Wildlife Crossing Design Influences Effectiveness for Small and Large Mammals in Banff National Park

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ABSTRACT Banff National Park (BNP) is Canada's oldest national park and a very popular one, with both year-round residents and millions of annual visitors. In turn, this means there are several busy road and rail transportation routes throughout the park. These factors can have a number of negative effects on local wildlife. The wildlife crossing structures of the Trans-Canada Highway in BNP have become a key conservation tool to conserve biodiversity in the park and beyond. As the first large-scale operation of highway mitigation of its kind in North America, it is a perfect case for understanding the conservation value of highway overpasses and underpasses for a variety of wildlife species including both large and small mammals. It was determined from the research that there is a vast majority of information available for large mammals compared to small mammals. Small mammals used the crossing structures to avoid predators, while large mammals used the crossing structures to avoid humans. The design of the structure was extremely influential on its effectiveness with black bears and cougars preferring narrow bridges with cover, elk preferring wide, open bridges, and smaller mammals, such as weasels, snowshoe hares, and some mice preferring culverts with vegetation cover. KEYWORDS road ecology, mammals, conservation, biodiversity, classroom tested

INTRODUCTION

Wild animal and human crashes happen daily at high traffic highways with high quantities costing animal and human lives instantly. Wildlife bridges on high traffic highways play a huge role in saving human lives and wildlife diversity. In this case study, we explore Canada's Banff National Park (BNP) and its wildlife crossing structures (WCS). Specifically, we ask whether the crossing structures for wildlife to cross the Trans-Canada Highway (TCH) in the park are effective for small and large mammal species of conservation interest.

Road Impacts on Wildlife

Not only do roads create the potential for an animal–vehicle collision, they separate habitats, resulting in habitat fragmentation, posing a threat to wildlife's food security, genetic diversity, and reproduction [1]. Human population rise is a threat to habitats of various species, with vehicle traffic on roads affecting a wide variety of species [2]. Avoidance of human activity by woodlands caribou on seismic exploration lines and roads resulted in a loss of up to 48% of habitat in Alberta, Canada [2].

Although some species, such as coyotes, do not seem to be significantly impacted by roads, other animals such as

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carnivores have proven to be very sensitive to roads and traffic. In fact, many smaller parks, such as Bryce Canyon in the United States, have seen the results of habitat fragmentation first hand. Roads have contributed to the extinction of lynx, grizzlies, and wolverines, while larger parks, including Banff, have managed to keep a larger portion of their endemic species [3]. Large carnivores are of critical conservation interest, as they are hypothesized to drive critical ecological processes such as fires, erosion, disease outbreaks, and forest regeneration [4].

In response, some animals avoid areas with roads or alter the timing of their movements. Wolves have been found to avoid areas of human activity near trails [2]. A study by Rogala et al. found that wolves and elk selected areas farther away from trails and roads with increasing human activity [2]. Wolf exclusion caused by humans led to changes in elk population dynamics and cascading trophic effects on aspen, willow, beaver, and songbirds. Thus, roads have both lethal and sublethal impacts on entire ecosystems and food webs, not just individual organisms or single species.

Road Crossing Structures as Linkages for Wildlife

In an attempt to address habitat fragmentation caused by roads and reduce the number of collisions, governments of all levels are considering the installation of wildlife crossings [1]. These crossings can vary greatly in price, scope, and size. In some cases, existing drainage culverts can be converted into a wildlife crossing or are already used by animals as a safe crossing point, even if that was not their original intended purpose [1]. An overpass in comparison can be as much as 10 times the cost of an underpass. Many crossings and other mitigation measures are created with predominantly larger species in mind, especially those that are endangered or can pose a risk to human safety [5].

