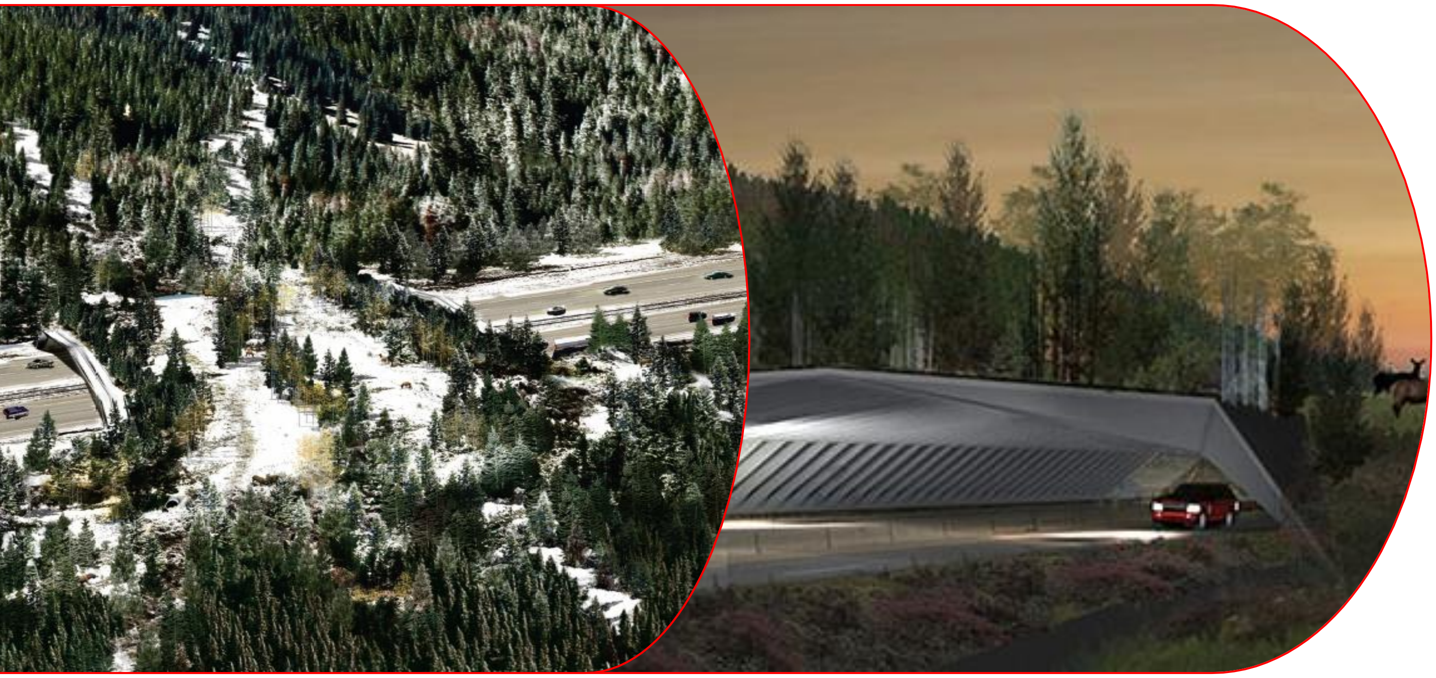
THE EFFICACY OF WILDLIFE CROSSINGS AS CONSTRUCTED CORRIDORS:

LESSONS FOR PLANNING NATURAL HERITAGE SYSTEMS IN ONTARIO



Images: HNTB with Michael Van Valkenburgh & Associates, New York (ARC International Wildlife Crossing Infrastructure Design Competition, 2010)

by Anita Sott

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And to my friends and classmates at SURP. What a blast.

EXECUTIVE SUMMARY

Habitat fragmentation resulting from development pressures including rapid population growth and unplanned development that necessitate the expansion of transportation infrastructure affects the viability of wildlife populations and landscape and habitat connectivity. The effects of roads on wildlife populations – habitat loss, reduced habitat quality, reduced landscape connectivity, and road-related mortality – have both immediate and cumulative deleterious effects. These include the degradation of remaining habitat, the disruption of ecological processes including animal migration and breeding, and the reduction or local extinction of wide-ranging species including carnivores, whose decline can destabilize entire biological communities.

Where these effects cannot be avoided through planning and management, implementation of wildlife crossing structures and associated mitigation measures may assist in the maintenance or restoration of connectivity by providing landscape-level linkages that facilitate the safe passage of wildlife across transportation corridors.

In Ontario, areas of the greatest species richness in the province coincide with the greatest density of people and roads. Significant forthcoming highway developments linking the Niagara and Halton regions to the Greater Toronto Area are threatening to encroach into the Niagara Escarpment and Greenbelt, which represent provincially protected natural heritage systems (NHSs).

The use of wildlife crossings to mitigate the effects of transportation developments on protected landscapes, habitats, and wildlife is a developing practice in Ontario, with some significant projects completed or underway. Provincial policy provisions explicitly support connectivity within and between NHSs, while the *Natural Heritage Reference Manual for Natural Heritage Policies of the Provincial Policy Statement, 2005* (Ontario Ministry of Natural Resources [MNR], 2010) cites the use of wildlife crossings as appropriate mitigation.

This research investigated the linkage function of wildlife crossings as *constructed corridors* with the potential to restore landscape and habitat connectivity within NHSs in Ontario that are transected by major transportation routes. Case studies of two exemplary wildlife crossing projects present best practices from which lessons can be learned to inform the implementation and success of wildlife crossing projects in Ontario's NHSs.

Research Methodology

This report addresses the following research questions:

+ How do wildlife crossings mitigate the effects of habitat fragmentation resulting from the transection of landscapes by transportation infrastructure?

+ Are wildlife crossings an appropriate tool in the planning of natural heritage systems in Ontario?
+ Is the application of wildlife crossings consistent with existing provincial policy directions in Ontario?
+ What lessons can be learned from the south Florida I-75 Project and Banff Wildlife Crossings Project that can inform the integration of wildlife crossings in Ontario's natural heritage systems?

A literature review outlined the translation of theoretical knowledge into practical mitigation practices related to the concept of corridors, the scholarly debate surrounding their efficacy in restoring habitat linkages between severed landscapes, and their relationship to wildlife crossings. The literature review consolidated research on the design, implementation, and monitoring of wildlife crossings and was used to derive a matrix of potential project components through which to organize case study data.

Using the matrix and content analysis of case study documents, the Interstate 75, south Florida and Trans-Canada Highway, Banff wildlife crossing projects were examined for lessons in design, implementation processes and requirements, and monitoring program structures. They are presented using a framework adapted from the recent publication *Safe Passages: Highways, Wildlife, and Habitat Connectivity* (Beckmann et al., 2010).

Wildlife overpass, Trans-Canada Hwy, Banff, AB.
Credit: Anita Sott, 2012.

Lessons Learned

Planning for wildlife crossing project locations is not an arbitrary practice and requires the employment of needs assessment tools to determine where wildlife movement is impeded and where it would be best facilitated, especially between areas of high habitat quality. Adjacent land management is essential to maximize the efficacy of crossing structures beyond the mitigated right-of-way.

The design of wildlife crossing structures should be selected to suit the needs of focal species but also feature elements that encourage use by multiple species, often facilitated by the provision of a diversity of structures. In combination with crossing structures, the installation and maintenance of exclusionary fencing on both sides of a mitigated roadway is the most comprehensive design solution to achieve both landscape connectivity *and* the reduction of wildlife road mortality.

Successful project implementation and post-construction management benefit from project champions (whether an individual or an organization), explicit roles and responsibilities for agencies and players involved, and public support campaigns or initiatives. These can build project momentum and relay successes and information from monitoring data back to the public and funding contributors.

Long-term monitoring programs should accompany all wildlife crossing projects and are necessary to evaluate post-construction project success. Under an adaptive management approach, monitoring can inform any required changes to improve the efficacy of crossing structures, inform future projects, and ensure public funds are being put to good use with the highest return on investment through maximal species use.

These and other best practices derived from the literature review and case study information were synthesized into key recommendations for the integration of wildlife mitigation in planning for Ontario's NHSs. Recommendations consider the application of provincial policy directions to enable the development of wildlife crossings to address habitat fragmentation, emphasized as a provincial priority.

Recommendations

① Conservation needs and the restoration or maintenance of connectivity in NHSs should be incorporated early in the planning process and integrated into transportation corridor designs.

② Wildlife crossing design and mitigation guidelines should be developed with sensitivity and specificity to the habitat and landscape features in Ontario's NHSs and the consideration of multiple species needs.

③ All wildlife mitigation projects should feature an adaptive management approach supported by long-term monitoring activities to ensure accurate post-construction evaluation of mitigation efficacy.

④ Information dissemination, public education initiatives, and efforts towards public support building should be prioritized and continued after project construction.

This report highlights successful project strategies requiring multi-disciplinary collaboration which can be used by planners and other professionals in order to maximize the success of future wildlife crossing projects. This information may be useful for the proactive consideration of wildlife crossings at initial stages of transportation planning and infrastructure design or retrofit. In Ontario, planners have the capacity, tools, and policies in place with which to prioritize the connectivity of natural heritage systems at the forefront of transportation planning processes and designs, towards a province-wide corridor system and leadership in wildlife mitigation.

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ACRONYMS

AM – Adaptive Management

BNP – Banff National Park

BWCP – Banff Wildlife Crossings Project

EA – Environmental Assessment

ECO – Environmental Commissioner of Ontario

EIS – Environmental Impact Statement

FDOT – Florida Department of Transportation

GGH – Greater Golden Horseshoe

GTA – Greater Toronto Area

I-75 – Interstate 75 (south Florida, USA)

MMAH – Ontario Ministry of Municipal Affairs and Housing

MNR – Ontario Ministry of Natural Resources

MTO – Ontario Ministry of Transportation

NEC – Niagara Escarpment Commission

NEP – Niagara Escarpment Plan

NGO – Non-governmental organization

NGTA – Niagara to GTA Transportation Corridor

NHS – Natural Heritage System

OREG – Ontario Road Ecology Group

ORMCP – Oak Ridges Moraine Conservation Plan

PPS – Ontario Provincial Policy Statement, 2005

PSW – Provincially Significant Wetland

RTP – Regional Transportation Plan

SAR – Species at Risk

TCH – Trans-Canada Highway

VEC – Valued Ecosystem Component

WTI – Western Transportation Institute (Montana State University)

1.0 INTRODUCTION

1.1 THE PROBLEM OF ROADS & HABITAT FRAGMENTATION

Habitat fragmentation is “a major driver of today`s biodiversity crisis” (Anderson & Jenkins, 2006, p.1). The problem of habitat fragmentation is one that requires implementable strategies in the short-term that can improve or restore landscape connectivity through natural corridors and protected areas for the long-term. Existing development pressures affecting wildlife populations include rapid population growth and unplanned development which necessitate the expansion of transportation infrastructure and enable human access to once remote areas. Resulting increases in capacity for future development and human disturbance through various land use activities are likely to produce cumulative detrimental effects on wildlife habitat quality and connectivity, and consequently, wildlife population viability (Beckmann & Hilty, 2010; O’Brien, 2006).

The emerging study of *road ecology* concerns the “interaction of organisms and the environment linked to roads and vehicles,” and considers the impacts of increasing *road density* (“the measure of a road network or the amount of roads in an area”) on wildlife and landscape connectivity (Forman et al., 2003, p.8-9; see Figure 1.1). In their formative book *Road Ecology*, Forman et al. (2003) explain that the effects of roads on wildlife populations – habitat loss, reduced habitat quality, reduced landscape connectivity, and road mortality – typically manifest at different rates. Whereas habitat loss to roads has the most immediate effect on wildlife population losses, the effects of road mortality due to wildlife-vehicle collisions may only be observable after one or two species generations. Cumulatively, effects observable today may only represent those caused by roads introduced decades ago, owing to rapid increases of development in recent years. In Canada, the road network has grown from just over 100,000 km in 1959 to over 300,000 km in 2001 (Forman et al., 2003).

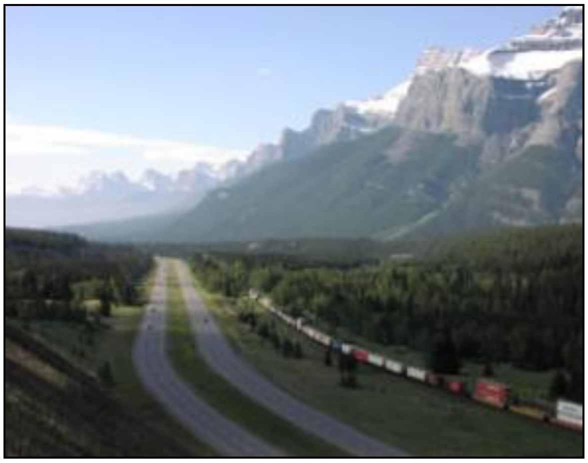


Image 1.1: Trans-Canada Hwy and Canadian Pacific railroad transecting critical habitat of the Bow River Valley, Rocky Mountains, Canada (Credit: Tony Clevenger, Parks Canada). Source: Lister, 2012.

As the development and expansion of new and existing transportation corridors increase, habitats become increasingly fragmented into patches, with deleterious effects. These include the degradation of remaining habitat by edge effects, the disruption of ecological processes including animal migration and breeding, and the reduction or local extinction of wide-ranging species including carnivores, the decline of which can destabilize entire biological communities (Anderson & Jenkins, 2006; Beckmann & Hilty, 2010). These effects can be mitigated if transport routes are planned through areas of existing disturbance, allowing for the preservation of continuous, untouched natural areas of higher value to wildlife populations (O'Brien, 2006). When avoidance of disturbance is not possible, mitigation measures are required to attempt to maintain or restore the viability of natural areas and their connectivity by landscape corridors.

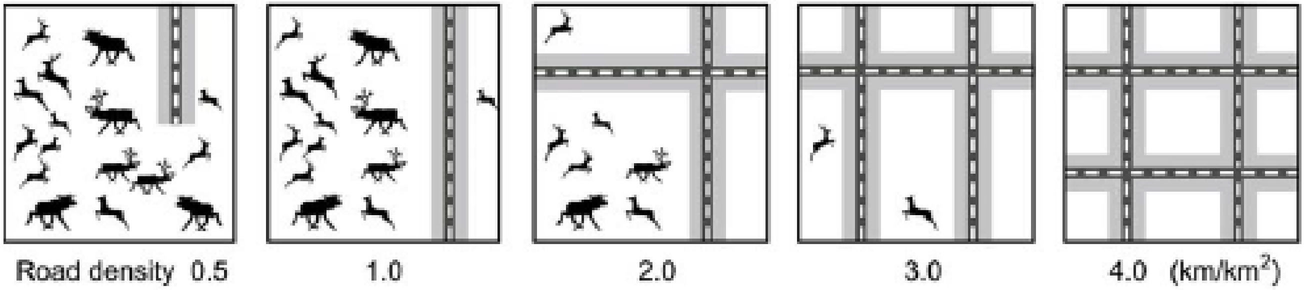


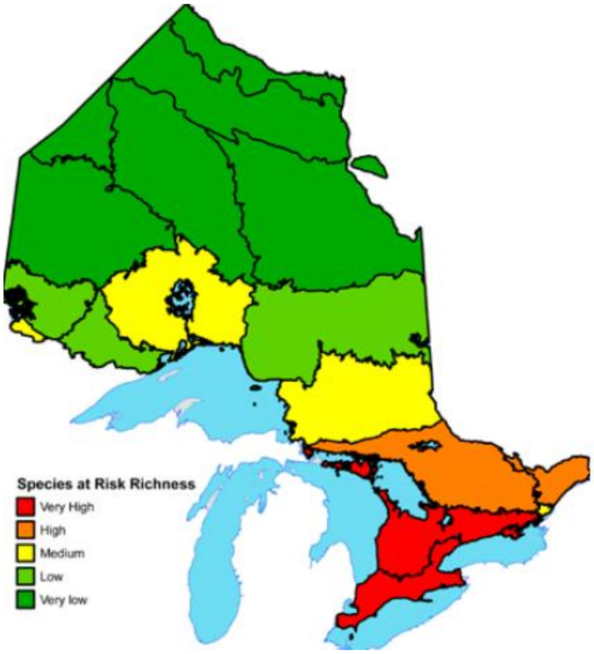
Figure 1.1: The effects of increasing road density on the fragmentation of habitat into patches and wildlife population viability.
Source: Clevenger & Huijser, 2009.

1.1.1 Wildlife Crossings as a Mitigation Measure

Wildlife crossing structures may facilitate the movement of wildlife across road barriers and act as constructed corridors that provide habitat linkages where transportation routes and related land uses have severed them. As such, these crossings have the potential to mitigate habitat fragmentation by restoring some connectivity, facilitating animal movement, and reducing wildlife-vehicle collisions that occur when animals attempt to navigate across transportation infrastructure (Clevenger & Ford, 2010; Forman et al., 2003; O'Brien, 2006; Ruediger & DiGiorgio, 2007). Appropriate design characteristics and considerations can be tailored to local contexts, species needs, and the physical attributes of landscapes (Ruediger & DiGiorgio, 2007; Grilo et al., 2008). The monitoring of these mitigation measures after implementation can serve to generate data to adapt crossing structures to better meet species needs and inform gaps in existing science (Clevenger & Waltho, 2000; Yanes, Velasco, & Suárez, 1995; Ruediger & DiGiorgio, 2007; Grilo et al., 2008). The use of policies to enable wildlife crossings and the role of planners in coordinating their implementation require immediate consideration.

1.2 RATIONALE FOR THE ONTARIO CONTEXT

Southern Ontario boasts the greatest biodiversity in the province, including 203 Species at Risk (SAR) as of 2010 (Ontario Road Ecology Group [OREG], 2010). This area of species richness coincides with the greatest density of people and roads. Over the last 60 years, major roads in southern Ontario have increased from 7,133 km to 35,637 km, resulting in a significant depletion of natural habitat (OREG, 2010; see Figure 1.2).



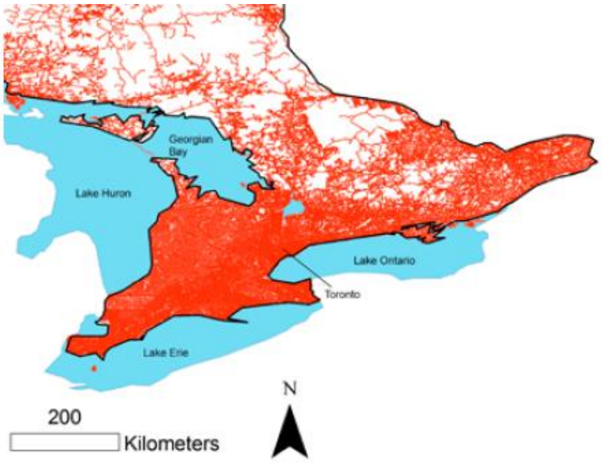


Figure 1.2: The area of Ontario highest in Species at Risk richness (left) coincides with the greatest road density in the province (right).
Source: Project WILDSPACE™ (left) & Eco-Kare International (right) in OREG, 2010.

The *Growth Plan for the Greater Golden Horseshoe, 2006* estimates a population increase in the region by over 3 million people in the next 20 years, inevitably contributing to an already congested provincial highway system. To accommodate existing transportation pressures and future demand, the Ontario Ministry of Transportation (MTO) has initiated roadway development and expansion of the 400 series provincial highways. These segments may traverse the provincially protected NHSs of the Greenbelt, Oak Ridges Moraine, and Niagara Escarpment, a UNESCO World Biosphere Reserve, and put habitats and protected landscapes at risk of further fragmentation (OREG, 2010).

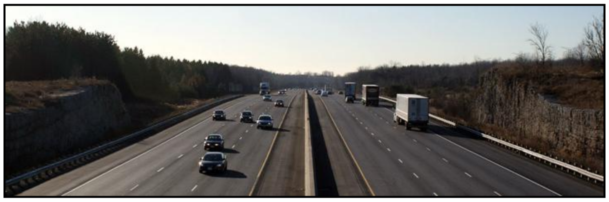


Image 1.2: Cut through Niagara Escarpment limestone on Hwy 401 looking west towards Kitchener from Nassagaweya 1st Line overpass.
Source: Steeves, 2004-2012. Retrieved from http://www.asphaltplanet.ca/ON/hwy_401_images/Hwy401_p7_images.htm

MTO has initiated Environmental Assessments (EAs) on the future transportation corridors that will link Urban Growth Centres, as defined by the *Growth Plan*, in and surrounding the Greater Toronto Area (GTA) through "an integrated system of transportation modes characterized by efficient public transit, a highway system for moving people and goods with improved access to intermodal facilities, international gateways (e.g. border crossings), airports and transit hubs" (MTO, 2012c, para. 4). To this end, MTO will coordinate with the regional transportation authority Metrolinx and other identified stakeholders including affected municipalities, regulatory agencies, and community groups to identify transportation problems and opportunities, assess route alternatives, and ultimately recommend Transportation Development Strategies for the Niagara to GTA (NGTA) and GTA-West corridors, as guided by the 25-year Regional Transportation Plan (RTP) (MTO, 2012c).

