 1990). Estimates from population surveys and WVC reporting from 1981 to 1996 along the TCH blamed road traffic for 48% of all ungulate mortality and 65% of carnivore mortality (Shury 1996). Furthermore, if few animals can safely cross roads, genetic mixing of populations they bisect may also be compromised (Jaeger et al. 2005), negatively affecting the long-term genetic fitness of wildlife populations.

In addition to mortality, roads create barriers to animal movement through avoidance behaviour, documented in songbirds (Reijnen et al. 1995; St. Clair 2003), small mammals (Ford and Fahrig 2008), ungulates (Rost and Bailey 1979) and large carnivores (Chruszcz et al. 2003; Mace et al. 1996). Many species need to move daily to locate forage, and they may also move intra-annually to find mates or to seek seasonally available resources (Clevenger and Waltho 2005). Lastly, many species also move inter-annually as part of a juvenile dispersal process. Disruption of these movements by road avoidance can have negative consequences for individual survival (e.g. inability to reach needed resources) and population persistence (e.g. loss of genetic connectivity) (Gerlach and Musolf 2000). Seasonal and once-in-a-lifetime movement patterns may be of the order of several hundred kilometres for the large mammal species within BNP. Studies have shown that animal movement in the Bow Valley is disrupted by the presence of the TCH (Clevenger et al. 2002; Gibeau et al. 2002; Chruszcz et al. 2003).

Attempts to minimize the negative effects of roads on wildlife in BNP must therefore focus on WVC reduction while, at the same time, ensuring that wildlife have access to 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.

## Mitigation measures along the TCH

While the presence of a major highway in a national park is unusual for North America, it was the upgrading of the highway that provided the impetus to mitigate its negative effects on wildlife. In 1978, the federal government proposed to widen the highway from two to four lanes, a process known as 'winning'. The TCH twinning project has proceeded in a series of phases, beginning with Phase I completed in 1984, Phase II in 1987, Phase IIIA in 1997 and continuing through the current day on Phase IIIB (Figure 1). Each phase has had an associated environmental assessment (EA) and monitoring component.

### *Phase I–II: 0–27 km*

The 1979 Federal Environmental Assessment and Review Process for Phase I identified WVCs as a major concern for human safety and wildlife conservation values. For example, 45% of the 780 ungulate road mortalities between 1964 and 1979 within BNP occurred along this 13-km stretch (Harrison et al. 1980). In 1978 alone, over 110 ungulate individuals were killed (FEARO 1979). Given the high frequency of WVCs in this area, the role of the highway verge as grazing habitat for large ungulates, and the predicted declines in moose (*Alces alces*) and elk population size as a result of road mortality, the FEARO (1979) recommended that mitigation should focus on changing ungulate movement patterns so that they were away from the highway right-of-way. Collisions involving carnivore species and small mammals were raised during the review, but as 'lesser concerns' (FEARO 1979: 26). The two main mitigation measures implemented as a result of these recommendations were the construction of ungulate-exclusion fencing and underpasses.

Ungulate-exclusion fencing consists of 2.4 m high page wire with 15 cm square mesh. Fencing was attached to wooden posts set back from the cleared highway right-of-way >14 m, depending on road curvature, to allow for errant vehicle recovery and safe run-out. Additional setbacks were made (c. 50 m) in some areas, as FEARO (1979) recommended that visual aesthetics be considered when locating the fence line, and the fence was not considered aesthetic. Gaps below the fence, less than 15 cm high, were considered acceptable since larger herbivores would not be able to pass through these. At adjoining secondary and service roads along the TCH, cattle guards were installed to reduce ungulate movement onto the highway while allowing vehicle access to areas away from the highway. One-way gates were designed to allow animals trapped on the right-of-way to escape, while preventing large animals from accessing the right-of-way.