Crossing structures are an extension of the development of corridors for wildlife conservation. Although the earliest definitions of corridors were specifically vegetation (narrow strips of habitat for focal species), the meaning was expanded to mean that a corridor "allows movement from somewhere to somewhere else" [6]. Crossing structures may be used by both "corridor dwellers" (organisms that will take generations to pass through the corridor) and "passage species" (organisms can move through the passive relatively quickly within its life) [7]. The biological or physical dimensions of a corridor aren't narrowly defined or required, as the goal is that it serves the function of linking landscape habitats or allowing dispersal for focal taxa. Road crossing structures fit this definition as a linkage, as it functionally promotes movement of wildlife to bypass "wildland blocks" [8], in this case roads.

Road crossing structures therefore must be designed specifically based on wildlife needs to ensure their efficacy. In order to ensure that animals use the crossings, rather than trying to cross the road, it is important to consider location, design (i.e., amount of shrubbery, width, and length of crossing), and human activity near the crossing sight [1]. Many of the newer crossing structures do not allow people to ensure that animals will be willing to use them [9]. Of all these factors, location may be the most important for determining the success of a crossing. Ideally, a crossing is placed in an area where animals typically cross to begin with so that it correlates with their behaviors and needs. Carnivores and ungulates were less likely to use a crossing with a lot of human activity, and distance from cover was also influential on their use of crossing structures. Other larger animals may avoid dense areas of cover all together out of fear of predators, whereas smaller animals may prefer large amounts of cover [1]. When considering the construction of a wildlife crossing, it is important to consider which animals its use is targeted for and the impacts of human activities in the surrounding areas.

BNP in Canada

BNP in the Central Rocky Mountains of Alberta is Canada's first national park and considered a flagship park for protected areas in the country [10]. The park receives about 2 million visitors per year and has approximately 9,000 full-time residents. As Canada has a target of protecting 17% of terrestrial and aquatic areas by 2020 to achieve its 2020 Biodiversity Goals and Targets [11], BNP plays an important role in achieving those benchmarks.

Banff is bisected by the TCH, a four-lane highway utilized by as many as 5 million people in a given year [12]. The TCH is the busiest highway in the country, with about 17,970 vehicles per day on average in BNP [13]. It serves as Canada's primary east–west transportation route, and it is just one of many roads in Canada where animal–vehicle collisions occurred frequently. There are an estimated 45,000 collisions yearly in Canada alone, with numbers only increasing in the last decade

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[5]. It is hard to gain an accurate number on the real amount of animal deaths as they can go unreported and scavengers often remove the carcasses [1]. Throughout Canada, these collisions are estimated to cost a staggering US$281,149,155 per year [5].

The park's highway structures play a vital role in conserving wildlife diversity. One of the world's most developed and well-known systems of wildlife crossings is located within the park [13]. Within the park boundaries, Park, there are currently 44 wildlife crossings (six of which are overpasses and 38 underpasses) [1]. Since the construction of these numerous wildlife crossings, there has been a large reduction in collisions, about 80%. Mortality rates for animals have also decreased by 50–100%, with death rates almost as low as zero for elk, when in previous years, 100 collisions with elk were recorded on average in a given year.

Crossing Structure Maintenance in BNP

Although animal–vehicle collisions cost a significant amount ecologically and economically, the installation and maintenance of wildlife crossings is also expensive. The five crossing structure designs, box culvert, large metal culvert, overpass, open-span bridge, and small metal culvert vary in cost from US$800,000 to US$1,700,000 per structure. This type of collision mitigation tactic has been shown to be effective with an 86% reduction in collisions, resulting in a cost per percent reduction of about US$8,368 [5].

A fence is often needed in combination with crossing structures to help funnel them toward the crossing. More than half of the Trans-Canada Highway is surrounded by a 2.4 m high wildlife fence on either side [12]. This fence needs to be maintained and eventually replaced (normally about every 75 years unless it can be salvaged). The annual maintenance alone costs about US$1500 per year with complete removal and replacement costing US$107,500 [5]. Federal land management and state transportation agencies are building costly structures for wildlife connectivity, but there is no long-term monitoring taken [14]. Structures require maintenance so that they do not hurt the road's infrastructures.