Highway 401 forms a common boundary between the two corridor studies which share a high level of coordination, as in the delineation of Preliminary Route Planning Study Areas which assess the provision of additional transportation capacity linking the Niagara Peninsula and Halton area to the GTA (MTO, 2012a; 2012c; see Figure 1.3). In June 2011, as part of the NGTA and GTA-West corridor EA processes, the Niagara Escarpment Commission (NEC) provided comments on the Draft Transportation Development Strategies in their capacity as a regulatory agency and stakeholder. The NEC expressly objected to the direction of the NGTA Study, which included one or more major crossings of the Niagara Escarpment Plan (NEP) area in the West area – Hamilton to Burlington/Oakville portion of the corridor, including the crossing of Lake Medad Valley Provincially Significant Wetland (PSW). The NEC and Conservation Halton considered such crossings contrary to the purpose and objectives of the NEP and the Provincial Policy Statement (PPS) section 2.1.2, considering the "anticipated significant environmental impacts on the natural character and features of the Niagara Escarpment" (Baran, 2011a, p.1). The NEC also summarized the comments from other municipalities and approval agencies, including Conservation Halton's disagreement with the Draft Strategy's contention that careful route planning can mitigate impacts on natural heritage. The agency cited concerns with indirect and cumulative impacts including barriers to wildlife movement, not thoroughly considered in the Draft Strategy (Baran, 2011a).

Figure 1.3: Delineation of study areas for proposed transportation corridors in the GGH, Southern Ontario. Both the NGTA & GTA-West Corridors encompass sections of the Niagara Escarpment (dark green) & Greenbelt (light green) plan areas. © Eco-Kare International.
Source: OREG, 2010.

Regarding the GTA-West Draft Strategy, the NEC informed MTO of its concern that the west terminus of the study area includes the Milton Heights and Scotch Block portions of the NEP, where development should be avoided. Furthermore, the NEC commented that any widening of Highway 401 sections that traverse the NEP area between the Village of Campbellville and the Town of Milton should avoid impacts on adjacent natural features, due to concerns of cumulative impacts on SAR habitats including forest interiors (Baran, 2011b).

Based on concerns of Niagara Escarpment crossings and other feedback received from stakeholders on the Draft Transportation Development Strategy for the NGTA corridor, a work plan for additional analysis was published in April 2012 that prioritizes greater avoidance and minimization of impacts to environmentally-sensitive areas and commits to context-sensitive planning in highway corridor development and widening alternatives (URS, MRC, & AECOM, 2012). Additional analysis on the GTA-West project and comparison of widening alternatives for Highway 401 versus a new corridor through Halton was planned to be presented for public consultation in June 2012 (MTO, 2012b). Final Transportation Development Strategies are targeted for release by Fall 2012 and January 2013 for the GTA-West and NGTA corridors, respectively (MTO, 2012d; 2012a).

Regarding a crossing of the Niagara Escarpment in the Waterdown area of the NGTA corridor, the construction of tunneling or animal underpasses is acknowledged as a potential impact mitigation strategy by Conservation Halton (Baran, 2011a). Through this suggestion and other existing and ongoing projects, it is evident that the use of wildlife crossings as a mitigation measure for habitat fragmentation by roadways is garnering consideration and being integrated in to transportation planning in Ontario. Thus, wildlife crossings warrant study as a mitigation practice relevant to current development in the province.

Anderson & Jenkins (2006) report that hundreds of corridor initiatives are underway worldwide, though most are in their planning stages, very few are under implementation, and none have had a full evaluation of their results. One such initiative is led by the Algonquin to Adirondack [A2A] Conservation Association, with the vision of linking Algonquin Provincial Park in Ontario and Adirondack Park in New York State along the Frontenac Axis, comprising approximately 93,000 km^2, including 30 protected areas and a buffer zone. A2A is supported by Ontario Nature's Greenway Initiative which focuses on the protection and restoration of natural heritage through the connection of natural core areas and corridors (A2A Conservation Association, 2012a). Notably, the A2A Conservation Association commissioned the *Highway 401 Porosity Study* undertaken by the Frontenac Arch Biosphere Reserve in partnership with Eastern Ontario Model Forest, Leeds County Stewardship Council, and St. Lawrence Islands National Park. It sought to determine the potential for improving the highway barrier to wildlife passage by "diverting, guiding and channeling wildlife, large and small, to new and/or improved structures" (A2A Conservation Association, 2012b, Highway 401 Porosity Study, para. 2). The study considered the permeability of road segments along a 49.6 km stretch of Highway 401 for wildlife passage and used a novel ranking system to help quantify the efficacy of existing underpass structures as passages for wildlife movement by mammals, reptiles, and amphibians (Ross, 2004).

Wildlife crossings were included in the road design of a segment of the 2002 Bayview Avenue road extension in York Region which traverses the Oak Ridges Moraine. To mitigate road effects on the natural environment by improving habitat connectivity and reducing wildlife-vehicle collisions, an 81 metre open span bridge, two corrugated steel pipe culverts for amphibian crossings, and five underpasses with funneling walls were installed (OREG, 2010).

Most recently, MTO, in cooperation with MNR, installed a $3.9 million wildlife overpass south of Sudbury – the first in Ontario. The overpass was designed as part of the Highway 69 four-laning project, 1 km north of Highway 637, where a high population of moose and re-introduced elk experience above-average wildlife-vehicle collisions (CBC News, 2012; MTO, 2010).

Image 1.3: Hwy 69 Wildlife Crossing Conceptual Plan. © Totten Sims Hubicki Associates, MTO.
Source: OREG, 2010.

6 km of fencing serve as a barrier to the road and guide wildlife towards the 30 metre overpass which will be landscaped with trees, shrubs, brush, and rock piles to provide a natural environment to encourage wildlife use and visually buffer highway traffic (MTO, 2010). As of March 2012, Eco-Kare International, responsible for the overpass monitoring through animal track counts and video imagery, reported some animal usage of the overpass even before fencing and vegetation planting were completed. Further plans include the installation of between 5 to 10 wildlife tunnels along Highway 69 to be used by animals including deer, lynx, and bobcats, each costing $1 million (CBC News, 2012; MTO, 2010).

Image 1.4: Hwy 69 wildlife overpass as viewed from road with images of deer and moose sculpted into side (top); overpass surface landscaping in progress (bottom). Credit: Kari Gunson. Source: CBC News, 2012.

OTHER EXISTING & ONGOING WILDLIFE CROSSING PROJECTS IN ONTARIO

Location	Mitigation
Caledon, Hwy 10 (OREG, 2010)	+ Metal anti-glare screen/mesh barrier fencing + 40 m corrugated steel pipe culvert for turtle crossings
Guelph (OREG, 2010)	+ Silt fencing + culverts for amphibian seasonal migrations
Hwy 17, north of Sault Ste. Marie (MTO, 2010)	+ Wildlife detection & warning system pilot project
Manitoulin Island, Hwy 540 east of Pleasant	+ Highway deer reflectors

Valley Road (MTO, 2010)	
Long Point – *Long Point Causeway Improvement Project* (Ecoplans Limited, 2008; OREG, 2010)	+ Electronic signs + Fencing + 2 dry ecopassages for terrestrial species + 1 wet ecopassage for aquatic species + Plan recommending total of 11 ecopassages, traffic calming by speed reduction, warning signs and interpretative signage at recreational nodes
Powassan, Hwy 11 to Parry Sound (McShane, 2012)	+ Wildlife detection system + 3.5 km of fencing + Underpass culvert

1.3 RESEARCH QUESTIONS & OBJECTIVES

This research investigated the potential for wildlife crossings to function as habitat linkages, or *constructed corridors*, within NHSs in Ontario that have been transected by major transportation routes. It compiled design elements and considerations which can contribute to landscape and habitat connectivity, maximize wildlife use of crossing structures, and mitigate roadkill resulting from wildlife-vehicle collisions. Finally, the research examined the potential integration of wildlife crossings within Ontario's NHSs to realize provincial policy directions. Case studies informed design schemes, processes of implementation, and monitoring program structures that have resulted in the successful application of wildlife crossings elsewhere in North America. The following questions guided these primary objectives:

+ How do wildlife crossings mitigate the effects of habitat fragmentation resulting from the transection of landscapes by transportation infrastructure?
+ Are wildlife crossings an appropriate tool in the planning of natural heritage systems in Ontario?
+ Is the application of wildlife crossings consistent with existing provincial policy directions in Ontario?
+ What lessons can be learned from the south Florida I-75 Project and Banff Wildlife Crossings Project that can inform the integration of wildlife crossings in Ontario's natural heritage systems?

Research findings were synthesized to form a set of key recommendations for the use of wildlife crossings in the planning of NHSs in Ontario.

1.4 OVERVIEW OF METHODS

A multiple-case study approach in this research identified exemplary projects that have been successful at mitigating the deleterious effects of roads on wildlife habitat and population loss and viability, wildlife mortality, and the costs to public safety as threatened by wildlife-vehicle collisions. Two wildlife crossing projects were examined for lessons in design, implementation, and monitoring that may inform mitigation application in Ontario.

The south Florida and Banff projects are consistently cited as international exemplars of the successful implementation of wildlife crossings (Anderson & Jenkins, 2006; Clevenger et al., 2009; Ford, Clevenger & Rettie, 2010; Forman et al., 2003; Ruediger & DiGiorgio, 2007). These case studies were described using a framework adapted from the recent publication *Safe Passages: Highways, Wildlife, and Habitat Connectivity* (Beckmann et al., 2010) which synthesizes road ecology, conservation science, and transportation planning, and specifically addresses the facilitation of wildlife movement across transportation corridors. Case study components included:

a) description of the project setting and context
b) planning issues that inform the project rationale
c) design scheme for the wildlife crossings
d) process through which the wildlife crossings were implemented (including the policy context and any circumstances that hindered or assisted implementation)
e) structure of the project's monitoring program
f) project outcomes
g) lessons learned

Sources of information and evidence informing this research included a literature review of academic texts, articles, and professional reports in the fields of conservation planning and science and road ecology. The case studies comprise a review of relevant documents including project reports, websites, and secondary articles.

Key recommendations in this report were derived from the literature review and case study information. They consider how planners and policymakers can use provincial policy to enable the development of wildlife crossings to address habitat fragmentation, which is emphasized as a provincial priority through the *Natural Heritage Reference Manual for Natural Heritage Policies of the Provincial Policy Statement, 2005* (Ontario Ministry of Natural Resources [MNR], 2010). Furthermore, the use of wildlife crossings to address this prevalent landscape-level concern has historically been more commonly employed in Europe than in North America (Corlatti, Hacklander, & Frey-Roos, 2009). By synthesizing case study findings, including those of an internationally-renowned Canadian wildlife crossing network, planners and other professionals can address the wider integration of wildlife crossings in to transportation planning and design using best practices. While significant projects are underway in Ontario, wildlife crossings are not yet a prevalent provincial practice and other Canadian jurisdictions have made greater progress in wildlife mitigation policies, though the pressures of urban development on the province's NHSs managed by the *Greenbelt Plan*, the *Oak Ridges Moraine Conservation Plan*, and *Niagara Escarpment Plan* are intensifying (ECO, 2008; OREG, 2010). By using policies to enable mitigation on the ground, the development of wildlife crossings can reaffirm the importance of landscape connectivity in the planning process.

1.5 REPORT STRUCTURE

This report is divided into six chapters. *Chapter 1* discusses the problem of roads and habitat fragmentation and considers its mitigation by the use of wildlife crossings in Ontario. *Chapter 2* presents a literature review that defines key concepts related to NHSs, provides background information, and introduces the mitigation potential and essential components of wildlife crossing projects. *Chapter 3* discusses the relationship of wildlife crossings to the relevant legislative and policy frameworks that support the development of NHSs in Ontario. *Chapter 4* describes this report's research approach and details the methods utilized to conduct, analyze, and synthesize the case study data collected. *Chapter 5* presents two case studies of exemplary wildlife crossing projects and discusses their findings organized by evaluative criteria developed through the literature review. *Chapter 6* concludes the report with key recommendations towards the implementation of wildlife crossings in Ontario and their contribution to the planning of well-connected NHSs.

2.0 LITERATURE REVIEW

The Ontario Ministry of Natural Resources' (2010) *Natural Heritage Reference Manual for Natural Heritage Policies of the Provincial Policy Statement, 2005* defines a *natural heritage system* as:

> a system of connected or to be connected green and natural areas that provide ecological functions over a longer period of time and enable movement of species. Natural heritage systems encompass or incorporate natural features, functions and linkages (also referred to as 'corridors') as component parts within them and across the landscape. They also enable the linking of different landscapes. (p.15)

The concept of NHSs has been integrated in to provincial policy in Ontario and is supported in Section 2 of the *Planning Act* which identifies the protection of ecological systems as a provincial interest (MNR, 2010). The function of corridors as habitat linkages is identified through these policies as an integral component of NHSs with ecological benefits. Just as corridors generally function to link fragmented habitats, wildlife crossings have been identified as a potential mitigation measure with a corridor function that can link habitats fragmented by transportation corridors, helping to restore wider landscape connectivity. The following literature review examines effective design considerations and guidelines, implementation tools and processes, and monitoring strategies for wildlife crossings. These project elements may inform the potential function and efficacy of wildlife crossings as *constructed corridors* and tools for the mitigation of road barriers in developing NHSs in Ontario.

2.1 THE IMPORTANCE OF CONNECTIVITY

Considered "one of the very core tenets of conservation," *connectivity* is defined as "a measure of the extent to which plants and animals can move between habitat patches" and includes such mechanisms as ecological networks, greenbelts, corridors, and highway crossing structures (Beckmann & Hilty, 2010, p.12). Though different species require connectivity at various scales (i.e. continental connectivity for the wolverine; site-specific corridors for elk and bighorn sheep), maintenance and restoration of connectivity largely occurs at the localized scale of facilitating regular wildlife movements (Beckmann & Hilty, 2010). As in the natural condition of a continuous landscape, higher survival rates are experienced by connected wildlife populations. Connectivity ensures greater flexibility for species to respond to given habitat conditions and increased resiliency to natural disturbances including drought and fire and larger environmental changes, particularly relevant to climate change (Beckmann & Hilty, 2010). Moreover, connectivity helps to maintain genetic diversity and prevents inbreeding within isolated populations, which can otherwise lead to an increased susceptibility to disease affecting reproductive and mortality rates. Such demographic effects may lead to species extirpation or extinction. The connectivity of even small subpopulations can reduce or eliminate the harmful effects of inbreeding within larger populations by encouraging recolonization and breeding (Beckmann & Hilty, 2010). With a long-term approach, the benefits of a connected landscape afford species populations with flexibility and resiliency and can extend to entire biological communities and ecological processes, while more localized connectivity efforts have the potential to protect threatened species and habitats in the short-term (Anderson & Jenkins, 2006).

2.1.1 Using Corridors in Planning for Conservation & Connectivity

First, it is useful to delineate the definition of a *corridor* as it is commonly accepted in the extant literature. Under the principles of landscape ecology, corridors are a basic structural element of the *patch-corridor-matrix model* that comprises a landscape (see Figure 2.1). *Patches* are habitat fragments connected by corridors within a *matrix*, or the background landscape or wider habitat (Anderson & Jenkins, 2006; Forman et al., 2003).

"Corridor" is considered to be an ambiguous term often used to describe landscape components with divergent functions (Rosenberg, Noon, & Meslow, 1997). Rosenberg et al. (1997) identify two primary functions of corridors - as wildlife habitat and as biological corridors operating at a larger ecosystem level. However, they caution that not all life history requirements of a species may be met in them, such as reproduction. Beier & Noss (1998) distinguish that corridors are proposed for conservation purposes with the intention of enhancing or maintaining the viability of specific wildlife populations in habitat blocks. Hobbs (1992) explains that structures such as highway underpasses and greenways have also been called corridors. Generally, corridors are described as linear features of vegetation that serve to connect and facilitate the movement of wildlife between fragmented habitat patches that may have been historically connected (Anderson & Jenkins, 2006; Beier & Noss, 1998; Hobbs, 1992; Rosenberg et al., 1997). While they come in various forms, corridors all exhibit general functions (Forman et al., 2010):

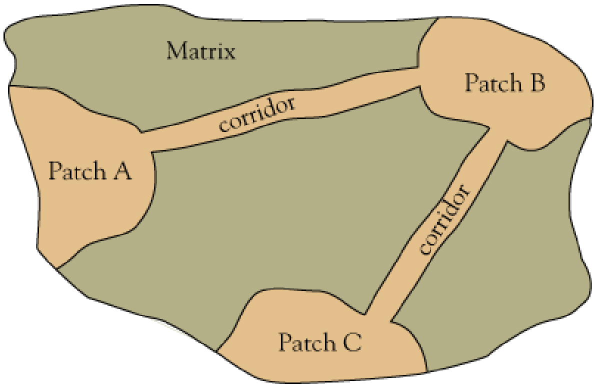


Figure 2.1: Patch-corridor-matrix model.
Source: http://www.ca.uky.edu/agc/pubs/for/for76/for76.pdf

+ As *barrier*: to the movement of organisms and abiotic materials, as in transitions between distinct habitats, which aids in targeting animals for conservation within a corridor while protecting corridor habitats from invasive species (Anderson & Jenkins, 2006);

- As *conduit*: a pathway that facilitates the movement of organisms, materials, and energy through the landscape; especially between habitat fragments (Anderson & Jenkins, 2006);
- As *source or sink*: providing a source from which organisms and abiotic materials spread to adjacent areas or acting as a sink which is dependent on organisms and abiotic materials arriving from outside the corridor (Anderson & Jenkins, 2006);
- As *habitat*: providing necessary environmental and ecological conditions for organisms to thrive (Anderson & Jenkins, 2006).

Based on this accepted notion of basic form and function, corridors have been identified as a potential mitigation measure applicable to the problem of increasing habitat fragmentation, identified in landscape ecology as the "primary consequence of human-development on the natural environment [...] which converts extensive or continuous areas of forest, wetlands, meadows and other types of habitat into isolated islands" (Hough, 2004, p.228).

Hough's description of fragmented habitat patches as islands recalls the theory of *island biogeography* introduced by MacArthur and Wilson in 1967, which demonstrated that large islands support more species of plants and wildlife than small islands do. This same principle is applied to terrestrial habitat patches (Hough, 2004). The theory has been generally accepted in the field of landscape ecology as the justification for corridors and their function of connecting habitat patches in order to address threats of habitat fragmentation on species survival (Boitani, Falcucci, Maiorano, & Rondinini, 2007). Habitat fragmentation can potentially lead to isolated species populations and consequent effects of inbreeding and loss of genetic diversity. Smaller populations are also more susceptible to extinction via processes and events like the rapid spread of disease (Anderson & Jenkins, 2006; Simberloff & Cox, 1987). As such, conservation plans have been designed utilizing corridors as the predominant strategy through which to increase the connectivity of isolated habitat patches (Rosenberg et al., 1997).

2.1.2 Mitigating Habitat Fragmentation with Corridors

The efficacy of corridors in mitigating the effects of habitat fragmentation has been actively debated through the literature. Little consensus has been reached as to their ultimate ecological benefit due to a lack of available data, uncertainty in the scientific evidence that does exist, disagreement about the validity of experimental versus observational studies, and the evolving nature of the fields of conservation biology and landscape ecology (Anderson & Jenkins, 2006; Beier & Noss, 1998; Haddad, Rosenberg, & Noon, 2000; Hobbs, 1992; Noss, 1987; Rosenberg et al., 1997; Simberloff & Cox, 1987). However, the potential advantages attributed to corridors are largely consistent among authors and are effectively summarized by Noss (1987). Corridors may have the capacity to:

a) Increase immigration rate to a reserve, which could:
    i. increase or maintain species richness and diversity (as predicted by island biogeography theory);
    ii. increase population sizes of particular species and decrease probability of extinction (provide a “rescue effect”) or permit re-establishment of extinct local populations;
    iii. Prevent inbreeding depression and maintain genetic variation within populations;

b) Provide increased foraging area for wide-ranging species, including large carnivores;

c) Provide predator-escape cover for movements between patches;

d) Provide a mix of habitats and successional stages accessible to species that require a variety of habitats for different activities or stages of their life-cycles;

e) Provide alternative refugia from large disturbances (a “fire escape”);

f) Provide “greenbelts” to limit urban sprawl, abate pollution, provide recreational opportunities, and enhance scenery and land values (Noss, 1987, p.160).