Underpasses were designed to allow animals to have safe passage from one side of the road to the other without encountering the road surface. However, the role of these underpasses in providing population connectivity was not explicit in the EA, perhaps since the science of landscape ecology was still nascent at the time. Consequently, evaluating the success of the underpasses was not explicitly linked to connectivity. Two crossing structures were built based on an open-span bridge design, c. 16 m long × 5 m high (Figure 1). The number and distribution of underpasses in Phase I were based on WVC records from 1968 onwards and on systematic surveys conducted during the winter of 1980 from both air and ground vehicles to identify the location of wildlife use hotspots. Two additional crossing structures were built in areas that did not coincide with high WVC counts. An open-span bridge was constructed 0.5 km from the eastern entrance of the park to reduce the chances that animals moving east along the fence would simply try to cross the TCH outside of Parks Canada's jurisdiction, thereby moving the problem of WVCs onto resource managers in the province of Alberta. At another site, a culvert 4 m in diameter was installed as a test design to determine if cross-highway animal movement could be achieved with less cost, as the culvert was approximately two-thirds the cost of the open-span bridge design (FEARO 1979). Phase I twinning began in October 1981 and was completed in 1984; fencing was completed in 1985. As part of the EA recommendations, monitoring of the crossing structures began in 1983 and was completed in 1987.

A Phase II EA report was completed shortly after construction began on Phase I. Highway aesthetics were less of an issue in this EA; mitigation measures proceeded seamlessly from Phase I. Overpass crossing structures (e.g. Figure 2C) were considered during the EA but not constructed due to cost concerns. Four more dedicated wildlife crossing structures (WCS) were built, based on the same open-span bridge design used in Phase I. In addition to these four WCS, abutment setbacks were added along a major stream crossing at the Bow River bridge to accommodate wildlife movement beneath the roadway (Figure 2B and identified by an open span symbol in Figure 1). Construction began in October 1984, with fencing and twinning complete by September 1987 (FEARO 1982).

### *Phase IIIA: 27–48 km*

Coinciding with the advent of EI-based management in the national parks system, Phase IIIA was the start of a new era in highway mitigation. Unlike earlier EAs, the Phase IIIA EA recommended that large carnivore conservation should be a priority in the implementation and evaluation of proposed mitigation measures (Parks Canada Agency 1995). Consequently, mitigation fencing included an additional partially buried chain-link apron 1 m deep below the page wire to reduce incidences of animals digging below the fence to access the right-of-way (Figure 3). The page wire

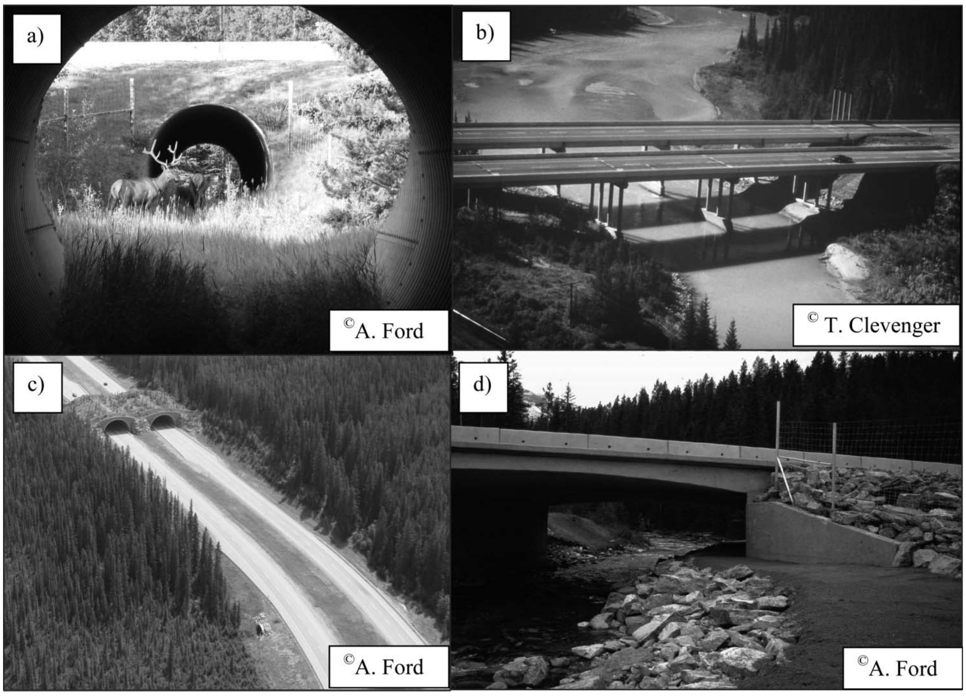


Figure 2. Images of different WCS designs: (A) Elk (*Cervus elaphus*) at Morrison Coulee 4-m culvert; (B) Five-Mile bridge at the Bow River; (C) Wolverine Overpass with Wolverine Underpass in the foreground; (D) Wolverine Creek riparian walkway.