The hope is for these costs to be lower than the cost related to an animal–vehicle collision. As more collisions are avoided, the average cost per individual collision avoided decreases. Given the average cost of a collision, the break-even point and the number of collisions that need to be avoided for a wildlife crossing to be economical can be determined. It was found that 2.7 deer collisions, 1.0 elk collisions, and 0.6 moose collisions per kilometer per year need to be avoided for a crossing structure to begin producing economic benefits [5].

Crossing Structures in Management Context

Mitigation of highway impacts on wildlife in BNP using crossing structures is just one element of wildlife management in the park. The park's management plan specifically aims to manage transportation corridors, including road and rail, to connect ecosystems as much as connecting people in transit [10]. Yet highway mitigation does not only mean the establishment of crossing structures; other points of intervention are possible and may be more effective for the park's management goals. For example, grizzly bears are of special concern in BNP [10]. A review of literature on grizzlies and traffic has found that changing road density, seasonally closing roads, and other motorized access controls that alter human movement, not just wildlife, may be effective in Western Canada to benefit grizzlies [15].

Grizzly management reveals both the scientific and societal challenges of managing wildlife in BNP and the surrounding areas, which extend far beyond road crossing issues. Grizzly bear populations have partially recovered since being listed as threatened in 2010, but the efforts to protect them remain contested. Interviews with residents in Alberta, where BNP is located, found differences in attitudes about bears and support for mitigation measures based on livelihood and identity [16]. In turn, some stakeholders have felt delegitimized and unrepresented in the recovery processes to date [17]. This dynamic reflects tensions between consensus and regulatory conservation efforts seen in other ecosystems and jurisdictions [18]. The larger goals of BNP and in Canada of protecting grizzlies and other species while maintaining public support for conservation, and allowing outdoor recreation while avoiding human–wildlife conflict, will require far more attention than crossing structures.

CASE EXAMINATION

This case study looks to compare the response of small animals and large animals to anthropogenic barriers, such as the Trans-Canada Highway in BNP, and the role that wildlife crossings have played in reconnecting habitats for both types of animals. It is very important to analyze the

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created bridges to know whether the costly structures are working properly for different size mammals. As noted before, a bridge requires maintenance and installation with the involvement of large sums of money. Impacts of customized bridge transportation on different size mammals will prove beneficial for future projects involved with wildlife management and preservation.

Crossing Structure Impacts on Large Mammals

THE TRANS-CANADA HIGHWAY AS A BARRIER. Roads have shown to drastically affect how large mammals move throughout a habitat. Although some are able to successfully adapt to vehicle traffic, they struggle to become desensitized to foot traffic. The degree of sensitivity varies greatly between species. Luckily, some of the constructed crossings have proven to successfully reduce the amount of light and noise associated with roads [9].

Roads can divide the population and isolate wildlife populations decreasing genetic diversity within populations. A genetic study on grizzly bear and black bears indicates that crossing structures provide genetic connectivity for two large carnivore species across TCH through Banff [19]. Gene flow was determined for two bear species at WCS by combining individual-based genetic analysis with parentage analysis to document migration, reproduction, and admixture [19]. There is a positive correlation between the use of crossings and number of breeding opportunities for males [19]. Male and female individuals using crossings structures are successfully migrating, breeding, and moving genes across the roadway [19]. Mitigation efforts studied in a range of large animals within BNP (elk, bears, coyotes, and other ungulates) found that crossing structures for most taxa (all but other ungulates) did not act as a population sink or ecological trap [20]. Results from a modeling study indicate that this may be due to the approach having several smaller passages, rather than a single large one, to help eliminate these concerns and other barrier effects [21].