Several possible disadvantages of corridors are identified in the literature, and are argued by Simberloff & Cox (1987) as reason to preclude the uncontested implementation of corridors in conservation planning without sufficient supportive biological data:

+ That contagious effects including fires, introduced predators, and diseases can be transmitted through corridors;
+ That corridors increase the exposure of species to domestic animals and the spread of disease, and increase the vulnerability of species to hunting, poaching, and predators by facilitating the monitoring or tracking of migration routes;
+ That corridors may facilitate the spread of invasive species or secondary successional species that can gradually degrade habitat;
+ That without cost-benefit considerations, corridor projects may detract resources from the viability of other valuable conservation initiatives (Simberloff & Cox, 1987; Noss, 1987).

Simberloff & Cox (1987) caution that each individual corridor should be considered on the basis of its own merits and that the generalization of corridor functions based on theory cannot be universally applied in practice; decisions should be based on data. In addition to a lack of scientific certainty and data validation of corridor function, studies which seek to demonstrate the increase of immigration and consequent decrease of species extinction in corridors are argued as often lacking the sufficient controls to demonstrate this point (Simberloff & Cox, 1987). In response, Noss (1987) contends that more research is needed to develop best management practices for habitat linkages, or what he refers to as “optimal connectivity strategies” (p.160).

This early debate of corridor efficacy in facilitating animal movement and conserving habitat focused both on theory and empirical observations. Anderson & Jenkins (2006) contend that the studies upon which empirical observations have been based relied too heavily on behavioural and population responses of wildlife in corridors, focusing on small animals with limited movements. Predominantly, corridor studies have avoided carrying out experimental studies involving larger species with wider ranges, such as top carnivores that play critical roles in biological communities and are often the focal species upon which corridor plans are designed (Anderson & Jenkins, 2006). More recent research indicates that "animal responses to corridors are highly species- and scale-specific," and that research designs should prioritize the details of particular species and scales relevant to conservation practice instead of addressing general questions of corridor viability (Anderson & Jenkins, 2006, p.23). Thus, corridor design is not a universal practice, as it necessitates data specific to the species and habitat requirements at the scale of the conservation practice in question. Experimental research has been inconclusive on ecosystem-level effects of corridors on factors including disturbance, invasive species, predation, and species richness (Anderson & Jenkins, 2006), perhaps because the long-term effects of many such conservation plans have yet to be ascertained.

Regardless of the immediate availability of this data, the continued severance of landscape linkages demands active strategies to combat the process and consequences of habitat fragmentation (Noss, 1987). This reasoning is consistent with the precautionary approach, as defined in the 1999 *Canadian Environmental Protection Act*, which states:

> Whereas the Government of Canada is committed to implementing the precautionary principle that, where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation. (p.2)

According to this principle, the following considerations may provide justification for the continued use of corridors in conservation planning:

- There is no current evidence on the negative impacts of corridors on plant or animal populations, communities, or ecosystems (Anderson & Jenkins, 2006; Beier & Noss, 1998);
- In the absence of data, it is safer to assume that in order to support natural processes, a landscape in its natural, connected condition is preferable to a fragmented one (Anderson & Jenkins, 2006; Beier & Noss, 1998);
- Loss of habitat resulting in isolated wildlife populations is detrimental to biodiversity (Anderson & Jenkins, 2006; Noss, 1987).

Considering the discord in the literature, whether the conservation or implementation of corridors is a panacea for habitat fragmentation remains unknown. However, the rapidity of habitat fragmentation does not allow for the acquisition of complete scientific evidence of the efficacy of corridors prior to taking conservation action. Indeed, data scarcity should justify continued research (Anderson & Jenkins, 2006; Hobbs, 1992). Meanwhile, the severity of the effects of habitat fragmentation on species' survival rates is uncontested and immediate mitigation measures must continue to be explored.

2.2 THE EFFECTS OF ROADS ON WILDLIFE

The construction of roads is considered "a leading cause of habitat fragmentation and the resulting loss of connectivity" worldwide, and represents a loss of about 4.8 million hectares of land to roads in the US alone (Beckmann & Hilty, 2010, p.5). The major effects of roads and vehicles on wildlife include a direct loss of habitat or changes in the quality of road-adjacent habitat, the occurrence of roadkill, and the impediment of animal movements.

2.2.1 Habitat Loss & Changes in Habitat Quality

Direct habitat loss occurs when existing habitats are converted to roads or roadsides. Additionally, indirect degradation or alteration of surrounding habitat may result from siltation of streams, drying of wetlands due to hydrological changes, pollutant runoff (i.e. nitrogen deposits), light and noise pollution, and high human activity (Beckmann & Hilty, 2010; Forman et al., 2003). The area impacted by habitat loss includes the lanes of road and area of roadside vegetation extending anywhere from 1 to 10 metres from the road's edge (Beckmann & Hilty, 2010).

Particularly in forest interiors, habitat loss and declining patch sizes result in a higher proportion of edge habitat where forest interior species cannot survive. *Edge habitat* comprises the area of once continuous habitat which has been converted to an abrupt edge, with effects that can permeate hundreds of metres into adjacent habitat (Beckmann & Hilty, 2010). Edge effects include a decrease in population density, competition with invasive species, the risk of edge predators, and poor habitat quality (Beckmann & Hilty, 2010). Habitat lost to road construction compounds with the creation of forest edge, representing loss several times the actual forest removal (Forman et al., 2003).

Reduced habitat quality related to road construction is usually manifests as a decrease in the abundance of breeding individuals or behavioural responses, such as road avoidance. Furthermore, roads can indirectly increase mortality by increasing risk of predation and human access and contact with wildlife (Forman et al., 2003).

2.2.2 Wildlife-Vehicle Collisions

An estimated 1 million vertebrates are killed daily on US roads (Beckmann & Hilty, 2010). For example, deer mortality is estimated to range from 720,000 to 1.5 million annually, with approximately 92% of collisions resulting in death (Forman et al., 2003). Road mortality resulting from wildlife-vehicle collisions can devastate small or threatened populations (Beckmann & Hilty, 2010). In Ontario, many such Species at Risk (SAR) whose populations are affected by roads are "slow-moving animals, such as reptiles and amphibians that do not readily avoid roads or vehicles," and for whom the risk of road mortality is extremely high (OREG, 2010, p10) (see Appendix 1.0 for Ontario Species at Risk Threatened by Roads). Risks of wildlife-vehicle collisions are influenced by both traffic speeds and volume and are increasing with the rate of human-use development. This includes expanding road networks, urban sprawl, and associated increases in traffic flows, especially in early morning and evening when both commuting and wildlife activity simultaneously peak (Forman et al., 2003).

Many wildlife-vehicle collisions involving larger species result in human injuries or casualties and thus constitute a significant threat to public safety. Furthermore, significant vehicle damage often occurs, with the average costs of property damage per collision in the US estimated at $1,577 (Forman et al., 2003).

Species most vulnerable to road mortality exhibit the following characteristics: high mobility, multiple resource needs, low densities and large area or range requirements, low reproductive rates, and an attraction to roadside habitat (Beckmann & Hilty, 2010; Forman et al., 2003). Reptiles may be attracted to roads and roadsides as basking or nesting sites, whereas some animals are attracted to edge habitat or roadside vegetation, roadkill, basking animals, or food spills from vehicles (i.e. grain) as food sources and are thus put at risk of collision (Forman et al., 2003).

Image 2.1: Mountain goats attracted to roadside vegetation, Highway 93 South in Kootenay National Park, BC, Canada (Credit: Tony Clevenger, Parks Canada).
Source: Clevenger & Huijser, 2009.

2.2.3 Roads & the "Barrier Effect"

Highways present a human-made boundary to an animal's range and may prevent its regular movements (Forman et al., 2003; O'Brien, 2006). Beyond actual roadways, physical structures impeding safe wildlife passage can include concrete barriers separating traffic lanes, guard rails, noise walls, and poorly-placed fencing

(Forman et al., 2003). Beyond the physical barrier of transportation infrastructure, associated barriers to animal movement include artificial light and noise, presence of vehicles, and fear of the physical danger of being killed or injured in crossing attempts. These attributes and consequences of transportation infrastructure comprise what is commonly referred to as the "barrier effect" on wildlife (Clevenger & Waltho, 2000; Forman et al., 2003; O'Brien, 2006; Yanes et al., 1995). O'Brien (2006) identifies animals most vulnerable to these barriers: rare species with small local populations and those with large individual ranges, including large carnivores and species with daily or seasonal migrations that may necessitate barrier crossings. These can include amphibians needing to reach breeding ponds, grizzly and black bears with large home ranges, deer migrating to grazing lands, and species that undertake seasonal long-distance migrations like moose and reindeer.

Image 2.2: Bighorn sheep in wildlife-vehicle collision.
Source: Lister, 2012.

Combined with high traffic volumes, these barriers significantly decrease the permeability of transport routes and have many direct impacts on wildlife and their habitats. Roadkill is a visible result of the conflict between roads and wildlife and also represents a public safety hazard through the potential for wildlife-vehicle collisions, ultimately posing a threat to both people and wildlife conservation (O'Brien, 2006). O'Brien (2006) identifies fencing as the only consistently successful deterrent of animal roadway crossings, but explains that fences merely exacerbate the barrier problem when unaccompanied by wildlife crossing structures and further prevent animals from navigating between fragmented habitats.

While road mortality and behavioural or physical barriers are individual effects on wildlife, wider effects are experienced locally and regionally. Reductions in landscape connectivity and local wildlife populations may ultimately result in a reduced regional population size and lower long-term persistence due to population isolation and impacts on gene flow and inbreeding. However, little is known about these long-lasting ecological effects, constituting a need for further research (Forman et al., 2003).

2.2.4 Transportation Planning Considerations

Ideally, the transportation planning incorporates planning for wildlife habitat connectivity and considers where it is possible to determine whether impacts can be successfully avoided or minimized to reduce the need for mitigation (Clevenger & Ford, 2010). The planning and situation of transportation infrastructure in areas of existing disturbance represents the preferred ecological approach of the prevention of habitat fragmentation and disturbance over the necessary mitigation of adverse effects. O'Brien (2006) advocates for initial transportation route selection that is informed by the early identification of sensitive areas so that transportation engineers and planners may identify potential routes that avoid as many sensitive areas as possible and identify habitat linkage sites in the process (see Figure 2.2).

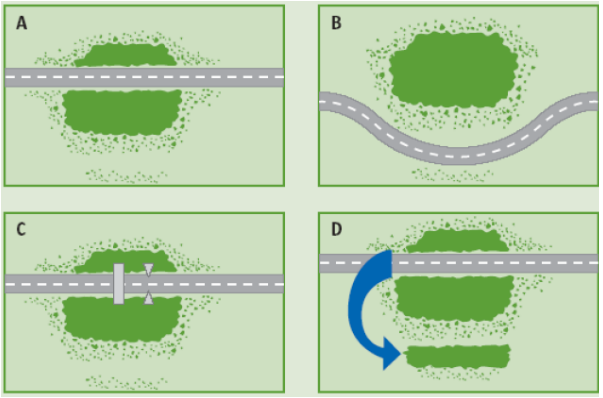


Figure 2.2: Road construction and habitat (A) fragmentation, (B) avoidance, (C) mitigation by use of wildlife crossings, (D) compensation by replacement habitat.
Source: Clevenger & Huijser, 2009.

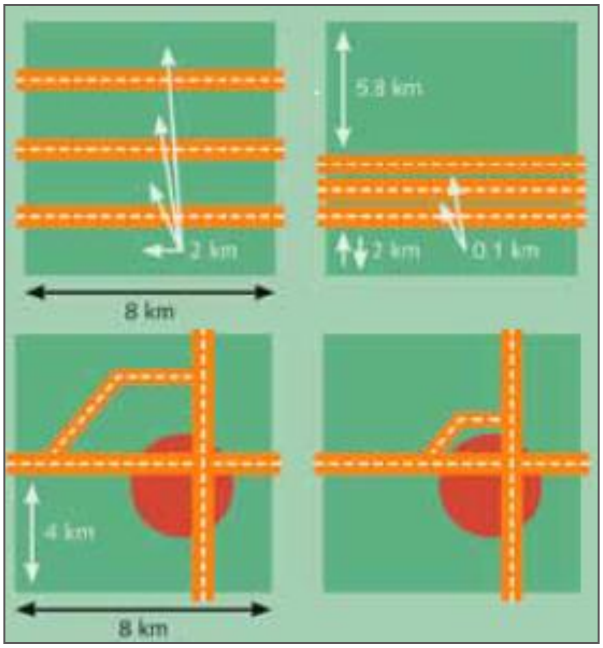


Figure 2.3: Bundling transportation routes (top) and building closer to settlements (bottom).
Source: OREG, 2010

Other considerations to minimize the effects of roads when planning transportation corridors include building fewer roads, reducing road width, raising road grading to discourage wildlife passage, designing medians permeable to animal crossings, and implementing temporary road closures during peak wildlife movements or migrations in areas where alternate routes are accessible (OREG, 2010). Bundling transportation routes serves to conserve habitat and limit fragmentation (see Figure 2.3). Similarly, habitat can be conserved by building road features such as by-passes closer to urban settlements (OREG, 2010).

2.3 WILDLIFE CROSSINGS AS A MITIGATION MEASURE

Where the prevention of habitat fragmentation is not possible through the avoidance or minimization of transportation infrastructure impacts on wildlife habitat, wildlife crossings can be introduced as a mitigation measure. These structures have the capacity to mitigate the effects of roadways on habitat fragmentation and provide linkages, or *constructed corridors*, between severed habitats.

2.3.1 The Function of Wildlife Crossings as "Constructed Corridors"

Members of the public are most likely to understand the term "corridor" as a connecting space, "the concept of which includes artificial structures such as tunnels or underpasses that are designed to permit animal movement (Anderson & Jenkins, 2006, p.4-5).” The linkage function of a corridor is reinforced in the aforementioned MNR definition of a NHS. As the overall objective of wildlife crossings are to increase permeability of roadways by providing landscape linkages and restoring connectivity (Forman et al., 2003), engineered wildlife crossing structures can be considered “constructed corridors.”

Image 2.3: Wildlife overpass, Trans-Canada Hwy, Banff, AB.
Credit: Anita Sott, 2012.

Wildlife crossings fall under the classification of a “linear corridor,” as they meet the following set of descriptors:

+ Provide a relatively straight linkage between two or more larger habitat blocks;
+ Are designed to maintain or restore target species, movement of short-ranged animals, and/or local ecosystem services, and;
+ Are most relevant in relatively disturbed landscapes (Anderson & Jenkins, 2006, p.6-7).

More specifically, wildlife crossings are considered either “movement corridors,” “dispersal corridors,” or “wildlife corridors,” as they are designed primarily to facilitate specific species movements or migrations (Anderson & Jenkins, 2006, p.18).

Drawing further comparison, Clevenger and Ford (2010) argue that wildlife crossing structures should allow for the same ecological functions as wildlife corridors:

1) Reduced mortality and increased movement (genetic interchange) within population;
2) Meeting biological requirements such as finding food, cover, and mates;
3) Dispersal from maternal or natal ranges and recolonization after long absences;
4) Redistribution of population in response to environmental changes and natural disturbances (e.g. fire, drought); movement or migration during stressful years of low reproduction or survival;
5) Long-term maintenance of metapopulations, community stability, and ecosystem processes. (p.44)

2.3.2 Objectives

The use of wildlife crossings as a mitigation measure has two main objectives:

1) Connecting wildlife habitats and populations, and;
2) Reducing wildlife road mortality and increasing motorist safety (Clevenger & Ford, 2010, p.32).

These objectives are directly related to the tolls of roads on wildlife, primarily that of habitat and wildlife population fragmentation and the threat of wildlife-vehicle collisions. The objectives should be integrated when planning for wildlife crossings, through a combination of design and safety measures targeting both animals and motorists including fencing, gates and escape ramps, signage, and speed reduction (Clevenger & Ford, 2010).

OTHER MITIGATION MEASURES (for individual use or as complement to wildlife crossing structures [Huijser & McGowen, 2010])	
Influencing Driver Behaviour	Public Information & Outreach
	Standard & Enhanced Warning Signs
	Seasonal Warning Signs
	Sensor-based Animal Detection Systems
	Increased Visibility (roadway lighting, vegetation removal, wider striping)
	Traffic Calming
	Reduced Vehicle Speed
	Temporary Road Closure
	Wildlife Crossing Assistants
Influencing Animal Behaviour	Vehicle Deer Reflectors & Mirrors
	Deer Whistles
	Gates & Escape Paths
	Minimal Nutritional Right-of-Way Vegetation
	Carcass Removal
	Increased Median Width
	Population Size Reduction (culling, relocation, antifertility treatment, habitat alteration away from road)
	Fencing

2.3.3 Design

While each situation that necessitates mitigation has its own set of site-specific species and connectivity concerns and land management priorities, general design principles and guidelines are emerging in the literature around existing wildlife crossings and related studies that may provide foundational direction for future projects (Forman et al., 2003).

Scaled Habitat Connectivity Planning

Clevenger & Ford (2010) emphasize that system planning is the appropriate time to evaluate connectivity for wildlife and the cumulative effects of roads on the landscape requiring mitigation measures. At this stage, there is opportunity to identify and prioritize critical habitat linkages which can then be coordinated with the planning of future projects across the entire system, helping to ensure that individual projects consider the larger ecological network (Clevenger & Ford, 2010; Clevenger & Huijser, 2009). At the systems-level, stretches of highway requiring mitigation would be identified and the intensity of required mitigation determined. To this end, regional landscape assessments assist in identifying key wildlife crossing areas and connectivity needs within a regional or province-wide transportation system, allowing potential wildlife crossing structure locations to be prioritized based on future transportation investments, scheduling, ecological criteria, and other project considerations (Clevenger & Ford, 2010; Clevenger & Huijser, 2009).

A project-level approach usually emerges in specific transportation projects that seek to address multiple management concerns with “proximate objectives”; that is, those within or adjacent to the transportation corridor in question

(Clevenger & Ford, 2010, p.20; Clevenger & Huijser, 2009). Such concerns might include the reduction of wildlife-vehicle collisions in specific fatality hotspots. As this level of project focus may not consider how crossing structures function as part of the regional landscape or corridor network, it should incorporate large spatial-scale considerations and future or projected land use changes in planning for wildlife crossing structures that do not lead animals to "ecological 'dead-ends'" with nowhere to go (Clevenger & Ford, 2010, p.20).

Site Selection & Placement

Selecting the most appropriate and effective site for placing a wildlife crossing structure is critical in determining its functional success and is often named the most important factor in promoting safe passage (Forman et al., 2003; Jackson & Griffin, 2000; OREG, 2010). Crossing structures should be placed where animals are observed to approach a highway naturally or where they have historically done so (Clevenger & Huijser, 2009; OREG, 2010). Animals are typically attracted to cross at a specific terrain feature, by specific vegetation, or where a reduction in traffic lanes occurs. Ruediger & DiGiorgio (2007) name ridges, valley bottoms, stream and river courses and wooded corridors as prime natural crossing locations.