Figure 3. Image of a ungulate-exclusion fence under construction along Phase IIIA. Note the chain link apron attached to the bottom of the page wire. Eventually the bottom 1 m of the apron will be buried.

fence design was also modified, with smaller-sized mesh (varying from 16 × 20 cm to 8 × 20 cm) placed at the bottom to reduce small (smaller than coyote-sized) animal movement onto the right-of-way. One-way gates were not installed along this stretch, since it had been discovered that smaller animals used the gates to access the right-of-way. The one-way gates on Phases I and II were subsequently sealed.

In addition to changes in fence design, two significant changes in crossing structure engineering reflected the broader ecological goals involved in mitigating this phase of the highway. First, two 52 m wide overpass structures were built. These structures are vegetated, with earthen berms along the edges to reduce visual and auditory disruption by the passing traffic below (Figure 2C). Second, more culvert-type structures were installed. The culvert test site on Phase I was deemed relatively ineffective for ungulate use compared to adjacent open-span bridges; however, since restoring carnivore movement was a priority for Phase IIIA, and because black bears (*Ursus americanus*) had been observed using the older culvert site, it was decided that culvert-type underpasses might perform adequately for carnivore species on Phase IIIA. In total, one 1.5 m diameter culvert, four 1.5 × 1.5 m box culverts, two riparian walkways, two 52 m wide overpasses and four 4 × 7 m elliptical steel culverts were installed on this section (Figure 1). McGuire and Morrall (2000) provide detailed information on the engineering components of the Phase IIIA mitigation.

Crossing structures were located at high-frequency WVC sites using GPS-located WVC locations from 1981 to 1993. In addition to these data, a 21 month study in 1984–1985 used ungulate pellet counts, wildlife trail use, road surveys and aerial surveys to locate areas of high ungulate use near the TCH (Logan 1986). In 1995, Parks

Canada undertook a winter snow-tracking study looking at canid, felid, ungulate and small mammal crossing areas along the highway. Combined, these varied sources of data were used to locate crossing structures, reflecting an evolution away from single-species mitigation focus to ecosystem-level management. As Phase IIIA was nearing completion in 1997, Parks Canada decided to hire an external project leader to study the effectiveness of the newly installed mitigation measures and to help inform the design of mitigation measures on subsequent stretches of the TCH. The Banff Wildlife Crossings Project (BWCP) was born.

### *Phase IIIB: 48–83 km*

In the most recent phase of highway twinning, road construction plans have incorporated more sophisticated techniques to locate wildlife crossing structures (WCSs). Habitat linkage models based on telemetry data and habitat selection models are used to locate areas of the landscape where wildlife is most likely to persist and move. By combining several environmental variables into a movement probability map, researchers can identify stretches of highway where wildlife are expected to cross (Clevenger and Wierzchowski 2006). These efforts have also shown that mortality and crossroad movement areas are not always sympatric (Clevenger et al. 2002), suggesting that WVC data should not be the sole source of information when planning mitigation measures. Several 'Valuable Ecosystem Components', or focal species, were selected to guide the placement of the Phase IIIB crossing structures (Golder Associates 2004). These include grizzly bears (*U. arctos*), black bears, wolves (*Canis lupus*), elk, deer (*Odocoileus* sp.), wolverines (*Gulo gulo*) and lynx (*Lynx canadensis*). Primary structures (large open-span bridges and overpasses) were to be located in areas where movement probability across the TCH was expected to be highest. Secondary structures were located at major creek and riparian areas not occupied by primary structures. Tertiary structures were located on the remaining sections of the TCH, so that there was some form of WCS approximately every 1.5 km. Fencing design remained consistent from Phase IIIA, with a buried apron and variable dimension page-wire mesh.

## Measuring success: long-term monitoring and research methods

Over time, questions used to evaluate the effectiveness of mitigation have evolved: were WVCs reduced (Phase I); did ungulates use the underpasses (Phase I and II); did large carnivores use the crossing structures (Phase IIIA); what are the population-level benefits of highway mitigation (Phase IIIB)? As these questions evolved, so too did the science to answer them. Early attempts at monitoring the success of a phase was limited to a year or two following construction. Occasionally, a species-specific study would be conducted and researchers would again perform some monitoring of the crossing structures, only to abandon their efforts once the study was completed. It was not until 1996 that a consistent, long-term monitoring commitment was made. The BWCP aims to determine the effectiveness of mitigation measures, namely, the amount of WVC reduction and the frequency of use of WCSs by large mammals.