INFLUENCE OF CROSSING STRUCTURES DESIGN. A study conducted in the Bow River Valley along TCH corridor in BNP, Alberta, observed 4,209 large mammal and human use through-passes from the 13 crossing structures monitored continuously from November 1997 to August 2000 [14]. Through-passage usage was high; the minimum was at Bourgeau underpass and maximum at Red Earth overpass. As a result, through passage was effective to 91% of all approaches [14]. Width, height, and openness of crossing structure and distance to forest cover were positively correlated with grizzly bear passages, while noise levels were negatively correlated [14]. Grizzly bears who were by themselves were more likely to use underpasses than family groups. Wolves' passages during summer were correlated with crossing structure height and openness, as well as the distance to the nearest town and nearby human activity levels [14]. Distance to nearest townsite and distance to nearest crossing structure were positively correlated with wolves' passage in winter [14]. Crossing structure height, openness, distance to forest cover, and townsite were negatively correlated with cougars' passage in summer [14]. Cougars negatively correlated with passage and crossing structure width and distance to the next structure and positively correlated with crossing structure length [14]. During winter time, cougars favored crossing structures near forest cover, townsites, and far from Canada Pacific Railway tracks [14]. Structure width, height and openness, distance to forest cover, and human use were positively correlated with elk passage in summer, while crossing structure length and noise levels were negatively correlated with elk passage in summer. Crossing structure width, height, and openness were positively correlated, while noise levels were negatively correlated with elk passage in winter [14].

EFFECTIVENESS OF WILDLIFE CROSSINGS. Three-year evaluation of the effectiveness of WCS provided grizzly and black bear population connectivity in the Bow Valley of BNP [13]. Hair sampling concurrent with trackpad monitoring of the black bear and grizzly bear can provide information on populations that used the crossing structures. The type of crossing structure used determines whether animals prefer to use it to cross the road. Higher percentage of male and female grizzly bears preferred large and open crossings than black bears which preferred smaller and constricted crossings [13]. Black bears were more adaptable to use a wider variety of crossing types than grizzly bears [13].

WCS in BNP provides spatial and temporal connectivity for wildlife populations across a major transcontinental transportation corridor. The number of grizzly and black bears that used those passages was fairly consistent across years [13]. Wildlife crossing can have a positive impact by reducing roadkill, increasing access to food and shelter, and allowing escape from predation by other animals [13]. Stress can affect behavior and demography of

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wildlife. Wildlife crossing may reduce stress on animals because they no longer have to worry about traffic or vehicle problems, resulting in higher survival rate and reproductive fitness.

Crossing Structure Impacts on Small Mammals

THE TRANS-CANADA HIGHWAY AS A BARRIER Studies conducted over the years have found that roads are especially damaging when it comes to the ability of small animals to move about. The road width, road surface type, and amount of traffic have all been found to be influential when it comes to small animals crossing the road. Even roads that are not well traveled and are fairly narrow can have devastating effects on animals' movements; however, the extent to which an animal is affected varies greatly between species [12].

In a recent study, meadow voles, deer mice, and red-backed voles were all translocated to analyze the effect of the TCH as a barrier to small animals' movement [12]. In general, all species struggled to cross artificial barriers (the road) more than they did natural barriers (highway medians). They were 20% less successful in traversing the highway than they were natural barriers, suggesting that the road only hindered their movement moderately. Although, given that the voles and mice were moved away from their familiar home territories, it is thought that this created a much greater desire for them to move back across the unfamiliar terrain [12].

It is also important to note that the degree to which the road proved to be a barrier varied greatly between species. To a large degree, the deer mice were less hesitant than the voles to cross the road. Additionally, the voles had a more tortuous path than the deer mice, especially with increased traffic, suggesting that they perceived that the nearby habitat (the road) was not suitable. In general, their path was less direct as they approached the edge of the barrier compared to when they traveled within the barrier itself [12].

The road also proved to be a barrier to other species including snowshoe hares, red squirrels, martens, and weasels. Using snow tracks, it was determined that only 10% of red squirrel tracks traversed the highway, 38% of Martens, 23% of weasels, and 32% of snowshoe hares traversed the road [22]. On the other hand, the exclusion fence that lines a significant portion of the road did not significantly hinder the movement of small mammals. Additionally, 77% of red squirrels, 83% of Martens, 78% of weasels, and 58% of snowshoe hare tracks passed through the fence [22]. Anthropogenic structures, including roads, vary in the extent to which they affect different species; some perceive the road to be more of a barrier to movement than others.