While systems-level habitat linkage assessments can provide a "big picture" perspective for locating and prioritizing wildlife-road conflict areas, they are generally unsuitable for defining specific locations for wildlife crossings because they do not consider topographic and engineering concerns at individual sites (Clevenger & Ford, 2010). A suite of tools is available to aid in identifying habitat linkages and siting wildlife crossings as part of connectivity plans or transportation projects:

+ Geographic Information System Models including those simulating wildlife movements based on habitat quality and availability of resources (Clevenger & Ford, 2010);
+ Aerial photography which can be used to identify vegetation patterns and types, housing and human developments, water bodies, terrain, and other details (Clevenger & Ford, 2010; Ruediger & DiGiorgio, 2007);
+ Land ownership maps which can be used to identify linkages and inform adjacent land use management critical to the success of wildlife crossings, ideally situated through public lands with mandated habitat protection (Clevenger & Ford, 2010; Ruediger & DiGiorgio, 2007);
+ Vegetation maps to identify habitat types (Clevenger & Ford, 2010; Ruediger & DiGiorgio, 2007);
+ Topographic maps that provide important information such as slopes and other landscape forms which will influence the placement and interaction of wildlife crossings with highways (Clevenger & Ford, 2010; Ruediger & DiGiorgio, 2007);
+ Wildlife habitat or range maps which often integrate information from multiple sources of local area knowledge (Clevenger & Ford, 2010; Ruediger & DiGiorgio, 2007);

- Roadkill information that provides the location and number of wildlife-vehicle collisions and identifies fatality hotspots or areas of frequent roadkill occurrence (Ruediger & DiGiorgio, 2007). However, research contends that roadkill locations do not necessarily coincide with optimal locations for safe wildlife passage (Clevenger et al., 2002a as cited in Clevenger & Ford, 2010). Because animals learn to adjust their movement patterns, passages should be placed to overcome road barriers between high-quality habitats or to reconnect major wildlife migration routes, the locations of which are not necessarily related to where roadkills are most abundant (Forman et al., 2003);
- Other field data including radio and satellite telemetry (i.e. GPS monitoring devices), live-trapping and marking of individuals, snow tracking, tracks beds that record animal movements, remote cameras, and genetic hair sampling (Clevenger & Ford, 2010);
- Expert information based on opinion or qualitative models based in literature, when transportation and natural resource agencies lack empirical field data (Clevenger & Ford, 2010), and;
- Local knowledge from long-term residents which also integrates public participation in project planning and encourages citizen-science (Clevenger & Ford, 2010).

These resources are most effective when used in combination to ensure greater accuracy in site selection (Clevenger & Ford, 2010).

Once location has been determined, interdisciplinary planning teams can investigate available wildlife crossing technologies to determine the most appropriate crossing structure or mitigation measure to the local situation and transportation route design. This decision should include various stakeholder input and interests such as cost-effectiveness and long-term objectives relating to wildlife crossing implementation, maintenance, and monitoring for success. Ruediger & DiGiorgio (2007) suggest starting with crossings that require a modest economic investment in order to monitor their effectiveness and gain experience and confidence that crossing structures can be an effective and cost-efficient way to improve highway safety and wildlife conservation. These factors may be of great significance from a public relations standpoint in order to develop and maintain a level of public support for wildlife crossing initiatives, which would also benefit from a consultation process.

Focal Species

Image 2.4: Grizzly bear as focal species in the Yellowstone to Yukon (Y2Y) Corridor Initiative, which includes the Banff Wildlife Crossings Project.
Source: The Environmental Magazine, 1998. Retrieved from http://www.emagazine.com/magazine-archive/high-noon-at-grizzly-gulch

Site selection considerations begin by "determining the wildlife species or group of concern" expected to use the passage (Clevenger & Ford, 2010, p.26; Forman et al., 2003). Focal species could include species of conservation interest including those that are threatened or endangered, specific species groups such as amphibians or reptiles, or abundant species that threaten motorist safety such as deer, elk, and moose (Clevenger & Ford, 2010).

The protection of key species is the most frequent objective of corridor design, which is critically influenced by species needs and life histories. These include home ranges, dispersal patterns, and habitat and resource requirements, which represent traits that “help determine the likelihood that animals will find, select, and successfully pass through a corridor” (Anderson & Jenkins, 2006, p.31). The focal species approach assumes that by targeting top carnivores (whose feeding behaviour regulates species populations) or keystone species with large ranges sensitive to fragmentation (the removal of which would disrupt ecosystem processes), numerous other species will also gain protection (Anderson & Jenkins, 2006). Using a flagship species, or one that is symbolic or attractive to the public, can help increase project awareness and build public support (Anderson & Jenkins, 2006).

However, Noss & Harris (1986) caution that reliance on large carnivores and other indicator species as targets for ecological management can create problems of reductionism in which a single species may not represent the responses of all species sharing the habitat to environmental changes, including habitat fragmentation. Thereby, the design of wildlife crossings as corridors with species-specific targets lacks scientific certainty. As the focal species approach does not guarantee the use of the corridor by all wildlife of conservation interest, Anderson & Jenkins (2006) recommend the consideration of multiple focal species towards a more comprehensive approach for biodiversity conservation.

Wildlife Crossing Types

Various types of wildlife crossings can be applied to meet the needs of localized situations, design constraints, and most importantly, species and habitat requirements (see Appendix 3 in Clevenger & Huijser [2009] for comprehensive design criteria of the following 11 crossing structures).

Source: Clevenger & Huijser, 2009

Landscape Bridge

- \+ Largest crossing structures that span highways; generally more than 100 m wide with a minimum width of 70 m
- \+ Enable habitat restoration if there is continuous habitat on either side
- \+ Utilized by broad spectrum of wildlife, particularly if habitat elements are provided on overpass (i.e. large/small mammals, reptiles, and semiarboreal, semiaquatic, and amphibious species if adapted for their needs)

(Clevenger & Ford, 2010; Clevenger & Huijser, 2009; Forman et al., 2003)

Source: Parks Canada, 2011

Wildlife Overpass

- + Generally 50-70 m wide, with minimum width of 40-50 m; commonly a bridge span or concrete arches
- + Same general design and species benefits as landscape bridge, but at smaller scale with more limited habitat restoration ability
- + Primarily intended for large mammals but are attractive to a spectrum of species if habitat elements provided

(Clevenger & Ford, 2010; Clevenger & Huijser, 2009; Ruediger & DiGiorgio, 2007)

Source: Clevenger & Huijser, 2009

Multiuse Overpass

- + Generally 15-25 m wide with a minimum width of 10 m
- + Similar design to wildlife overpasses but accommodate use by both wildlife and humans for passive recreation or agriculture
- + Human use should be confined to one side with wider space for wildlife
- + Used most by small- and medium-sized mammals, particularly generalist species that are comfortable in human-dominated environments; frequent human use and activities will deter most large mammals from use

(Clevenger & Ford, 2010; Clevenger & Huijser, 2009)

Source: Clevenger & Huijser, 2009

Canopy Crossing

- + Above-grade crossing structure designed for semiarboreal and arboreal species allowing for movement between tree canopies
- + Design and materials are site- and species-dependent; generally consist of thick ropes or cables anchored to trees or permanent fixtures (i.e. signage beams); more stable fixtures needed for multilane roads

(Clevenger & Ford, 2010; Clevenger & Huijser, 2009)

Source: Clevenger & Huijser, 2009

Viaduct or Flyover

- + Largest underpass structure but usually not built specifically for wildlife
- + Wide clearance allows for use by broad spectrum of wildlife
- + Support pillars limit habitat and vegetation disturbance; aid in restoration or maintenance of hydrological flows and biodiversity in riparian habitats
- + Commonly used in crossing wetland habitats

(Clevenger & Ford, 2010; Clevenger & Huijser, 2009)

Source: Clevenger & Huijser, 2009

Large Mammal Underpass

- Largest and most common underpass structure designed for wildlife; commonly an open span bridge, multi-plate arch, or box culvert
- Generally at least 10 m wide with 4 m vertical clearance with a minimum of 7 m width and 4 m clearance
- Drainage features should be designed to prevent flooding
- Primarily designed for large mammals but should be adapted to species-specific crossing requirements
- The use of brush or stumps along walls of underpass provides cover for small- and medium-sized mammals

(Clevenger & Ford, 2010; Clevenger & Huijser, 2009; Ruediger & DiGiorgio, 2007)

Source: Clevenger & Huijser, 2009

Multiuse Underpass

- Generally at least 7 m wide with 3.5 m vertical clearance with a minimum of 5 m width and 2.5 m clearance
- Drainage features should be designed to prevent flooding
- Similar design to large mammal underpasses but accommodate both humans and wildlife, though human use should be confined to one side and/or shielded by vegetation
- Adequate for some large mammals but mainly used by small- and medium-sized mammals, particularly generalist species that are comfortable in human-dominated environments

(Clevenger & Ford, 2010; Clevenger & Huijser, 2009)

Source: Clevenger & Huijser, 2009

Underpass with Water Flow

- Designed to accommodate both wildlife and moving water; aim to restore function and connection of aquatic or riparian and terrestrial habitats
- Generally at least 3 m wide with 4 m vertical clearance with a minimum of 2 m width and 3 m clearance
- Frequently used by large mammals but should be adapted for species-specific crossing requirements
- Retention of riparian habitat or cover along underpass walls by use of logs, brush, or root wads encourages use by small- to medium-sized mammals

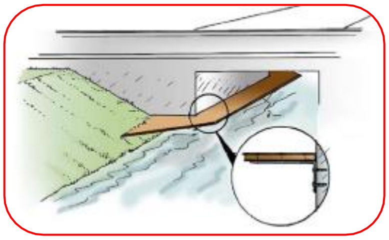
(Clevenger & Ford, 2010; Clevenger & Huijser, 2009)

Source: Parks Canada, 2011

Small- to Medium-Sized Mammal Underpass

- Smallest wildlife crossing structures designed primarily for use by small- to medium-sized mammals, with wildlife use depending on species-specific crossing and cover requirements
- Dimensions will vary depending on target species; generally range from 0.4-1.2 m diameter metal culverts, concrete bottomless arches, or concrete box culverts
- While culverts can be constructed from metal, molded plastic, or concrete, the latter exhibits some attributes of natural ground surfaces including drainage and retention of moisture; ground should be covered with substrate of native soils
- Drainage features should be designed to prevent flooding and impacts on existing vegetation should be minimized by using minimal clearing widths

(Clevenger & Ford, 2010; Clevenger & Huijser, 2009; Ruediger & DiGiorgio, 2007)



Source: Clevenger & Huijser, 2009

Modified Culvert

- Canal bridges adapted for the movement of small- to medium-sized wildlife within riparian habitat, wetlands, or irrigation canals
- 2 in. x 10 in. wooden planks used to construct dry platforms or elevated walkways along interior walls on both sides of canal bridge above the high-water mark and are connected to adjacent habitat by ramps
- Should have minimal human disturbance

(Clevenger & Ford, 2010; Clevenger & Huijser, 2009)

Source: Clevenger & Huijser, 2009

Amphibian & Reptile Tunnels

- Designed specifically for amphibian and reptile movement where roads intercept migration routes; used by other small- and medium-sized vertebrates
- Designs should meet specific species requirements as amphibians and reptiles cannot orient their movement to locate crossing entrances; walls or drift fences are critical in directing wildlife to the crossing structure
- Shorter tunnels are better for amphibian movement, though use of tunnels ranging in length from 6.7 m to 40 m has been recorded
- Greater airflow and natural light conditions occur in larger tunnels while grated slots placed flush with road surface allow light and moisture in smaller tunnels; special attention should be paid to microclimatic conditions including temperature, light, and humidity for maximal crossing usage

(Clevenger & Ford, 2010; Clevenger & Huijser, 2009)

The following sections present additional features that affect wildlife crossing structure use and should be considered in their effective design (Jackson & Griffin, 2000).

Size & Dimensions

The aforementioned sizes and dimensions of the 11 wildlife crossing types are optimal for structures spanning four-lane highways and provide for basic connectivity and animal movement (Clevenger & Huijser, 2009). Optimal sizes for passage structures vary between species (Jackson & Griffin, 2000). For example, deer and other ungulates have been found to prefer underpasses at least 7 m wide and 2.4 m high with nearby vegetation cover (Forman et al., 2003). While structure dimensions should correspond to species requirements, overpass widths of 50 to 60 metres are widely considered to benefit the most wildlife (Forman et al., 2003). For other species, the openness of a structure, rather than its size, is more important in determining wildlife use (Jackson & Griffin, 2000). Carnivores, for example, require unobstructed sightlines of the habitat on the other side of the passage which are optimized in parabolic overpasses that are wider at the ends than in the center (Forman et al., 2003; OREG, 2010).

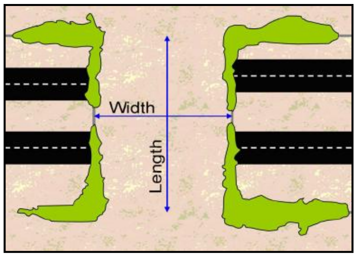


Figure 2.4: Length & width measurements of wildlife overpass. Source: Clevenger & Huijser, 2009.

In general, wildlife crossings should be constructed with attention to their length-width ratio; that is, the longer the structure is, the wider it should be to reduce a funnel effect (O'Brien, 2006; see Figure 2.4). Structures should not exceed 70 to 80 metres in length, except in situations where they span highways of six or more lanes or multi-modal transportation corridors (i.e. highways and railways). Length is also influenced by whether the crossing structure spans a divided or undivided highway (Clevenger & Huijser, 2009).

Spacing

The spacing of wildlife crossings on a roadway, or the intervals at which they are located, depends upon numerous factors including "the variability of landscape elements, terrain, and the juxtaposition of critical wildlife habitat that intersects the roadway" (Clevenger & Ford, 2010, p.34). Highly fragmented landscapes lacking natural habitat require fewer crossings than continuous landscapes, as wildlife movement is directed to intact habitat corridors (Clevenger & Ford, 2010).

Crossing structures should be associated with dominant topographic features in wildlife movement corridors, including riparian areas. To accommodate multiple species and varying home ranges, different wildlife crossing types should be placed at frequent intervals and enhanced with microhabitat elements such as root wads to support the movement of small species (Clevenger & Ford, 2010; Clevenger & Huijser, 2009). Low crossing usage by wildlife has been linked to inadequate numbers of crossing structures in an animal's home range (Ruediger, 2001 as cited in OREG, 2010). The success of wildlife crossings depends upon the coordination of land management by relevant agencies to ensure long-term protection of suitable habitat adjacent to crossing structures. Finally, wildlife crossings should connect to a larger regional corridor network. Together, these principles provide guidance for the number and location of wildlife crossings for maximal conservation value (Clevenger & Ford, 2010; Clevenger & Huijser, 2009).

Naturalization

While wildlife crossings are constructed structures, naturalizing their appearance by integrating the structures with adjacent local habitats is a high priority to avoid deterring wildlife. Incorporating vegetation in and around structures that is consistent with adjacent habitat conditions encourages animals to approach crossings and provides vegetated linkages between fragmented habitats. Naturalization measures can include the implementation of natural bottom design or stream bed conditions with the use of native soils and minimizing the use of unnatural features such as cement walkways, rip-rap, debris, unnecessary fill, signage, and poles (Clevenger & Huijser, 2009; Jackson & Griffin, 2000; O'Brien, 2006; Ruediger & DiGiorgio, 2007). O'Brien (2006) offers that overpass bottoms can be left to naturalize but may benefit from the planting of food sources. While planting food sources may attract animals to use structures, an abundance of food may promote animals to linger within crossings, potentially putting them at risk of predator interactions. However, there is little evidence to support that predators target prey in passage structures (Forman et al., 2003).

The internal environment of a crossing structure is integral in promoting wildlife use. Lighting, moisture, and ground cover must be appropriate for focal species, ideally mimicking adjacent natural conditions (OREG, 2010).

+ *Light*: Lack of light or artificial lighting can deter species from using structures. Overpasses provide optimal natural lighting, while underpass size and use of open-top grating help to provide natural light (Jackson & Griffin, 2000). Light should be maximized to increase vegetation growth and the continuity of native soils in and adjacent to a structure (Clevenger & Huijser, 2009).
+ *Moisture*: While some species are less likely to use a crossing structure without proper drainage, others require riparian habitat or wet substrate for movement, as in amphibians. Where underpasses lack flowing water, open-top grating can provide sufficient moisture for target species. Similarly, some amphibians are deterred by temperature disparities within small underpasses, which may be addressed by larger underpasses or open-top designs allowing for more air flow (Clevenger & Huijser, 2009).
+ *Noise*: Overpasses should incorporate vegetated buffers and underpasses should have open-top designs to limit crossing deterrence for some species with sensitivity to traffic noise (Jackson & Griffin, 2000).

- *Human Disturbance*: Unless otherwise designed, human activities should be restricted in wildlife crossings (Clevenger & Ford, 2010; Clevenger & Huijser, 2009).

Approaches

Approaches are the portion of the landscape directly adjacent to or leading to wildlife crossings and can be critical in determining whether an animal uses a crossing structure (OREG, 2010). They should be designed to promote the use of the structures by focal species by integrating habitat elements. Vegetation should be maintained leading to the crossing structure to provide cover for animals from artificial light and noise of roadways and lessen perceptions of vulnerability, especially at narrow culverts and underpasses where natural light is limited (O'Brien, 2006; OREG, 2010; Ruediger & DiGiorgio, 2007). Importantly, approaches featuring vegetation, fencing, rock walls, and other barriers can guide wildlife to crossing structures (Clevenger & Huijser, 2009). Approaches should be free from as many unnatural elements as possible, particularly construction materials and equipment. Lastly, they should maintain a line of sight so that approaching animals can see through the structure to the habitat on the other side. Wildlife crossings should therefore be designed as flat and straight as permitted by local topography, avoiding drop-offs, fill areas, cliffs, and steep grades (Jackson & Griffin, 2000; OREG, 2010; Ruediger & DiGiorgio, 2007).

Fencing

Though there is little research on best management practices for effective fence designs, they are one of the most common mitigation measures to prevent wildlife-vehicle collisions and have dramatically reduced ungulate road mortality. While fencing alone along roadways acts as a barrier to wildlife movement and resource access, it is useful when used in combination with wildlife crossing structures (Huijser & McGowen, 2010). Fencing can be used to guide animals toward crossings and is particularly effective when used in conjunction with hedgerows which naturalize the infrastructure. Fencing placement is most important at the crossing location to prohibit animals from avoiding the structure and choosing to navigate the roadway instead (O'Brien, 2006; Ruediger & DiGiorgio, 2007).

Fences should be impermeable to wildlife to prevent wildlife-vehicle collisions and encourage use of crossing structures (Clevenger & Huijser, 2009). When designing for smaller species, the size of mesh is an important consideration to avoid animals squeezing through fencing (O'Brien, 2006; Ruediger & DiGiorgio, 2007). Fencing can be spliced to ensure impermeability to both small- and medium-sized mammals at ground-level and large mammals.

Image 2.5: Small- and medium-sized fencing spliced to large mammal fencing, Banff, AB.
Source: Clevenger & Huijser, 2009.

Importantly, in the case that wildlife become trapped inside the fenced right-of-way, escape measures should be provided in the form of swing gates, hinged metal doors, or earthen ramps.

Image 2.6: Swing gate, Banff, AB.
Source: Clevenger & Huijser, 2009.

Buried fences and concrete bases at swing gates prevent some animals from digging under them (Clevenger & Huijser, 2009). Such design foresights will reduce future maintenance costs but general maintenance is still necessary to repair holes, remove litter, standing water, and other crossing hindrances. Maintenance should be accounted for in long-term budgets (Clevenger & Huijser, 2009; Clevenger & McGowen, 2010; O'Brien, 2006; Ruediger & DiGiorgio, 2007).

While fencing should be continuous along both sides of the road, intersecting features such as recreation trails and access roads necessitate special modifications such as swing gates and Texas gates (at-grade grates that deter wildlife from crossing the roadway, sometimes with an electric jolt). Fences should terminate at a crossing structure or in a location where wildlife are unlikely to cross the road (i.e. steep, rugged terrain) to prevent them from making crossing attempts at fence ends. Increased lighting and signage warning motorists of fence ends and potential wildlife activity are important considerations (Clevenger & Huijser, 2009).

2.3.4 Implementation

The following sections introduce elements for consideration in the development of an implementation strategy for wildlife crossing projects.

Potential Obstacles

Wildlife crossings are designed to address the effects of roads on landscape connectivity, wildlife movement, and the threat of wildlife-vehicle collisions but do not address the root causes of habitat fragmentation. Wildlife crossings should be integrated as part of a wider biodiversity vision that addresses socioeconomic processes such as population growth, land use and infrastructure development, and conflicts with wildlife habitat (Anderson & Jenkins, 2006). Furthermore, the public often has little awareness and a lack of understanding of the threats of habitat fragmentation and the need for landscape connectivity. Often, biodiversity conservation efforts are overshadowed by other social issues. Because habitat fragmentation and biodiversity loss are difficult to perceive and may not necessarily impact members of the public individually, public support building can be challenging but is critical to achieving successful project implementation and meeting significant funding needs (Anderson & Jenkins, 2006; Van Der Grift & Pouwels, 2006). Lastly, wildlife crossings and their associated corridors may traverse private lands, the owners of which may be adverse to conservation efforts when they involve land use restrictions and impinge on landowners' resource control or personal interests (Anderson & Jenkins, 2006; Van Der Grift & Pouwels, 2006). Similarly, resource restrictions on publicly-owned lands may impact the operations of petroleum, timber, and mining companies. As such, it is integral to involve stakeholders and address competing concerns in the decision-making process (Anderson & Jenkins, 2006).