Parks Canada has tracked the spatial distribution of WVCs for a variety of species over several decades along more than 70 km of highway. Thanks to a large pool of trained staff (e.g. wardens and highway service personnel), who regularly travel the highway within BNP, WVC data with reliable species identification and location information are gathered on a daily basis. During the 1980s, interest was focused on ungulate and large carnivore mortality (Woods 1990). During the 1990s, this effort was further expanded to track WVCs for small mammals, birds and herpetofauna. Data collection also began to include sections of the highway in jurisdictions adjacent to BNP.

Determining the frequency of WCS use by various species was a critical issue for the BWCP. The primary method used to document species presence was through tracking. Track pads 1–3 m wide in the direction of animal movement were constructed of local substrate (sandy loam) and placed at either end and in the middle of the WCS. Track pads extend across the functional width of the crossing structure. Since November of 1996, researchers have visited track pads every 2 days during the summer and every 4 days during the winter. At each visit to a track pad, the researcher records the species and direction of movement for all mammals coyote-sized and larger. In recent years, track pad data have been supplemented with data gathered from motion-sensitive cameras at some crossing structures. By analysing images from these cameras, additional information about the crossing event can be collected, such as time, behaviour (e.g. running, foraging), animal demographics (e.g. sex, age), group size and ambient temperature (Figure 4).


Figure 4. Image from a remote, motion-sensitive camera at one of the overpasses showing the first grizzly bear (*Ursus arctos*) crossing event of 2008.

Although tracking and cameras provide some information on species use and behaviour at the crossing structures, they cannot provide data regarding the population-level benefits of highway mitigation measures. Furthermore, these methods do not reveal how many unique individuals are using the crossings. For example, Riley et al. (2006) found that bobcats and coyotes used wildlife crossings along a major highway in southern California, but had a low probability of successfully mating with individuals on the far side of the road. Consequently, animal use was not concomitant with population-level connectivity in that ecosystem. The BWCP needed to determine how many individuals were using the crossing and how populations of animals separated by the highway were genetically related. DNA from hair obtained through non-invasive hair sampling methods placed at crossing structures (e.g. barbed wire hair-snagging fences, rub trees) and in the surrounding area enables researchers to characterize relatedness across the landscape and individual use of the crossing structures (Sawaya et al. 2007). One element of the BWCP involves targeting movements by grizzly bears and black bears, while opportunistically collecting hair from wolves and cougars (*Puma concolor*). Motion-activated video cameras have been used to examine the response of animals to the presence of the hair-snagging devices placed at two test sites. Analysis of the footage has confirmed that the hair sampling system is not a barrier to movement (Sawaya et al. 2007) and, from 2006 to 2008, the pilot study was expanded to include 20 crossing structures.

## Results of monitoring and research studies

Wildlife exclusion fencing dramatically improved motorist safety and reduced the occurrence of WVCs. Clevenger et al. (2001) showed that fencing reduced WVCs by 90% for ungulates and 86% for carnivores over 2 years. Furthermore, Clevenger et al. (2002) showed that the fence intrusions were 83% lower on highway sections with buried fence aprons than on those with unburied fence sections.

Since 1996, when consistent monitoring protocols of the WCS were implemented, over 120,000 crossing events[1] by moose, sheep, elk, deer species, lynx, cougar, fox (*Vulpes vulpes*), coyote (*C. latrans*), wolf, black bear and grizzly bear have been recorded. Over 65,000 of these crossing events have been by ungulates, including 88 moose and 4600 bighorn sheep. Carnivore crossing events include 4607 wolves, 1268 cougars, 1168 black bears and 535 grizzly bears.

Evaluating WCS performance is challenging, given issues of statistical replications, auto-correlation and heterogeneous distribution of species-specific habitats along the TCH. Clevenger and Waltho (2005) determined that some crossing structure designs work better than others, but that this variability is species-specific: cougars and black bears prefer more concealed underpasses, while ungulates, grizzly bears and wolves prefer overpasses and more open underpasses. This determination was assisted by the installation of overpasses and underpasses within 100 m of each other in Phase IIIA (Figure 3B). This layout provided an opportunity to test if species have preferences for different structure designs by controlling for habitat conditions that may affect animal distribution.