INFLUENCE OF CROSSING STRUCTURE DESIGN. Deer mice, meadow voles, and red-backed voles preferred small crossing structures having larger diameters [23]. Small mammals prefer dense and proximate overhead cover because smaller structures seem safer for them. Smaller mammals are less likely to use overpasses due to energy demands and predator risks. Small- and medium-sized animals use crossing structures having lower traffic volume during night time [23]. Enhancing entrance cover at crossing structures and along the exclusion fence influence small mammals' movement across the crossing structures and fence [22, 23]. Simple crossing structures may reduce energy demands and confusion. Mice travel easily on ground and arboreal substrates, so they had success in all cover amounts, while meadow voles felt discomfort on nongrassy subtracts under heavy cover [23]. Other species, such as red squirrels, snowshoe hares, weasels, and martens, were more likely to cross with vegetation cover [22]. Small mammals had limitations detecting crossing structures because released mice crossed the highway without using crossing structures [23].

Discovery and use of crossing structures is as critical as the design of the crossing structure itself. Research from Quebec on Highway 175 in the Laurentides Wildlife Reserve found the most important design factors for use of passages by small mammals were location in more suitable habitats and distance from human activity and noise [24]. In BNP, animals would more likely use crossing structures if they were near their home ranges [23]. Given the habits of small mammals, they are more likely to use crossing structures, especially culverts with openings on the same side of the exclusion fence as their habitat. This is also beneficial during the winter months when snow from plows may block culvert openings that are too close to the road, effectively prohibiting animal movement [22]. Similar to large animals, different culvert designs are more suitable for different species. However, the majority of small mammals prefer to cross in areas where brush and other vegetation can provide cover.

EFFECTIVENESS OF WILDLIFE CROSSINGS. When studying the usage of WCS by three specific small

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mammal species, the only species found using the WCS was the habitat generalist deer mouse. Habitat specialists, such as the red-backed and meadow voles, were virtually absent along the WCS despite their frequency in contiguous woodlands and roadside grassland [25]. Deer mice, meadow voles, and red-backed voles successfully returned through 0.3-m diameter drainage culverts than through 3-m diameter underpass and successfully returned across 14-m wide overpasses [23].

CONCLUSION

Crossing structures in BNP for wildlife to bypass the TCH may provide a safer route, with less noise and stress for numerous large mammals to traverse from one side of the road to the other. Small mammals preferred crossing structures that had covers and protected them from predators. Although some evidence suggests that smaller mammals do not perceive roads to be as much of a barrier, some species still utilized crossing structures. As people have looked for a way to reduce the ecological and economic costs of habitat fragmentation and animal–vehicle collision, WCS have been installed throughout BNP. Although a costly solution, these structures have been shown effective when taking into consideration animals' preferred habitats and habits.

CASE STUDY QUESTIONS

1. How may animals be negatively impacted by roads? What role do crossing structures play in addressing these issues?

2. When may it be appropriate to use crossing structures for wildlife linkages instead of living habitat corridor? When may it not be appropriate to support conservation?

3. How may observation of wildlife crossings influence the design and implementation of future crossing structures?

4. Do the benefits of wildlife crossings to both humans and animals outweigh the high construction and maintenance costs in BNP? Why or why not?

5. Why should wildlife crossings be built to focus primarily on large animals?

6. How does wildlife crossing design impact the effectiveness of such structures?

7. Park managers in BNP must manage for the conservation of many species, not just one. How should the diverse needs of species in the park shape decisions around wildlife crossings as a management tool?

AUTHOR CONTRIBUTIONS

The conceptualization as well as the writing of the case examination and introduction was completed equally by LS, BR, EZ, and GP. BR, EZ, LS, GP, and KSW contributed to writing. KSW wrote the revisions.

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The authors have declared that no competing interests exist.

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