Support Building

Effective communication and active public involvement in project planning and execution are integral to building project support. Public support is especially important to combat criticisms of wildlife crossing infrastructure costs, often fueled by a lack of understanding about their ecological benefits. Public education initiatives and clear communication of project plans that emphasize the importance of connectivity in the local context are required to justify the need for wildlife crossing structures and their benefits to both wildlife population viability and public safety (Van Der Grift & Pouwels, 2006). Anderson & Jenkins (2006) suggest that "gaining and maintaining public interest requires achieving early successes and building on them," such as identifying objectives achievable in the short-term and constructing project components with high visibility and probability of success in order to build and keep project interest and momentum (p.64).

Defining leadership by engaging project champions who will inspire others and persuade institutional involvement can be essential to support building. Developing local leadership can motivate local involvement necessary for long-term project management and inform design solutions based in knowledge of the local context. While local individuals, institutions, and communities should be at the forefront of project implementation, nonlocal actors including nongovernmental organizations (NGOs) can provide project funding and technical assistance. Local government agencies can assist in building coalitions to broaden project support by engaging the public, nonprofit, and private sectors in project development (Anderson & Jenkins, 2006).

Performing a stakeholder analysis to identify key actors and their interests is essential for broadening public support, identifying existing or potential resistance to wildlife crossing projects, and developing strategies for stakeholder involvement or overcoming opposition (Anderson & Jenkins, 2006). Ultimately, integrating stakeholders in project implementation requires cooperation between federal, state, and local management agencies, private parties, and concerned citizens. Managers must work together to navigate competing legal and organizational mandates and management goals and work towards a common goal of managing wildlife crossings to fulfill project objectives and encourage stakeholder involvement (Grumbine, 1994). Relationship management between parties with competing interests requires identifying and involving stakeholders early in the process, understanding their sphere of influence, and identifying strategies for building relationships, including workshops, regular meetings, and events hosted by key actors to gain their perspectives (Wieler, 2007).

Incentives

Anderson & Jenkins (2006) discuss the potential of both positive and negative incentives in contributing to successful corridor implementation, which are most often used to persuade the participation of landowners. Negative incentives include loss of biodiversity and critical environmental services and threats to cultural values and lifestyles associated with accessibility to natural areas. Corridors and land adjacent to wildlife crossings are spaces in which regulations can be applied in the form of resource-use restrictions, fines, and reduced speed limits. Positive economic incentives can include: compensation to property owners such as purchasing land or conservation easements; property tax benefits; growth of ecotourism and increased public revenues; and the provision of technical assistance for land management to local stakeholders (Anderson & Jenkins, 2006; White, 2010).

Governance

Co-management of wildlife crossing projects and the landscapes they link provides the most effective form of governance, especially within extensive corridor systems that span multiple jurisdictions. It requires the clear definition of the roles and responsibilities of all relevant players including government entities, NGOs, and the public. For example, while national governments can provide sources of project funding, NGOs can promote specific program interests, and local governments can provide insight to local conditions and manpower for monitoring and regulation (Anderson & Jenkins, 2006).

The above elements can contribute to an integrated implementation strategy for wildlife crossing projects that applies diverse approaches tailored to meet local needs and conditions. A comprehensive toolkit is in the process of being developed by a variety of North American contributors including Utah State University, Ryerson University, and the USDA Forest Service. It identifies and details stages and guidelines for wildlife crossing planning, design, implementation, and monitoring and can be accessed at www.wildlifeandroads.org.

2.3.5 Monitoring

Considering the expenses incurred in implementing wildlife mitigation, monitoring the function of wildlife crossings aids in assessing their conservation value and is considered “a judicious use of public infrastructure funds” that can increase future cost-savings (Clevenger & Ford, 2010). To this end, basic monitoring guidelines have been developed around the ecological functions of wildlife crossings delineated in section 2.3.1 which inform project and monitoring objectives, study designs, and monitoring methods (Clevenger & Ford, 2010).

Adaptive Management

The US Geological Survey defines adaptive management (AM) as:

> A type of natural resource management in which decisions are made as part of an ongoing science-based process. Adaptive management involves testing, monitoring, and evaluating applied strategies, and incorporating new knowledge in to management approaches that are based on scientific findings and the needs of society. Results are used to modify management policy, strategies, and practices. (Kintsch, 2008, p.42)

As ecosystems are dynamic and constantly changing, AM allows for revisions in conservation strategies based on scientific analyses of the effects of implemented measures on conservation objectives. In the case of wildlife crossing projects, the objective is usually landscape reconnectivity to facilitate wildlife movement and reduce wildlife-vehicle collisions. AM represents a process based on “learning by doing” and an inherent flexibility that allows for both immediate action and adaptations in future management informed by long-term monitoring (Morghan, Sheley & Svejcar, 2006, p.216). A study of *Adaptive Management for the Greater Yellowstone Ecosystem* asserts that AM plans are “suited to decision making in a regime of chronic information shortage” (Lynch, Hodge, Albert, & Dunham, 2008, p.823). Thus, AM can reconcile a lack of understanding as to how ecosystems respond to human intervention with flexible policies and immediate actions that allow management to proceed without a certainty of outcomes (Morghan et al., 2006). In order to maximize the success of an AM plan, Morghan et al. (2006) argue for a simple initial plan, with complexity and nuances added over time as data is collected. Lynch et al. (2008) advocate for active stakeholder engagement throughout the AM process to aid in discerning ineffective management actions and policies and allows for “cross-level interactions,” or the integration of both science and the local experience or ecological knowledge of participants, including hunters and indigenous populations. The inclusion of experts and researchers in all stages of management results in scientifically valid monitoring and management programs (Morghan et al., 2006).

Adaptive management is particularly well-suited to monitoring wildlife crossings because their science and practice are still emerging; adaptive management is essential to ensure that new mitigation efforts benefit from knowledge gained from previous efforts. In turn, these may contribute to a growing knowledge base for conservation practitioners, natural resource managers, and transportation professionals to determine successful measures for particular species and locations. Long-term adaptive management can ultimately aid in preventing costly future retrofits, refining mitigation components like fencing and approaches to crossing structures, and determining appropriate levels of human use permitted around crossings without deterring wildlife passage (Kintsch, 2008). Changes to wildlife crossing projects informed through AM may include changes to microhabitat elements, revision of fence design and materials, and changes in the locations and types of crossing structures used (Clevenger & Huijser, 2009).

Delineating a Study Design

Development of the study design should consider the spatial scale of the project. It must balance requirements for successful operation with spatial boundaries large enough to include relationships between the project, other existing initiatives, and the consideration of cumulative effects and affected environmental components (Noble, 2010). Boundaries may include the functioning of the roadway and adjacent critical habitat areas and the relationship of an individual crossing structure to the entire wildlife crossing network. As such, the spatial scale should reflect the "maximum detectable zone of influence," represented by a geographic point where the effects of the crossing are no longer significant (Noble, 2010, p.93). This point may be marked by the transition between habitats or ecosystems that no longer support focal species or the point at which continuous habitat is again bisected by a roadway. As previously explained, the spatial scale should be determined by ecological boundaries based on regional species populations and habitat connectivity, irrespective of administrative, political, or jurisdictional boundaries. The management scale of the monitoring program reflects the partnerships between agencies acting as monitoring, management, and decision-making bodies (Clevenger & Huijser, 2009).

Monitoring study designs should begin with baseline data collection and maximize the ability to infer whether mitigation efforts have achieved their objectives (Roedenbeck et al., 2007 as cited in Clevenger & Huijser, 2009). For example, the Before-After, Control-Impact (BACI) study design ensures that pre- and post-mitigation data are comparable. It requires the study of environmental and demographic changes which may not result from crossing installation by comparing the treatment site to a control site that lacks mitigation (Kintsch, 2008).

Community Engagement

Community-inclusive monitoring techniques can increase stakeholder involvement and citizen engagement, helping to instill a sense of ownership, and thereby, stewardship of the project. To encourage capacity building through the monitoring process, program activities should be designed to include the maximum number of participants, based on an initial skills assessment (Pollock & Whitelaw, 2005). Workshops may be offered to further develop monitoring skills and present volunteers with incentives and opportunities to stay engaged in the project. Volunteers should be encouraged to share their local knowledge (i.e. wildlife fatality hotspots) and circulated internal project communication to maximize organizational transparency. Recognizing volunteer contributions can further mitigate the loss of volunteer interest (Pollock & Whitelaw, 2005).

Maintaining a volunteer-expert balance can integrate individuals from different disciplines while maintaining high-level organizational accountability. Volunteers can be trained by experts and taught standardized monitoring protocols which should be regularly evaluated for quality assurance. Ultimately, volunteer contributions can potentially relieve municipalities and other agencies involved of funding and resource restrictions (Pollock & Whitelaw, 2005).

Image 2.7: Digital observation platform, HNTB with Michael Van Valkenburgh & Associates (New York).
Source: ARC, 2010.

Effective community engagement initiatives can include a *Wildlife Watch* website where the public can record wildlife sightings, roadkill, and other observations (Kintsch, 2008). In the 2010 ARC International Wildlife Crossing Infrastructure Design Competition, the firm of HNTB with Michael Van Valkenburgh & Associates developed plans for viewing platforms that are integrated in to an overpass design and feature monitoring stations away from wildlife in order to mitigate human-use disturbances. Digital observation platforms feature real-time video, helping to engage the public using new technologies (ARC, 2010).

Objective-Setting

In setting monitoring program objectives, the identification of Valued Ecosystem Components (VECs) can focus attention on aspects of the physical and human environment considered to be important from scientific or public perspectives. VECs require comprehensive baseline studies and are typically identified on the basis of regulatory status, ecological and socio-economic importance, and conservation concern (Noble, 2010). Establishing desired project outcomes and VEC conditions (i.e. of focal species) is critical for project evaluation and the representation of primary conservation, performance, and data collection priorities. Objectives related to VECs might include maintaining the viability of native vegetation incorporated in crossing design, maintaining crossing infrastructure in good repair, and limiting human-use disturbances to structures (Clevenger & Huijser, 2009).

Monitoring objectives should represent three levels of biological organization: genes, species/population, and community/ecosystem. This hierarchical approach to data collection represents objectives relevant to most transportation and natural resource management needs of reducing road impacts on wildlife populations and recognizes that roadways can have cumulative effects at site- and species-specific levels and on wider ecosystems (Clevenger & Huijser, 2009).

Broad monitoring questions should be asked in order to guide the development of more specific indicators and related targets, specific to selected VECs (i.e. is road mortality increasing or decreasing as a result of mitigation measures?). These general questions are then further refined, especially for each focal species (Paige & Darling, 2009).

Indicators focus baseline studies, impact prediction, monitoring, and impact management and define acceptable limits of change after which management actions are required. In relationship to VECs, indicators are considered measurable parameters of change and should be quantitatively or qualitatively measurable, indicative of the VEC, and sensitive to project-induced stress. Indicators should also be appropriate to the spatial scale of the monitoring program and standardized through monitoring protocol used by monitoring bodies (Paige & Darling, 2009). Wildlife crossing monitoring should include the following indicators: gene flow and genetic structure to indicate whether exchange of genes is occurring; population distribution, abundance, and movement data; and demographic processes such as dispersal and mortality rates to assess species or population-level effects (Clevenger & Huijser, 2009). This information is typically gathered for the focal species of the project and should produce monitoring data that is relevant to the greatest number of species in the area or to those most sensitive to roadway crossing (Clevenger & Huijser, 2009).

Following indicators, targets through which to measure the success of the project and fulfillment of its objectives should be established collaboratively by participating agencies Targets should be scientifically defensible evidence that can support the efficacy of wildlife crossings and may include decreases in wildlife road mortality and frequency of crossing by focal species. They should be adjusted according to the principles of adaptive management (Clevenger & Huijser, 2009).

Wildlife Monitoring Methods

A variety of survey methods are available for wildlife monitoring and range from the simple reporting of wildlife-vehicle collisions by transportation agencies to complex initiatives like GPS collaring and tracking of individual animals. The monitoring method selected should be determined by its appropriateness to project objectives and focal species (Clevenger & Huijser, 2009). Project researchers must balance the costs of monitoring methods with data requirements and available resources; the range of methods allows for a broad range of stakeholder participation at different levels of expertise (Clevenger & Huijser, 2009).

Image 2.8: Automated wildlife detection camera (left) and track bed (right).
Source: Clevenger & Huijser, 2009.

Through surveys at 15 crossing structures along the Trans-Canada Highway, Alberta, Canada, a recent study comparing the efficacy of monitoring methods determined that motion-activated cameras outperformed track pads in data collection and were more cost-effective for surveys longer than one year (Ford et al., 2009). Tracks pads were more cost-intensive because they require shorter intervals between field visits to prevent data loss but more often detected large carnivores including coyotes and grizzly bears (Ford et al., 2009).

Whatever method is chosen as most appropriate for the species and data requirements and funding available to project managers, it is critical that monitoring bodies are aware of wildlife adaptation periods. Clevenger & Huijser (2009) attest that:

> Most monitoring efforts do not sample for sufficient duration to adequately assess how wildlife utilize crossing structures because they don’t give them enough time to adapt to the structures and the changes made to the surrounding habitat where they reside. (p.75)

Monitoring programs should be maintained for the long-term to accommodate the learning curve for wildlife in using the structures, which varies in length between species. Monitoring programs of one or two years are too brief to capture the most accurate data revealing crossing usage and movement patterns (Clevenger & Huijser, 2009).

Data Collection & Information Management

The use of standardized monitoring protocols directs data collection (Paige & Darling, 2009). The monitoring protocol should: establish training procedures and tools for skills development; outline field and data management procedures to ensure data is continuous, transferable, and comparable from pre- to post-construction; and be adapted to changes in project conditions or objectives (Wilson, 2009). Monitoring protocols should also include quality assurance measures facilitated through training, data quality inspections in the field, and peer review which will aid in the acceptance of data and resulting recommendations by decisionmakers, land and wildlife managers, stakeholders, and the public (Paige & Darling, 2009).

Information dissemination should be guided by a communication strategy including the production of annual reports, pilot studies, and results published by organizations involved. Reports can be made accessible via project websites to aid in maintaining project support and momentum by emphasizing project successes (Paige & Darling, 2009).

Monitoring results should be synthesized in to management and policy recommendations by technical teams responsible for monitoring on the ground, then peer-reviewed and presented to decisionmakers. Management actions may also undergo effectiveness evaluations to assess the success of actions in achieving project objectives and provide information to make beneficial changes to the project including crossing structure retrofits and maintenance and policy-level changes (Paige & Darling, 2009).

Observational studies conducted and published by researchers indicate the importance of monitoring in confirming that wildlife crossings function to link habitats effectively, facilitate the movement of species across transportation corridors, and reduce wildlife-vehicle collisions (Clevenger & Waltho, 2000; Grilo et al., 2008; Yanes et al., 1995). It is through systematic monitoring over extensive periods of time that the efficacy of wildlife crossings is made apparent; that is, when animals are given a chance to adapt to using them in their movements and migrations. Monitoring of these behaviours over time can provide science-based evidence for wildlife crossings as successful mitigation measures when appropriately designed for the landscape context and species they target. Such studies and monitoring reports will then contribute to confidence in wildlife crossing technology, early integration in transportation infrastructure design, and financial investment in them as both public infrastructure and ecological mitigation against the effects of habitat fragmentation.

2.4 SUMMARY

In fulfillment of this report's research questions, the literature review examines the function of wildlife crossings and their linkage function as corridors for the mitigation of habitat fragmentation. The consideration of design characteristics, processes of implementation including partnerships and public engagement strategies, and monitoring program structures for post-construction evaluation of mitigation success informs how wildlife crossing projects may be executed in Ontario's NHSs.

As per the methodology presented in Chapter 4 of this report, the literature review was used to determine elements and best practices contributing to the success of wildlife crossing projects. Categories of information and thematic project elements were compiled as criteria for organizing the south Florida and Banff case studies and were used to perform content analysis of case study documents, as outlined in Table 4.1 and completed in Table 5.1.

3.0 ONTARIO'S LEGISLATIVE & POLICY CONTEXT

While literature on corridor efficacy in mitigating habitat fragmentation and on wildlife crossings is continuously developing, discussion of their integration in to real-world policy frameworks is limited. Ontario has a policy framework that supports and prioritizes natural heritage systems and the concept of landscape and habitat connectivity. Through this supportive framework, wildlife crossings may be implemented at the landscape-level to provide linkages across transportation infrastructure and mitigate ongoing effects of habitat fragmentation on the ground. The following excerpts from relevant provincial legislation and policy documents are considered for their potential relationship to the use of wildlife crossings as mitigation measures contributing to well-connected NHSs.

3.1 PLANNING ACT

The *Planning Act* is Ontario's premier legislation for the control of land use planning. Among its provisions, it sets the basis for considering provincial interests and delineates a variety of tools for use by municipalities in planning for and regulating future development (Ministry of Municipal Affairs and Housing [MMAH], 2010).

Document Excerpt	Relationship to Wildlife Crossings
Provincial interest **<u>2.</u>** The Minister, the council of a municipality, a local board, a planning board and the Municipal Board, in carrying out their responsibilities under this Act, shall have regard to, among other matters, matters of provincial interest such as, (a) the protection of ecological systems, including natural areas, features and functions; […] (o) the protection of public health and safety; (*Planning Act*, RSO 1990, c P.13, s 2)	This provision demands that planning approval authorities have regard to matters of provincial interest, as delineated in the PPS (MMAH, 2010). NHSs are made up of natural areas and features linked by corridors for the protection of ecological functions and connectivity (MMAH, 2005). Wildlife crossings can restore linkages across fragmented landscapes in NHSs. Furthermore, wildlife crossings can contribute to the protection of public safety through their objective of reducing wildlife-vehicle collisions (Clevenger & Ford, 2010).
Policy statements and provincial plans **<u>3. (5)</u>** A decision of the council of a municipality, a local board, a planning board, a minister of the Crown and a ministry, board, commission or agency of the government, including the Municipal Board, in respect of the exercise of any authority that affects a planning matter, (a) shall be consistent with the policy statements issued under subsection (1) that are in effect on the date of the	Decisions of planning approval authorities must be consistent with PPS, as issued under the authority of this *Act* to provide policy direction on matters of provincial interest in land use planning and development (MMAH, 2010). These include policies pertaining to the protection and management of natural heritage areas, features, and systems as outlined in section 2.0 of the PPS. Planning decisions must also conform to provincial plans including those governing the Greenbelt, Niagara Escarpment, and Oak Ridges Moraine NHSs and the

decision; and (b) shall conform with the provincial plans that are in effect on that date, or shall not conflict with them, as the case may be. 2006, c. 23, s. 5. (*Planning Act*, RSO 1990, c P.13, s 3)	development permissions and restrictions therein. The plans prioritize connectivity within and between systems, which may be facilitated by wildlife crossings providing system linkages across transportation infrastructure.
Zoning by-laws **34.** (1) Zoning by-laws may be passed by the councils of local municipalities: **Natural features and areas** 3.2 For prohibiting any use of land and the erecting, locating or using of any class or classes of buildings or structures within any defined area or areas, i. that is a significant wildlife habitat, wetland, woodland, ravine, valley or area of natural and scientific interest, ii. that is a significant corridor or shoreline of a lake, river or stream, or iii. that is a significant natural corridor, feature or area. (*Planning Act*, RSO 1990, c P.13, s 34)	Zoning by-laws are a municipal planning tool for the regulation of land use activities and development of "structures", which can be interpreted to include transportation infrastructure (MMAH, 2010). This *Act* allows the use of zoning by-laws to prohibit such development in significant wildlife habitat and natural corridors, features, or areas. Determining the location, scale, and connectivity needs of these areas is paramount to the maintenance of uninterrupted ecological processes. The use of wildlife crossings is a mitigation measure applicable where these connections have been severed and can be avoided by proactively employing municipal planning tools like zoning by-laws and official plan policies to prohibit disruptive development and maintain landscape and habitat connectivity.

3.2 PROVINCIAL POLICY STATEMENT, 2005

As part of a policy-led planning system in Ontario, the *Provincial Policy Statement, 2005* (PPS) provides policy directions on matters of provincial interest in land use planning and development. Among its directives, the PPS prioritizes the protection of the natural environment and responsible management of important provincial resources (MMAH, 2010). Section 2.0 Wise Use and Management of Resources and subsection 2.1 Natural Heritage therein provide policies for the protection and management of natural heritage features, areas, and systems, previously defined in Chapter 2. In considering the relationship of natural heritage policies in the PPS to the use of wildlife crossings within NHSs, the *Natural Heritage Reference Manual for Natural Heritage Policies of the Provincial Policy Statement, 2005* (MNR, 2010) (henceforth "the manual") provides technical guidance for the implementation of policies in land use planning in a manner that is consistent with the intent of the PPS.