Use of WCS by some species has increased during the last 12 years, at a rate exceeding even the most liberal estimates for changes in population size. For example, grizzly bear use of the WCS has increased exponentially, from six passages in 1997 to 115 passages in 2007 (Figure 5). Meanwhile, the population of grizzly bears is believed to have been relatively consistent over that time (M. Gibeau, Regional Carnivore Specialist, Parks Canada, pers. comm.). These results demonstrate the importance of long-term monitoring. That is, had the results of the first 3 years been considered finite, the structures would have been considered a failure. However, having had sufficient time to adapt, bears now use the crossings on a regular basis (Sawaya et al. 2007). During the 2005 DNA pilot study, there were a total of 56 approaches by carnivores at the two underpasses. Of these, 24 were made by black bears and 19 by grizzly bears. Bears

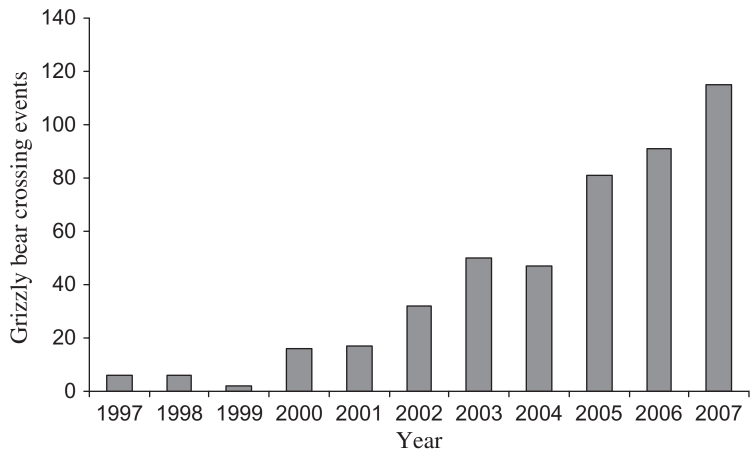


Figure 5. Grizzly bear (*Ursus arctos*) use of crossing structures along Phase I, II and IIIA from November 1996 to December 2007, as measured by track pad records. See text for methods.

turned around or avoided the underpasses on less than 10% of their approaches (two black bears and only one grizzly bear). The hair-capture success rate was high for both bear species; hair was found on more than 90% of the occasions that a bear used the underpass, and 81% of the hair samples yielded sufficient DNA to allow genetic profiling. We identified five individual grizzly bears (three females, two males) and four individual black bears (two females, two males).

In the simplest definition of success, mitigation has achieved the goals it was designed to accomplish: we know that animals use WCSs and that fencing reduces WVCs. We are now getting a better sense of how individual animals use crossing structures and are beginning to understand the population-level benefits of mitigation. The next challenge is to inform park residents, the public and visitors about the success of the crossing structures – to create a community of informed citizens with a connection to nature through increased understanding and, ultimately, to build support for ecological integrity-based actions.



## Securing public support

Consistent evidence of successful highway mitigation performance is needed for the continued implementation of mitigation measures by transportation and resource management agencies. In BNP, funding for highway mitigation and twinning draws upon a fixed budget for the entire road upgrade, and this funding is derived from tax dollars. This means, for example, that for every WCS installed, fewer kilometres of highway can be twinned. Indeed, the proportion of the total highway budget allotted to mitigation increased from 13% during Phases I and II to 25% during Phase IIIA, and now stands at 36% of the budget for Phase IIIB. Consequently, public support for highway mitigation is an important consideration for Parks Canada managers, because the public will ultimately decide whether funding mitigation is justified.

Key to garnering support is to dispel suspicions that the structures are ineffective. In the late 1990s, before the implementation of focused public education and outreach programmes, these suspicions circulated amongst the public and even among some Parks Canada staff (A. Clevenger, Principal Investigator, BWCP, pers. comm.). The highly visible overpasses were subject to the most aggressive criticism. For example, many drivers who frequently used the highway thought the overpasses were constructed for hikers who needed to cross the highway. By 2002, monitoring and research results indicating the effectiveness of the highway mitigation measures had begun to accumulate in the scientific literature (reviewed in Forman et al. 2003), but public opinion that the crossing structures were ineffective still persisted. In response, the BWCP established funding for a dedicated outreach and education position in 2006. Currently, the schedule of outreach activities includes museum exhibits, school programmes, presentations, local and national newspaper articles and television coverage. Between January 2007 and April 2008, information on the BWCP was presented to 4144 students in grades 1–10, along with 276 teachers, throughout western Canada (Gill 2007). While public support is essential for the ongoing success of the project, ultimately a long-term funding arrangement is critical to its operational capacity.

## Securing funding for long-term monitoring and research

Sustained funding is crucial to the success of any monitoring project because, by definition, monitoring must occur over time to detect trends. Between 1996 and 2003, the Parks Canada Highways Service Centre provided CDN$2 million for research and monitoring on Phases I, II and IIIA. In 2003, the Highways Service Centre was prepared to proceed with the next phase of highway twinning but, faced with skyrocketing construction costs and a restricted budget they could only contribute limited funding for monitoring. At this point, in order to determine whether its ecological integrity goals were being met by the WCSs, Parks Canada sought other sources of funding to advance research on population-level benefits of highway mitigation. An international, public–private partnership agreement was created, including Parks Canada, the Western Transportation Institute (WTI) at Montana State University in Bozeman, Montana and three foundations from the United States: the Woodcock Foundation, the Wilburforce Foundation and the Henry P. Kendall Foundation.

The international partnership contributed initially to the 2005 DNA pilot project, and Parks Canada secured matching funds. The international public–private partnership benefits all parties: the foundations achieve one of their goals of supporting road ecology research in North America, the scientists of the WTI have access to an exceptional field laboratory and can collaborate with Parks biologists, and Parks Canada can continue to gather data needed to address a key ecological integrity issue in one of Canada's most complex national park landscapes.

## Conclusion

As with the many national parks (IUCN 1994), management decisions in BNP are directed by a dual mandate: use and preservation. Creative approaches to addressing both traditional human-use values and ecological integrity-based management policies have become necessary. At least three innovative management approaches enabled researchers to evaluate the success of highway mitigation measures at meeting biodiversity conservation (ecological integrity) goals.

First, management took a long-term approach to monitoring WVCs and crossing structure use. This approach not only required patience and planning, it also required relatively consistent funding and logistical resources to carry out the labour required to perform the monitoring. Had monitoring ceased within the first 2–5 years – the normal duration of most wildlife studies – conclusions about the effectiveness of mitigation might have been equivocal. The commitment to long-term monitoring along the TCH has enabled researchers to rigorously evaluate the effectiveness of mitigation measures over time.

The second key management innovation was to build a diversity of crossing structures. In so doing, engineers and wildlife researchers were able to determine the most cost-effective means of ensuring wildlife movement across the highway (Clevenger and Waltho 2005). Parks Canada managers now have the information needed to tailor mitigation measures towards focal species, in a variety of terrain conditions, and with a suite of cost options.

Finally, evaluating the success of highway mitigation measures from both a WVC reduction and landscape connectivity view must address several levels of biological organisation and species, recognizing that mitigation effectiveness needs to be evaluated from a perspective of preserving genetic, species–population and community–ecosystem diversity (Clevenger and Waltho 2005). Mitigation measures have ensured that wide-ranging species are able to interact at scales that invariably overlap with the TCH. Monitoring has shown that all species common to the Bow Valley ecosystem use the crossing structures, and more recent research has given a clearer picture of genetic flows across the highway. Future BWCP research will address the effects of the TCH and benefits of mitigation for an even broader range of species, including birds, insects and plants.

Informed stakeholder involvement and on-going public consultation will be necessary for future stages of twinning and highway expansion in Canada's national parks. Indeed, the success of highway mitigation in BNP has directly influenced transportation planning in other nature-based tourism areas in western North America, such as Highway 93 in Montana, Interstate 70 in Colorado and Interstate 90 in Washington State. However, communicating the results of BWCP research and monitoring extends beyond technicians, planners and biologists. By emphasizing the public education component in their efforts, the BWCP is creating a community of informed citizens who are becoming active in their understanding of nature and science. The hope is that, ultimately, this understanding will lead this community to support decisions derived from ecological integrity values.

## Note

1. An event is a record of an animal using a crossing structure to cross the highway and may reflect several repeat crossings by individuals.

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