Document Excerpt	Relationship to Wildlife Crossings
1.1 MANAGING AND DIRECTING LAND USE TO ACHIEVE EFFICIENT DEVELOPMENT AND LAND USE PATTERNS 1.1.1 Healthy, liveable and safe communities are	This policy may be interpreted to include the avoidance of transportation infrastructure development and expansion and increased accessibility to future development in previously remote areas that sever landscape connectivity and create

sustained by: c) avoiding development and land use patterns which may cause environmental or public health and safety concerns; (MMAH, 2005, p.4)	habitat fragmentation (Beckmann & Hilty, 2010). Moreover, development that occurs through known wildlife habitat may result in increased risk of wildlife-vehicle collisions during wildlife passage attempts, posing threat to public safety where it previously did not exist.
1.2 COORDINATION 1.2.1 A coordinated, integrated and comprehensive approach should be used when dealing with planning matters within municipalities, or which cross lower, single and/or upper-tier municipal boundaries, including: b) managing natural heritage, water, agricultural, mineral, and cultural heritage and archaeological resources; c) *infrastructure*, *public service facilities* and *waste management systems*; d) ecosystem, shoreline and watershed related issues; (MMAH, 2005, p.7)	The planning and management of transportation infrastructure and its effects on NHSs and their ecological functions should be coordinated regionally to maximize connectivity. Coordination should occur across municipal boundaries which do not necessarily coincide with the boundaries of watersheds and natural heritage areas and features. This coordination should incorporate planning for wildlife crossings, as they provide linkages for wildlife movement between landscapes and habitats which may be necessary across municipal boundaries.
1.5 PUBLIC SPACES, PARKS AND OPEN SPACE 1.5.1 Healthy, active communities should be promoted by: d) considering the impacts of planning decisions on provincial parks, conservation reserves and conservation areas. (MMAH, 2005, p.10)	When planning for the development or expansion of transportation infrastructure, its impacts on the parks and open spaces delineated in this policy must be considered. This is particularly important if transport routes will be directly adjacent to or traversing protected areas, in order to avoid negative impacts on their recreational and ecological value. Wildlife crossings and the delineation of wildlife corridors, like those implemented by Parks Canada in Banff National Park, can be used to mitigate the deleterious effects of transportation infrastructure on wildlife movement and habitat quality within parks and protected areas.
1.6 INFRASTRUCTURE AND PUBLIC SERVICE FACILITIES **1.6.6 Transportation and Infrastructure Corridors** 1.6.6.4 When planning for corridors and rights-of-way for significant transportation and *infrastructure* facilities, consideration will be given to the significant resources in Section 2: Wise Use and Management of Resources. (MMAH, 2005, p.12)	This policy expressly demands that the planning of transportation corridors should consider the resources in section 2 of the PPS. These include natural heritage features, areas, and systems and their connectivity, potentially facilitated by wildlife crossing installation and discussed in greater detail below.
2.1 NATURAL HERITAGE 2.1.1 Natural features and areas shall be protected for the long term. 2.1.2 The diversity and connectivity of natural features in an area, and the long-term *ecological function* and biodiversity of *natural heritage systems*, should be maintained, restored or, where possible, improved, recognizing linkages between and	In discussing the need for protecting natural heritage in Ontario, the manual explains that planning for NHSs "addresses fragmentation by identifying and protecting core areas, ecological linkages and landscape features that contribute to a system" (MNR, 2010, p.19). The linkage aspects of NHSs can provide long-term protection of ecological functions and biodiversity (MNR, 2010). Long-term protection includes "the protection of ecological

among *natural heritage features and areas*, *surface water features* and *ground water features*. 2.1.3 *Development* and *site alteration* shall not be permitted in: a) *significant* habitat of *endangered species* and *threatened species*; b) *significant wetlands* in Ecoregions 5E, 6E and 7E; and c) *significant coastal wetlands*. 2.1.4 *Development* and *site alteration* shall not be permitted in: a) *significant wetlands* in the Canadian Shield north of Ecoregions 5E, 6E and 7E; b) *significant woodlands* south and east of the Canadian Shield; c) *significant valleylands* south and east of the Canadian Shield; d) *significant wildlife habitat*; and e) *significant areas of natural and scientific interest* unless it has been demonstrated that there will be no *negative impacts* on the natural features or their *ecological functions*. 2.1.6 *Development* and *site alteration* shall not be permitted on *adjacent lands* to the *natural heritage features and areas* identified in policies 2.1.3, 2.1.4 and 2.1.5 unless the *ecological function* of the *adjacent lands* has been evaluated and it has been demonstrated that there will be no *negative impacts* on the natural features or on their *ecological functions*. (MMAH, 2005, p.15)	systems, the conservation and management of natural resources and the promotion of development that is designed to be sustainable" (MNR, 2010, p.8). To this end, planning authorities should incorporate the precautionary approach in decision-making where appropriate, previously defined in section 2.1.2 of this report (MNR, 2010). As wildlife crossing structures are built to last for the long-term with an average life span of 75 to 80 years (Clevenger & Ford, 2010), they are a compatible infrastructure towards the long-term protection of linkages within NHSs, especially for wildlife movement (MNR, 2010). PPS policy 2.1.2 emphasizes the maintenance, restoration, or improvement of connectivity within NHSs, which may be facilitated by the installation of wildlife crossings. The decision to implement wildlife crossings may result from a landscape analysis, promoted in the manual for the evaluation of "the contributions of all land cover and habitats to the ecological function and biodiversity of the landscape, and examining deficiencies that should be rectified to address diversity and connectivity" (MNR, 2010, p.16). Policies 2.1.3 through 2.1.6 prohibit development and site alteration in natural heritage features and areas and their adjacent lands and in significant habitats and landscape types. One type of development discussed in the manual is that of linear transportation corridors in NHSs located in settlement areas or areas designated for urban growth. The manual instructs that transportation infrastructure should be kept to a minimum, suitably designed, and integrate mitigation measures such as wildlife crossings or passages to minimize "human–wildlife conflicts" and "maintain linkages between and among natural heritage features" (MNR, 2010, p.36). The manual provides an appendix detailing potential development impacts on NHSs and associated mitigation measures for implementation. Development impacts of roads at water crossings include the attraction of wildlife to roads and roadsides and the creation of barriers to wildlife movement. Identified mitigation measures include the identification of wildlife use of existing linkages and the sizing of passages accordingly, building underpasses with fencing to direct wildlife, and extending bridges beyond watercourse shorelines to provide adequate land for wildlife

	passage (MNR, 2010). Development impacts of road paving include the loss of wildlife habitat, potentially mitigated by ensuring the maintenance of important animal movement corridors or alternative corridor development. Barriers to wildlife movement and wildlife road mortality may be mitigated by avoiding the intersection of wildlife migration routes, funnelling wildlife through culverts, and the provision of overpasses for large wildlife species, low barrier fencing or vertical walls for amphibian guidance to passage culverts, and dry wildlife passage culverts under roadways. Evidently, wildlife crossings are expressly considered an applicable mitigation measure through which to address the impacts of road development within and adjacent to Ontario's NHSs in the provincial manual for the interpretation of PPS natural heritage policies. As such, wildlife crossings are provincially endorsed as an appropriate mitigation measure in the planning of NHSs.
4.0 IMPLEMENTATION AND INTERPRETATION 4.5 The official plan is the most important vehicle for implementation of this Provincial Policy Statement. 4.6 The policies of this Provincial Policy Statement represent minimum standards. This Provincial Policy Statement does not prevent planning authorities and decision-makers from going beyond the minimum standards established in specific policies, unless doing so would conflict with any policy of this Provincial Policy Statement. 4.9 *Provincial plans* shall take precedence over policies in this Provincial Policy Statement to the extent of any conflict. Examples of these are plans created under the *Niagara Escarpment Planning and Development Act* and the *Oak Ridges Moraine Conservation Act, 2001*. (MMAH, 2005, p.24-25)	This policy recognizes the importance of official plans in enforcing PPS policies and allows planning authorities the freedom to exceed their minimum standards (MMAH, 2005). Official plans have the capacity to identify and protect a municipality's green spaces and areas of natural significance by setting appropriate land use designations and directing future development to appropriate areas (MMAH, 2005). Official plans must be kept up-to-date with the PPS and integrate provincial interests (MMAH, 2005). The manual explains that to implement the natural heritage policies of the PPS, official plans should include policies to: identify natural heritage features and areas and their ecological functions and provide for their protection from incompatible land uses and activities; identify NHSs and the ways in which to maintain, restore, or improve their biodiversity, connectivity, and ecological functions; and provide a planning mechanism for impact assessment (MNR, 2010). Wildlife crossings may be considered as a mitigation alternative for connectivity restoration in impact assessment processes (i.e. EAs). The provincial plans for the Greenbelt, Niagara Escarpment, and Oak Ridges Moraine (see Figure 3.1) take precedence over the PPS in the event of any conflicting policies. Notably, the policies of a growth plan (e.g. *Growth Plan for the Greater Golden Horseshoe, 2006*) do not prevail over the PPS

	where there is a conflict over policies relating to the natural environment (MNR, 2010). The use of wildlife crossings to increase connectivity within NHSs should be considered as a mitigation option in both provincial and official plans.

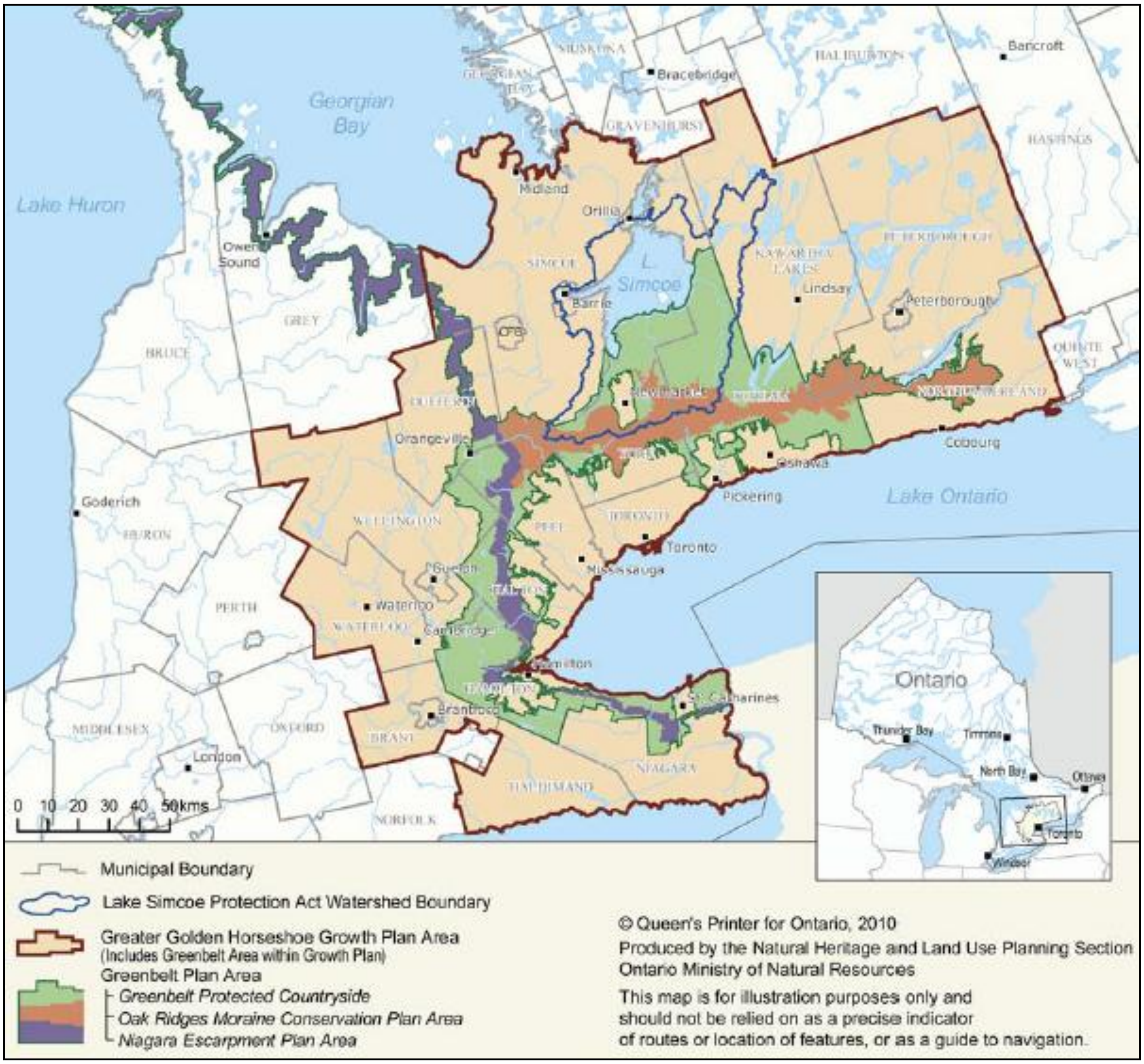


Figure 3.1: Provincial plans and plan areas applicable in the guidance and regulation of land use planning in southern Ontario, including the Greenbelt Plan area (green), Niagara Escarpment Plan area (purple), and Oak Ridges Moraine Conservation Plan area (brown). Source: MNR, 2010.

4.0 METHODOLOGY

4.1 RESEARCH APPROACH & ITS RELEVANCE TO PLANNING

This research process has been conducted using qualitative methods, as per the methodology used by Brown (2010); a multiple-case study approach was employed to draw cross-case conclusions or best practices. Compiling explanatory case studies was appropriate for this topic as they describe contemporary events within a real-life context with focus on the examination of organizational processes, programs, and decisions, and so are preferred in investigating the integration of exemplary wildlife crossing projects with transportation infrastructure on the ground.

Case study protocol demanded that a chain of evidence be maintained by keeping an organized database of research materials and their sources, citing these materials in the report, and linking the data collected to the initial research questions. A research schedule was developed with flexibility for adjustment (Yin, 2009). This case study protocol increases the reliability of the research by documenting the procedures that can be used to achieve the same results (Yin, 2009). The methods utilized in constructing the case studies include a literature review and document review.

Case studies are often criticized as lacking external validity, or whether a study's findings may be generalized beyond their immediate context (Yin, 2009). Case studies rely on analytic generalization, in which the researcher strives to "generalize a particular set of results to some broader theory" (Yin, 2009, p.43). In this research, the case study findings seek to generalize the success of the south Florida and Banff wildlife crossing projects to theories of the effectiveness of corridors in linking fragmented habitats and facilitating the movement of wildlife across landscapes, specifically those transected by transportation infrastructure. However, the results of all wildlife crossing projects cannot be generalized as doing so. The chosen case studies are identified as successful projects in academic literature (Anderson & Jenkins, 2006; Beckmann et al., 2010; Forman et al., 2003; Ruediger & DiGiorgio, 2007); this research delineates and describes components that contribute to their success. This report will not conclude the generalizability of case study findings to any wildlife crossing project, because all occur in different local contexts with varying needs. As such, these case studies serve as planning precedents which inform essential elements of future projects undertaken by planners and multi-disciplinary teams, and the enabling of the projects through local policy directions to meet situational needs.

4.2 METHODS

4.2.1 Literature Review

The literature review was conducted to contextualize the research questions, understand relevant concepts in conservation planning and landscape ecology, provide background information, and aid in the selection of case studies. McCracken (1988) warns that the literature review should not produce preconceptions about the research topic; instead, the researcher must exercise constant skepticism and identify assumptions in the literature and how they inform the definition of problems and findings. This process focused on reviewing relevant books, peer-reviewed journal articles, government publications, and industry reports in order to understand the issues related to corridors, the use of wildlife crossings to mitigate habitat fragmentation and wildlife-vehicle collisions, and their corridor function in facilitating animal movement.

4.2.2 Case Study Selection & Document Review

Yin suggests that a rationale for the multiple-case study approach is the selection of two or more cases that are believed to be literal replications, "such as a set of cases with exemplary outcomes in relation to some evaluation questions" (Yin, 2009, p.59). Selecting these cases requires the prior knowledge of their outcomes and focuses on why these outcomes have occurred. In this research, exemplary projects that have successfully designed and implemented wildlife crossings and associated monitoring studies are examined for lessons that may inform project replication in Ontario. The case studies explain the organizational and institutional processes and decisions involved in the implementation of wildlife crossing projects to mitigate landscape-level issues in real-world contexts.

The south Florida and Banff projects are consistently cited as international exemplars of the successful implementation of wildlife crossings to link fragmented landscapes, reduce human-animal collisions, and facilitate the movement of wildlife across transportation corridors (Anderson & Jenkins, 2006; Beckmann et al., 2010; Forman et al., 2003; Ruediger & DiGiorgio, 2007). This research describes the case studies using a framework adapted from the recent publication *Safe Passages: Highways, Wildlife, and Habitat Connectivity* (Beckmann et al., 2010) which synthesizes road ecology, conservation science, policy, and transportation planning and specifically addresses the facilitation of wildlife movement across transportation corridors. Case study components include: a description of the project setting and context; a discussion of planning issues that inform the rationale for the project; the design plan for the wildlife crossings; the process through which the wildlife crossings were implemented (including the policy context which allowed for their implementation); and the structure of the project's monitoring program.

Information through which to understand the case studies was gained from a document review of relevant planning documents and reports, scientific reports and monitoring data, and official project reports and websites produced by the proponents and their partners. These documents were analyzed for their relevance to the categories of wildlife crossing design, the process of their implementation, and the structure of their monitoring programs, with the flexibility to include any other categories of information identified at the time of conducting the research.

4.2.3 Process of Analysis

The case study documents were reviewed through directed content analysis which uses analytic category codes relevant to the research questions. These category codes were derived using both an inductive and a deductive approach. In the inductive process, the researcher immerses himself or herself in the data in order to identify themes that seem meaningful to the producers of each document or message (Berg, 2009). The deductive process uses a categorical scheme suggested by a theoretical perspective and uses it to analyze documents which provide a means for assessing the hypothesis (Berg, 2009). This research described the case studies using the predetermined category codes of the projects' wildlife crossing designs, the processes of their implementation, and the structure of their monitoring programs. These categories organized the contents of the collected data and allowed for comparisons between case studies (Rapley, 2007). The categories were identified as potential components of the projects that have contributed to the success of the wildlife crossings on the ground and may be replicated in another situation, such as within Ontario's NHSs. These identifications were made using the *Safe Passages* case study framework and the researcher's judgment, as informed by the literature review and linking to the research questions, due to a lack of formally accepted evaluative criteria in this field of study.

The process of content analysis begins with devising research questions. The categories organize information to answer the research questions of how the case study projects mitigate habitat fragmentation and what lessons they can provide for the implementation of wildlife crossings in Ontario. In reading through the case study documents, information was organized under these categories, with other categories and related themes inductively derived from the documents themselves. That is, unanticipated categories and themes through which to sort the data emerged through reading the data itself. Unrestricted open coding was applied by noting relevant category labels and themes for sorting the data during reading. Berg (2009) suggests that these likely include some of the analytic categories the researcher identified prior to performing content analysis, which accurately reflects the predetermined categories mentioned above.

The initial analytic categories of wildlife crossing design, implementation process, and monitoring program structure and their associated themes are presented below (see Table 4.1: Working Content Analysis Matrix). The category labels and many themes that resulted from open coding were narrowed through axial coding. This involved more intensive coding around one category according to the relevance of the data to the research questions (Berg, 2009). Coding was frequently interrupted to write theoretical notes, as the process of coding documents often triggers a researcher's ideas (Berg, 2009). As per Ramey (2010), the categories are intended to relate directly to the research questions while the corresponding themes are patterns of information found in the documents. The comprehensive list of categories and themes are reproduced as an Appendix in the report (see Appendix 2.0 Content Analysis Categories & Thematic Criteria Matrix).

Table 4.1: Working Content Analysis Matrix

CONTENT ANALYSIS CATEGORIES & THEMATIC CRITERIA		
Category: WILDLIFE CROSSING DESIGN		
Theme	Source	Data Source
Crossing Type & Design Specifications	Beckmann et al. (2010); Clevenger & Huijser (2009); Forman et al. (2003); O'Brien (2006); Ruediger & DiGiorgio (2007)	Content analysis of case study documents
Focal Species	Anderson & Jenkins (2006);Beckmann et al. (2010); Clevenger & Huijser (2009); Forman et al. (2003); Noss (2003); Ruediger & DiGiorgio (2007)	Content analysis of case study documents
Number of Crossings	Beckmann et al. (2010); Forman et al. (2003); O'Brien (2006); Ruediger & DiGiorgio (2007)	Content analysis of case study documents
Approaches	Beckmann et al. (2010); Clevenger & Huijser (2009); Forman et al. (2003); O'Brien (2006); Ruediger & DiGiorgio (2007)	Content analysis of case study documents
Category: IMPLEMENTATION PROCESS		
Theme	Source	Data Source
Organizations/Institutions/Experts/ Partnerships Involved	Beckmann et al. (2010); Noss (2003); Ruediger & DiGiorgio (2007)	Content analysis of case study documents
Guiding Plans & Policies	Anderson & Jenkins (2006); Beckmann et al. (2010); Noss (2003); Ruediger & DiGiorgio (2007)	Content analysis of case study documents
Project Finance	Anderson & Jenkins (2006)	Content analysis of case study documents
Support Building	Anderson & Jenkins (2006)	Content analysis of case study documents
Role of Planners	Beckmann et al. (2010)	Content analysis of case study documents
Category: MONITORING PROGRAM STRUCTURE		
Theme	Source	Data Source
Monitoring Body	Forman et al. (2003)	Content analysis of case study documents
Length of Program	Clevenger & Waltho (2000); Grilo et al. (2008); Yanes et al. (1995)	Content analysis of case study documents

Methods/Tools/Protocols	Clevenger & Huijser (2009); Clevenger & Waltho (2000); Ford et al. (2009); Grilo et al. (2008); Noss (2003); Yanes et al. (1995)	Content analysis of case study documents
Data Usage	Clevenger & Waltho (2000); Grilo et al. (2008); Yanes et al. (1995)	Content analysis of case study documents

Tally sheets were compiled with the specific categories listed at the top of each sheet. During document review, each time a segment of data fit a thematic criterion, its location was recorded (i.e. document title, page #, paragraph or line #). The processes of coding organized the data and prepared the researcher for the interpretation of patterns, such as commonalities between case studies. The tally sheets were used to consider pattern findings and note similarities and differences between cases (Berg, 2009). By examining any regularity and variability in the data, tentative cross-case findings were able to be formed.

The knowledge gained through the document review has been synthesized in Chapter 5 of this report. Research findings have informed a set of key recommendations for the planning of NHSs in Ontario, with emphasis on the feasibility of integrating wildlife crossings in to provincial policy or enabling these projects through the application of policy directions found in the Ontario *Provincial Policy Statement, 2005* (MMAH, 2005) and the Ontario *Natural Heritage Reference Manual for Natural Heritage Policies of the Provincial Policy Statement, 2005* (MNR, 2010).

4.3 RESEARCH LIMITATIONS

Forman et al. (2003) define 'wildlife' as "nondomesticated terrestrial vertebrates" (p.15). As such, this report focuses on wildlife crossings for terrestrial animals and not does address in detail wildlife crossings for aquatic species. However, the installation or modification of culverts is a common practice and well-documented mitigation measure to facilitate the movement of fish and other aquatic species along waterways intersected by roads (Blank, 2010).

Though the decision to conduct this research through the compilation of case studies is based in recently published precedents (Beckmann et al., 2010), no existing, formally accepted evaluative criteria is available upon which to base case study components. As such, the case studies may lack a holistic or nuanced understanding of the wildlife crossing projects, limited to what has been documented.

Consequently, potential researcher bias is the primary methodological limitation of this research project, as categories and themes comprising evaluative criteria were identified based on a single researcher's perspective and evolved through the research process. The identification of these limitations and a discussion of the value of these case studies in outlining successful planning precedents and their project components provide a high degree of academic and professional integrity to this report.

Additional research and semi-structured interviews would serve to mitigate researcher bias, as in the interpretation of the relevance of wildlife crossings to the context of Ontario's provincial policy direction. The conducting of interviews would provide for a greater triangulation of evidence through which to corroborate information gained from case studies (Yin, 2009). However, the time required to compile detailed case studies, combined with resource limitations and the focused scope of the Master's report, did not allow for this degree of comprehensiveness. The conducting of semi-structured interviews to this end presents an opportunity for data validation in the future study of this research problem.

While the author of this report has extensive experience conducting document-based research at the graduate level, she is not trained in the conducting of a cost-benefit analysis. This level of detail would be necessary to inform the realistic financial context in which wildlife crossing projects would be constructed, either at the provincial or municipal levels. The author is also not trained as a transportation engineer with a nuanced understanding of the suitability of existing Ontario highways to the retrofits required to install wildlife crossings. As such, this report will not examine the financial or technical feasibility of implementing wildlife crossings, including engineering considerations pertaining to the planning or retrofitting of transportation infrastructure. However, every effort has been made to provide a qualitative understanding of wildlife crossing projects, their effective design for the purposes of linking landscapes for wildlife movement at the conceptual level, the appropriateness of implementing these projects within relevant local legislative and policy contexts, and the structure of effective monitoring programs.

5.0 CASE STUDIES

Table 5.1 summarizes the data collected on the Interstate 75 (I-75), south Florida and Trans-Canada Highway (TCH), Banff wildlife crossing projects using content analysis of case study documents organized by the categories and themes introduced in Chapter 4 of this report. This evaluative criteria matrix was previously presented as a working version in Table 4.1; it presents the case study data in a simplified form. Case study information is presented in greater detail in sections 5.1 and 5.2.

Table 5.1: Summary of Case Studies: Content Analysis Matrix

CONTENT ANALYSIS CATEGORIES & THEMATIC CRITERIA		
Category: WILDLIFE CROSSING DESIGN		
Theme	**CASE STUDIES**	
	I-75, south Florida	**TCH, Banff, AB**
Design Objectives/Goals	+ Restore hydrological connectivity; facilitate movement for panther, reduce road mortality, and provide habitat connectivity to allow dispersal and maintain genetic viability of population (Evink, 1990 & 2002; Jansen et al., 2010)	+ Reduction of road mortality and habitat fragmentation; improving motorist safety (Ford et al., 2010; Parks Canada, 2012b)
Type & Design Specifications	+ Underpasses: 2.4 m high by 36.6 m long by 13. 1 m wide spanning 4 lanes; each consisting of two open span bridges separated by a 22.3 m wide median open overhead (Evink, 2002; Foster & Humphrey, 1995; Jansen et al., 2010) + Bridge extensions: 12.19 m (Evink, 2002) + Approx. 1 mile between crossings (Evink, 1990)	+ 1) Creek bridge underpass [3 m high x 11 m wide; expanded bridge spanning waterway] + 2) Elliptical, metal culvert underpass [4 m high x 7 m wide] + 3) Prefabricated concrete box underpass [2.5 m x 3 m] + 4) Open-span concrete bridge underpass [3 m high x 11 m wide] + 5) 50 m wide overpass (Parks Canada, 2012k)
Focal Species	+ Florida panther (Anderson & Jenkins, 2006; Evink, 1990 & 2002; Foster & Humphrey, 1995; Jansen et al., 2010)	+ Phase I & II: ungulates (deer, elk, moose) + Phase IIIA&B: carnivores (incl. grizzly and black bears, wolves, cougars), ungulates (Ford et al., 2010; Clevenger et al., 2002)
Site Selection/ Placement	+ Wildlife crossings along 64 km stretch of 4-lane I-75 (Jansen et al., 2010) + Crossing locations determined using data from 18 radio-collared panthers tracked by aircrafts to identify seasonal movement corridors and habitats used by panthers (Evink, 1990) + Placement associated with known panther crossing points and vegetative features providing preferred panther cover (Foster & Humphrey, 1995; Jansen et al., 2010)	+ 1978: Parks Canada proposed TCH twinning from 2 to 4 lanes, proceeding in phases along 81 km (Ford et al., 2010) + Crossing locations determined using GIS habitat linkage, regional and local movement, and road mortality modelling; roadkill data (Clevenger et al., 2002) + Phase I: Banff National Park East Gate (km 1) to km 11 + Phase II: km 11 to km 27 + Phase IIIA: km 27 to km 45 + Phase IIIB: km 45 to km 81 (BC border) (Parks Canada, 2009b)

Number of Crossings	+ Total: 36 – 23 underpasses and 13 bridge extensions (Evink, 2002); alternatively documented as 24 underpasses and 12 bridge extensions (Jansen et al., 2010; Sierra Club, 2008)	+ Total upon twinning completion: 44 – 6 overpasses and 38 underpasses (Parks Canada, 2012d)
Approaches	+ 3.4 m high continuous chain-link fencing topped by 1 m outrigger with 3 strands of barbed wire on both sides of I-75 prevents wildlife from entering roadway and funnels animals towards structures (Jansen et al., 2010) + Importance of unobstructed view of habitat on far side of underpass (Foster & Humphrey, 1995)	+ 2.4 m high unburied and buried fencing prevents wildlife from entering right-of-way and guides animals to crossing structures (Parks Canada, 2012k) + Maintain "viewshed" (Clevenger et al., 2002) + Limitation of human disturbance near crossing structures via relocation of foot trails, restricted use of underpasses (Clevenger et al., 2002)
Habitat Features/Quality	+ Native vegetative cover (Jansen et al., 2010) + Crossing points associated with forested habitat (Foster & Humphrey, 1995)	+ Availability of both open areas and cover (Parks Canada, 2012l) + Proximity to riparian drainage areas + Addition of stump walls or berms to facilitate crossings and provide light/noise barrier (Clevenger et al., 2002)
Landscape Context/ Connections	+ I-75 project traverses Big Cypress National Preserve, Fakahatchee Strand State Preserve, and Florida Panther National Wildlife Refuge in Collier County, south Florida (Foster & Humphrey, 1995)	+ Bow River Valley, Central Rocky Mountains (Clevenger et al., 2002) + Within Yellowstone to Yukon corridor (Anderson & Jenkins, 2006; Parks Canada, 2009e)
Category: IMPLEMENTATION PROCESS		
Theme	**CASE STUDIES**	
	I-75, south Florida	**TCH, Banff**
Organizations/ Institutions/ Experts/ Partnerships Involved	+ Initiated by Florida Fish and Wildlife Conservation Commission; executed by Florida Department of Transportation (Foster & Humphreys, 1995; Jansen et al., 2010) + Governor Bob Graham's 1983 "Save Our Everglades" initiative raised conservation awareness (Jansen et al., 2010) + Florida Panther Interagency Committee consulted for fencing design (Evink, 1990)	+ Principal investigator Dr. Anthony P. Clevenger (Clevenger, 2003) + Initially led by Parks Canada; as of 2005, an international public-private partnership between Parks Canada and the Miistakis Institute for the Rockies, the Western Transportation Institute (WTI) and the Woodcock, Wilburforce, and Kendall Foundations (Clevenger et al., 2009; Parks Canada, 2012a)
Guiding Plans & Policies	+ Environmental Impact Statement prepared, as mandated by National Environmental Policy Act; recommended I-75 mitigation (Sierra Club, 2008) + I-75 project Recreational Access Plan determined alternative access to public lands for recreationists through self-closing gates (Jansen et al., 2010)	+ Banff National Park Management Plan (Parks Canada, 2010)
Project Finance	+ Florida Preservation 2000 program and Florida Forever program for conservation of landscape corridor (Anderson & Jenkins, 2006) + Adjacent conservation lands purchased by combining access rights funds with state Conservation and Recreational Lands purchase funds (Evink, 2002) + Alligator Alley tolls (Evink, 2002)	+ 1996-2002: Parks Canada funded research and monitoring (Parks Canada, 2012a) + 2002: Parks Canada funding scaled back to provide only basic monitoring funding from Highway Service Centre + External grant applications (Clevenger, 2003) + 2005-2009: Parks Canada funding matched 2-to-1 by partners (Clevenger et al., 2009)
Adjacent Land Management	+ Governance of state conservation lands shared by Florida Fish and Wildlife Commission and Florida Division of Forestry (Anderson & Jenkins, 2006)	+ Land adjacent to crossing structures is managed by Parks Canada as part of Banff National Park (Ford et al., 2010)

	+ Private lands adjacent to project area acquired by state through conservation easements and managed through management plans by private owners (Anderson & Jenkins, 2006)	+ Towns sites of Banff and Lake Louise subject to *Canada National Parks Act* (Parks Canada, 2010) + Wider Y2Y corridor lands may require cooperation of private landowners (Anderson & Jenkins, 2006)
Incentives	+ Private landowners provided with "severance of access" compensation (Jansen et al., 2010) + P2000 and Florida Forever programs acquired private lands by paying fair-market value, closing deals efficiently, and paying cash in lump sums + Tax benefits for private landowners; county governments may gain back lost tax revenues from timber sales, economic activities, and sale of sporting licenses (Anderson & Jenkins, 2006)	+ Adjacent lands (Y2Y corridor) may require buy-in from industrial interests and ranchers via income and inheritance land tax breaks with conservation easements; monetary compensation for livestock loss to predators (Anderson & Jenkins, 2006)
Obstacles	+ Acquisition of private lands adjacent to I-75 project for conservation (Anderson & Jenkins, 2006; Evink, 2002; Jansen et al., 2006) + Shortage of research to guide wildlife crossing design (Jansen et al., 2010)	+ Partially discontinued funding from Parks Canada (Clevenger et al., 2002)
Stakeholder Engagement	+ N/A – no strategies discussed in case study documents	+ Phase IIIB: open houses, site hours, special presentations, Stakeholder Advisory Committee, and Canadian Environmental Assessment Agency public participation process (Parks Canada, 2012f)
Support Building	+ Prior to project, panther deaths reported in news + 1982: Florida schoolchildren chose Florida panther as state animal, helping to raise awareness + Governor Bob Graham's "Save Our Everglades" campaign (Jansen et al., 2010) + Project information distributed at I-75 tollbooths (Jansen et al., 2010; Sierra Club, 2008)	+ Dissemination of monitoring data and results to inform public of environmental and societal benefits of wildlife crossings investments (Ford et al., 2010) + Focused public education and outreach using key monitoring tools: track pad data, still and video camera images, results of genetic analysis (Ford et al., 2010)
Role of Planners	+ National practice priorities for planners of wildlife crossings include the combination of mitigation measures, incorporation of wildlife mitigation needs early in planning process, and integration of conservation priorities in transportation planning (Bissonnette & Cramer, 2008) + See Monitoring category for wildlife crossing research priorities for planners	+ Stricter development and human use limitations (Clevenger & Waltho, 2000) + Incorporation of monitoring data from impact assessments, performance evaluations, and design recommendations in future transportation planning decisions (Clevenger et al., 2002) + Consider multiple species use in planning for mitigation (Clevenger & Waltho, 2000) + Prioritization of mitigation measures as part of a management plan (Clevenger et al., 2003)
Category: MONITORING PROGRAM STRUCTURE		
Theme	**CASE STUDIES**	
	I-75, south Florida	**TCH, Banff**
Monitoring Body	+ Individual monitoring projects by researchers Foster & Humphrey, Lotz et al., and Jansen et al. (Jansen et al., 2010)	+ Parks Canada staff; WTI leads scientific research (Ford et al., 2010)
Study Design	+ N/A – no formal study designs identified in case study documents on monitoring studies	+ Some discussion of null movement models (Clevenger & Waltho, 2000)
Length of Program	+ Foster & Humphrey: ranged from 2-16 months during 1989-1991 construction phase (Foster &	+ Long-term approach since 1996 (Parks Canada, 2012a)

	Humphrey, 1995; Jansen et al., 2010) + Lotz et al.: 1996, length unknown (Jansen et al., 2010) + Jansen et al.: October 2008 and April 2009 (Jansen et al., 2010)	
Frequency	+ N/A – no frequencies of monitoring activities discussed in case study documents	+ Sand track pads visited every 2 days in summer and every 4 days in winter (Ford et al., 2010)
Methods/Tools/ Protocols	+ Foster & Humphrey: 4 underpasses monitored by game counters and cameras with automatic flash units triggered by infrared-light; underpasses chosen for monitoring were determined most likely to be used by panthers, as judged by tracks and telemetry data acquired by radio-collaring panthers and bobcats (Foster & Humphrey, 1995; Jansen et al., 2010) + Lotz et al.: N/A + Jansen et al.: monitored home range data for a sample of 91 panthers to determine extent of crossing usage; field-checked state of underpasses in wet and dry seasons; used GPS to measure underpass dimensions and document fence breaches (Jansen et al., 2010)	+ Wildlife-vehicle collision tracking: Parks Canada staff record date, GPS coordinates, descriptive location, species, number of individuals, and physiological information from necropsies in database (Ford et al., 2010) + Structure use: sand track pads – researchers record species, direction of movement, number of individuals for large mammals; DNA hair sampling; monition-sensitive cameras – information on time, animal behaviour, ambient temperature during crossing events (Ford et al., 2010)
Indicators/ Measures of Success	+ Effectiveness of underpasses judged using criteria of roadkill reduction, maintenance of habitat connectivity, continuity of genetic interchange, and allowance of dispersal and recolonization (Jansen et al., 2010)	+ Initial lack of indicators or criteria established prior to mitigation construction; performance measured by wildlife-vehicle collision reduction, rates of crossing structure passage, and effects at individual and population level (Ford et al., 2010) + 6 criteria developed for mitigation effectiveness (Clevenger et al., 2002)
Data Usage	+ Evaluation of project effectiveness (Jansen et al., 2010) + Foster & Humphrey (1995) recommend reduction in human trespassing, fence inspection and repair, and contingency plan for wildlife caught between fencing on roadway + Lotz et al. recommended grade adjustments to reduce standing water in underpasses (Jansen et al., 2010) + Jansen et al. (2010) recommend fence inspection and repair, increase in visibility for wildlife through crossings, and more formalized monitoring study	+ Results to inform adaptive management of mitigation design, provide information to transportation planners and land managers, inform wide audience of benefits of wildlife crossings (Ford et al., 2010)
Information Dissemination	+ N/A – no discussion of how monitoring results have been communicated to public or decisionmakers in case study documents + Information on highway wildlife improvements and status of panthers distributed at I-75 tollbooths (Jansen et al., 2010)	+ As of 2010, 9 peer-reviewed publications incl. one book produced, 5 manuscript submissions; organized training courses and workshops; 180 school presentations since 1996 (Ford et al., 2010)
Adaptive Management	+ Jansen et al. (2010) advocate for adaptive management through their recommendation of post-evaluation evaluation and routine monitoring to ensure project goals are met and obstacles to wildlife use are identified and addressed	+ Used to streamline planning (Ford et al., 2010) + Alteration of mitigation plans for Phase IIIB based on data from Phase I-IIIA; results guided design and location of 18 new structures between Castle Junction and BC border (Ford et al., 2010; Parks Canada, 2011)

Efficacy	+ Overall reduction in road mortality - since project completion, only two panthers killed within project area (one at ramp of unfenced State Road 29 intersection and one at human-made fence breach (Jansen et al., 2010) + No cumulative monitoring data available on number of panther crossings; individual monitoring studies recorded evidence of increasing use by panthers and multiple species (Foster & Humphrey, 1995; Lotz et al., 1996; Jansen et al., 2010)	+ 200,000+ crossings by 11 species of large mammals monitored since 1996 (Parks Canada, 2012c&e) + Wildlife-vehicle collisions declined by 80% and by >95% for ungulates (Parks Canada, 2009a) + Genetic interchange occurring (Clevenger et al., 2002)
Additional Research Required	+ National research priorities identified for planners of wildlife crossings include further study of wildlife usage dynamics, development of wildlife crossing design guidelines for multiple species, and standardized monitoring protocols (Bissonnette & Cramer, 2008)	+ Establishment of usage patterns + Further testing of methodologies + Determine crossings by radio-marked individuals + Testing of novel mitigation measures + Population viability analysis + Research on cost-effective design (Clevenger et al., 2002)

5.1 INTERSTATE 75 (I-75), SOUTH FLORIDA, USA

Project Description

The I-75 project was constructed along the former State Road (SR) 84, more commonly known as Alligator Alley, after increases in human settlement spurred the need for an interstate highway linking the south Florida coasts between Naples and Ft. Lauderdale (Jansen et al., 2010; Land & Lotz, 2007). The highway would traverse the last remaining habitat for the Florida panther, whose population had dwindled to between 30 and 50 individuals (Evink, 2002). As 64 km of the I-75 paralleled the existing SR 84, the two-lane road was reconstructed to a four-lane divided interstate highway, in part to be more cost-effective and address the original road's negative hydrologic effects on Big Cypress Swamp, a 640,000 hectare wetland bisected by SR 84. Design improvements to facilitate passage for the federally endangered panther across the I-75 were considered 10 years later – a series of underpasses and bridge extensions accompanied by continuous fencing were constructed along the 64 km stretch of Alligator Alley, beginning 14 km east of SR 951 in Collier County and east to the Broward County line (Jansen et al., 2010; see Figure 5.1).

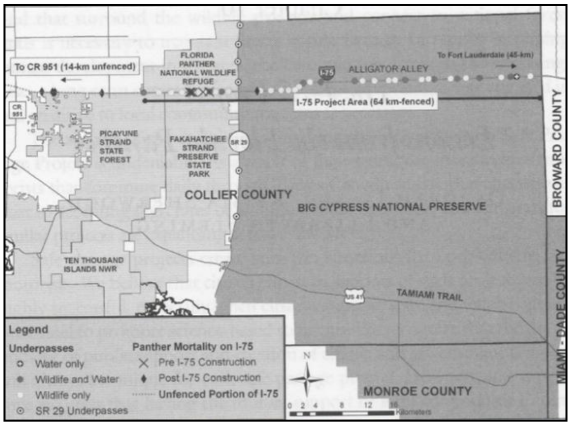


Figure 5.1: I-75 project area showing underpass types and panther mortality locations.
Source: Jansen et al., 2010.

Planning Issues & Project Rationale

The I-75 project wildlife crossings were some of the first implemented in the United States, after the need for conservation mitigation was identified in the Environmental Impact Statement (EIS) for the I-75, as mandated by the Federal Highway Administration's National Environmental Policy Act regulations (Jansen et al., 2010; Sierra Club, 2008). The project was initiated after research projects in the late 1970s and early 1980s by the Florida Game and Fresh Water Fish Commission (now the Florida Fish and Wildlife Conservation Commission) determined there were very few remaining panthers, the population viability of which would be significantly threatened with the loss of even a single individual (Jansen et al., 2010).

Habitat fragmentation and landscape connectivity for the panther were considered paramount to other interstate planning issues, emphasized in a letter from the Commission to the Governor's Office of Planning and Budgeting which stated that the "redesign of roads in known panther habitat should fully accommodate this concern" (Jansen et al., 2010, p.209). Panthers would need to cross the I-75 to access food resources as habitat conditions changed between wet and dry seasons, and to allow for the dispersal of young and the maintenance of genetic viability in the population (Evink, 1990). Considering that panther-vehicle collisions accounted for 47% of all documented panther mortality between 1981 and 2008, mitigation was required to facilitate their movement (Jansen et al., 2010). The I-75 project would also contribute to the restoration of a landscape corridor towards predominantly intact wildlife habitat linking Everglades National Park and conservation areas in southeastern Georgia (Anderson & Jenkins, 2006). Locally, wildlife crossing mitigation would provide critical habitat linkages along the 64 km stretch of the I-75 traversing Big Cypress National Preserve, Fakahatchee Strand State Preserve, and the Florida Panther National Wildlife Refuge in Collier County, south Florida (Foster & Humphrey, 1995).

Wildlife Crossing Design

Construction of the I-75 wildlife crossings began in 1986 and occurred in 10 phases, prioritized by the locations of panther road mortality (Jansen et al., 2010). Crossing locations were chosen based on known panther and bear travel routes and heavily vegetated and forested areas that provide preferred panther cover (Evink, 1990; Foster & Humphrey, 1995; Jansen et al., 2010). More specifically, data from 18 radio-collared panthers tracked by aircraft was used by the Florida Department of Transportation (FDOT) to identify habitats being used by panthers and seasonal movement corridors corresponding to wet, dry, mating, and breeding seasons. Several crossing locations were on higher ground than surrounding areas, with some coinciding with consistent roadkill locations (Evink, 1990).

Image 5.1: The 64 km I-75 project area has 36 underpasses across 4 lanes of divided highway.
Source: Lotz & Land, 2007.

Due to a shortage of research to guide wildlife crossing design, a literature review delineated design characteristics of successful wildlife crossings in other locations. Passage design was intended to minimize a tunnel effect while fencing design and height was determined in consultation with experts from captive animal facilities and the Florida Panther Interagency Committee of experts working towards panther recovery (Evink, 1990). Underpasses were designed 2.4 metres high by 36.6 metres long by 13.1 metres wide, spanning four lanes. Each underpass consisted of two open span bridges separated by a 22.3 metre wide open median open (Evink, 2002; Foster & Humphrey, 1995; Jansen et al., 2010). Bridges were updated with 12.19 metre extensions to provide for water flow under the roadway through canals and by sheet-flow into wetlands (Jansen et al., 2010). Upon project completion in 1993, wildlife crossing mitigation consisted of a total of 36 structures – 23 underpasses and 13 bridge extensions (Evink, 2002), alternatively documented as 24 underpasses and 12 bridge extensions (Jansen et al., 2010; Sierra Club, 2008).

To prevent wildlife from entering the roadway, two sections of 3.7 metre high fencing topped by four to six strands of barbed wire were installed in medians. Continuous 3.4 metre high chain-link fencing of galvanized steel topped by a 1 metre outrigger with three strands of barbed wire was installed along both sides of the 64 km I-75 project area, serving to both keep wildlife off the roadway and funnel wildlife to crossing structures (Jansen et al., 2010).

Image 5.2: Open span underpass with median across I-75.
Source: Lotz & Land, 2007.

Implementation

Public and agency support building was instrumental to implementation of I-75 wildlife mitigation. The report of panther deaths in the news and the naming of the Florida panther as the state animal in 1982 helped to raise awareness on the status of the federally endangered species. Governor Bob Graham furthered awareness for hydrologic restoration and panther preservation through the 1983 "Save Our Everglades" initiative (Jansen et al., 2010). These efforts highlight the powerful role public awareness campaigns can play in raising support for species conservation and the impact a project champion can have on driving conservation action. Following construction, awareness of the project is maintained by the distribution of informational pamphlets to drivers at I-75 tollbooths, detailing highway wildlife improvements and the status of panthers (Jansen et al., 2010; Sierra Club, 2008).

Adjacent land management has been critical to the success of the I-75 project and the larger objective of habitat restoration and landscape connectivity. FDOT required that all property adjacent to the road be secured under conservation agreements before building underpasses, sometimes requiring private owners to provide management plans (Anderson & Jenkins, 2006). Land acquisitions included compensation for habitat loss and wetland damage incurred during I-75 construction (Jansen et al., 2010). In 1988, 100 hectares adjacent to Big Cypress Swamp and the SR 29 corridor (intersecting the I-75) were acquired from the Collier family, with an additional 8,000 hectares acquired by the US Fish and Wildlife Service to create the Ten Thousand Island National Wildlife Refuge. In 1989, 10,700 hectares were purchased to establish the Florida Panther National Wildlife Refuge to provide secure panther habitat and watershed protection (Jansen et al., 2010). The governance of state conservation lands is shared by the Florida Fish and Wildlife Commission and the Florida Division of Forestry (Anderson & Jenkins, 2006).

Habitat linkages between protected areas and those located on private lands required the cooperation of private landowners for constructing the I-75 and implementing the wider landscape corridor in Florida. After lands were purchased into public ownership, some private landowners lost entry points to their property and were provided “severance of access” compensation and alternative access points (Jansen et al., 2010, p.210). The I-75 Recreational Access Plan provided six alternative access sites outfitted with self-closing gates to compensate for lost entry for recreational access to public lands (Jansen et al., 2010).

The implementation of the wider landscape corridor was supported by public funding from the Florida Preservation 2000 (P2000) program; Florida Forever has provided the majority of conservation funding since 2000 (Anderson & Jenkins, 2006). Funding for the I-75 wildlife mitigation measures is derived in part from highway tolls (Evink, 2002). Adjacent conservation lands were purchased by combining access rights funds with state Conservation and Recreational Lands purchase funds (Evink, 2002). To attract private landowners and acquire properties, the P2000 and Florida Forever programs offered fair-market value, efficient deal closings, and lump sum cash payments (Anderson & Jenkins, 2006). Continued land acquisition for conservation in Florida provides some private landowners with tax benefits while county governments may gain back revenue lost from private land taxes through timber sales, economic activities including ecotourism, and the sale of hunting and fishing licenses (Anderson & Jenkins, 2006).

Though the role of planners in the I-75 project is not discussed in the case study documents, the US National Cooperative Highway Research Program’s

2008 evaluation of the use and effectiveness of wildlife crossings delineated national practice and research priorities for planners (Bissonnette & Cramer, 2008). Practice priorities include: the use of combined mitigation measures; incorporating wildlife mitigation needs early in the planning process; integrating conservation plans and connectivity analyses in transportation planning; assessing retrofit opportunities of existing infrastructure for wildlife mitigation; and establishing effective communication and collaboration with stakeholders (Bissonnette & Cramer, 2008). Research priorities include: the further study of wildlife crossing structure use and information dissemination; developing and summarizing cost-effective crossing designs; developing crossing designs and guidelines for multiple species; developing standardized wildlife crossing inventories by state to improve crossing structure management, maintenance, and needs assessment; developing standardized monitoring protocols and guidelines for decision-making; and increasing understanding of road density effects on wildlife populations (Bissonnette & Cramer, 2008).

Monitoring

Little has been published on post-construction monitoring of the I-75 project, perhaps due in part to the lack of a formal, state-led monitoring program (Jansen et al., 2010). Jansen et al. (2010) cite that two studies have evaluated project effectiveness.

Foster and Humphrey (1995) monitored four underpasses during the 1989-1991 construction phase for approximately two, four, 10, and 16 months, respectively. The underpasses determined to be most likely used by panthers were chosen for monitoring, based on evidence of tracks and telemetry data from radio-collared panthers and bobcats (Foster & Humphrey, 1995; Jansen et al., 2010). Wildlife activity in underpasses was monitored using game counters strapped to wooden platforms (three per underpass) and cameras with automatic flash triggered by infrared-light units. Over the course of monitoring, 837 photographs were captured: 133 crossings by bobcats, 361 by deer, 167 by raccoons, nine by alligators, two by black bears, and 85 photos of humans and human-use objects. Panther crossings totaled 10 passes, determined by telemetry data to be made by two individuals crossing exclusively at night (Foster & Humphrey, 1995).

Lotz et al. (1996 in Jansen et al., 2010) monitored wildlife use of two I-75 underpasses and two SR 29 underpasses and found that panther use of crossing structures had increased since Foster and Humphrey's study. However, monitoring was impeded for approximately four months due to high water, prompting the authors to recommend grade adjustments at the structures to prevent impediments of standing water to wildlife use (Lotz et al., 1996 in Jansen et al., 2010).

Jansen et al. (2010) examined data for 91 panthers with home ranges within 1.6 km of the I-75 project area to determine the extent of underpass usage since project completion. Underpasses were checked in October 2008 and April 2009, representing wet and dry seasons, and measured for dimensions. Cuts or breaches in fencing were documented using GPS. At fence breaches, researchers recorded water depth, wildlife tracks, invasive plant species, and the density of vegetation, providing initial observations of wildlife crossing use and impediments. Panther tracks were found at four underpasses in the wet season and at 12 in the dry season, along with signs of multiple species use (Jansen et al., 2010).

Project Outcomes

The effectiveness of underpasses has been judged using the criteria of roadkill reduction, maintenance of habitat connectivity, continuity of genetic interchange, and the facilitation of dispersal and recolonization (Jansen et al., 2010). There has been an overall reduction in road mortality in the project area. As of 2010, only two panthers had been killed within the project area after mitigation – one at the ramp to the unfenced SR 29 intersection and one at a human-made fence breach (Jansen et al., 2010). Furthermore, though there is no cumulative monitoring data available through which to determine the total number of wildlife crossings made, individual studies have recorded evidence of increasing use of crossing structures by panthers and other species including white-tailed deer, bobcat, black bear, alligator, raccoon, opossum, marsh rabbit, coyote, birds, turtles, and snakes (Foster & Humphrey, 1995; Lotz et al., 1996; Jansen et al., 2010).

Based on evidence of species use, Foster and Humphrey (1995) inferred that the I-75 underpasses were reducing habitat fragmentation and road mortality for some species, though a full evaluation of effects would require more detailed analyses of species movement patterns. Nevertheless, the authors deduced that panthers, bobcats, and black bears largely used underpasses to travel within their home ranges, pointing to the efficacy of wildlife crossings in facilitating habitat connectivity (Foster & Humphrey, 1995).

The monitoring studies identified a number of potential impediments to wildlife use at the structures. Jansen et al. (2010) found that 20 of 23 underpasses were inundated with an average of 14 cm of standing water in the wet season. Furthermore, the researchers found some dense vegetation indicating water inundation for a significant portion of the year, potentially impeding terrestrial wildlife passage (Jansen et al., 2010). Notably, Jansen et al. (2010) reported 59 fence breaches during their monitoring periods, large enough to allow human or animal passage. The researchers report that fence inspections are not completed in the project area regularly, though contractors are required to make immediate temporary repairs followed by permanent repairs within five days of a fence damage report (Jansen et al., 2010). Both Foster and Humphrey (1995) and Jansen et al. (2010) recommended a reduction in human trespassing in the crossing structures and routine inspection and repair of fence breaches. Foster and Humphrey (1995) further recommended a contingency plan for wildlife caught between roadway fencing, while Jansen et al. (2010) recommended increased visibility for wildlife through structures and a formalized monitoring study addressing multiple species use and the effects of year-round availability of dry passage on wildlife use. Jansen et al. (2010) appear to advocate for adaptive management of the crossing structures through their consideration of post-construction evaluation and routine monitoring as critical to ensuring that project goals are being met and obstacles to wildlife use are being identified and addressed.

Despite some shortcomings, the success of the I-75 mitigation influenced the implementation of six underpasses on SR 29, which intersects the I-75, between 1995 and 2007.

Lessons Learned

Jansen et al. (2010) found that male panther crossings far exceeded that of females by 52% to 17%, respectively, or an average of 55 male crossings for every 2 female crossings. This data is consistent with the biological knowledge that male panthers have large home ranges and must cross roads within their territory to sustain their biological requirements, while female panthers maintain smaller ranges often contained by road networks with typically fewer crossings (Lotz & Land, 2007). However, Jansen et al. (2010) add that females may be deterred by crossing distance, traffic volume, standing water, lack of visibility due to vegetation, and the presence of human activity.

Foster and Humphrey (1995) also observed that the frequency of crossing by some species may be affected by the presence or repeated use of crossing structures by other wildlife, as in deer avoiding an underpass consistently used by panthers, bobcats, and humans. The researchers also deduced that the combination of wildlife crossings and fencing provides the most effective design solution addressing both habitat fragmentation and wildlife-vehicle collisions. Foster and Humphrey (1995) also suggested that the importance of maintaining unobstructed habitat views through crossing structures to prevent a tunnel effect outweighs structural dimensions in facilitating wildlife use.

5.2 TRANS-CANADA HIGHWAY, BANFF, ALBERTA, CANADA

Project Description

The Banff Wildlife Crossings Project (BWCP) is situated in Banff National Park (BNP) which attracts four million visitors a year, is home to the town sites of Banff and Lake Louise, and is bisected by the Trans-Canada Highway (TCH) and Canada Pacific Railway (CPR) (Ford et al., 2010). Following Parks Canada's initiation of highway twinning in response to high traffic volumes, this portion of the TCH has been retrofitted with the highest number and greatest diversity of wildlife crossing structures of any highway project. Also boasting the longest year-round monitoring program and largest structure usage data collection, it is considered “one of the most intensely mitigated and studied stretches of highway in the world” (Ford et al., 2010, p.157; Parks Canada, 2012i).

Planning Issues & Project Rationale

The TCH was originally built in the 1950s as a low-volume two-lane highway. Since becoming a major commercial route, the portion of the TCH which traverses through the Bow Valley of BNP was proposed for “twinning,” or expansion from two to four lanes, by the federal government in 1978 (Ford et al., 2010). Twinning was to proceed in phases and incorporate wildlife mitigation measures after the TCH was recognized as a major source of wildlife road mortality and potential barrier for animal movement through BNP and the wider Central Rocky Mountain ecosystem (Banff-Bow Valley Study, 1996 in Ford et al., 2010). Large mammals with wide home-range requirements and other wildlife that depend on the low elevation of the Bow Valley bottom habitat are impeded by the transportation corridor and associated land uses (Clevenger et al., 2002). Obstructed wildlife movement through the Bow Valley could have wider effects through the Yellowstone to Yukon (Y2Y) corridor, severing its northern and southern portions (Anderson & Jenkins, 2006).

Broadly, the 1996 BWCP sought to assess the permeability of the TCH and address its impacts on wildlife road mortality, wildlife movements, and habitat connectivity in the Bow Valley (Clevenger et al., 2002; Parks Canada, 2011). Wildlife-vehicle collisions and the improvement of motorist safety posed the primary concerns of highway mitigation (Parks Canada, 2012j). Evidence of the problem included the rates of road-related ungulate and carnivore mortality reaching 48% and 65%, respectively, between 1981 and 1996 and a predicted decline in elk populations largely due to collisions (Woods, 1990 in Ford et al., 2010; Parks Canada, 2012k). Specifically, the BCWP aimed to evaluate older crossing structures and assess the effectiveness of new ones in order to provide Parks Canada with scientifically defensible data upon which to base future mitigation recommendations (Clevenger et al., 2002). The dissemination of monitoring results aims to inform transportation planners, land and wildlife managers, and the public of the benefits of mitigation measures in order to validate infrastructure investment, provide information to facilitate well-founded decision-making, and inspire similar projects in other communities (Clevenger, 2003; Clevenger et al., 2002; Ford et al., 2010).

Anticipated population growth in the park and wider Y2Y regions and an observed 40% increase in TCH traffic over the last 10 years necessitate continued research and mitigation action towards landscape connectivity (Clevenger, 2003; Parks Canada, 2009e). Parks Canada maintains a commitment to remain at the forefront of this research, including the completion of Phase IIIB mitigation in 2013 and its monitoring (Parks Canada, 2012b&o).

Wildlife Crossing Design

Highway mitigation in BNP has occurred alongside the TCH twinning process in three phases (see Figure 5.2). Phase I construction occurred between 1982 and 1985 from BNP East Gate to km 11 and consisted of the installation of five underpasses and 2.4 metre high wildlife fencing on either side of the TCH to prevent wildlife from entering the right-of-way and guide wildlife to crossing structures (Parks Canada, 2009b; 2012k). Considering the high frequency of ungulate wildlife-vehicle collisions along this stretch of the TCH, the predicted decline of moose and elk from road-related mortality, and the grazing habitat within the highway right-of-way, a 1979 federal EA recommended concentrating on the movement patterns of ungulates as the phase's focal species for mitigation (Ford et al., 2010). Phase II mitigation occurred between 1986 and 1987 from km 11 to km 27 at the Sunshine interchange with the construction of wildlife fencing and six underpasses following Phase I designs (Ford et al., 2010; Parks Canada, 2009b). Fencing design in Phase I and II included one-way gates for animal escape if caught in the right-of-way and Texas gates where fencing intersects roads to keep wildlife off the TCH (Parks Canada, 2012k).

Phase IIIA mitigation resulted from a federal proposal for further twinning in the mid-1980s; an EA process independent from Parks Canada suggested the prioritization of mitigation for large carnivores including cougar, wolves, and black bears (Ford et al., 2010). As a result, fencing, 11 underpasses, and two overpasses were constructed between 1995 and 1997 from km 27 to km 45 between the Sunshine and Castle Mountain interchanges (Parks Canada, 2009b). Fencing notably featured a 1.5 metre section of fence material buried into the ground at a 45 degree angle away from the fence as a result of Phase I and II monitoring which showed evidence of carnivores digging under unburied fencing (Ford et al., 2010; Parks Canada, 2012k).

Image 5.3: 2.4 m high fence with buried apron.
Credit: Tony Clevenger.
Source: Parks Canada, 2011.

Phase IIIB is currently under construction in the upper Bow Valley from km 45 to km 81 (Parks Canada, 2009b). Twinning has been completed between Castle Junction and the Icefields Parkway Junction to Jasper; the final 8.5 km of twinning between Lake Louise and the BC border is anticipated for completion in 2013 (Parks Canada, 2012b). Mitigation design is primarily focused on large mammal species, including wolverine, lynx, grizzly bear, and moose which have low population densities and are sensitive to human disturbance (Ford et al., 2010). Upon completion, Phase IIIB mitigation measures will bring the total number of wildlife crossings in BNP to 44 – 38 underpasses and six overpasses (Parks Canada, 2012d).

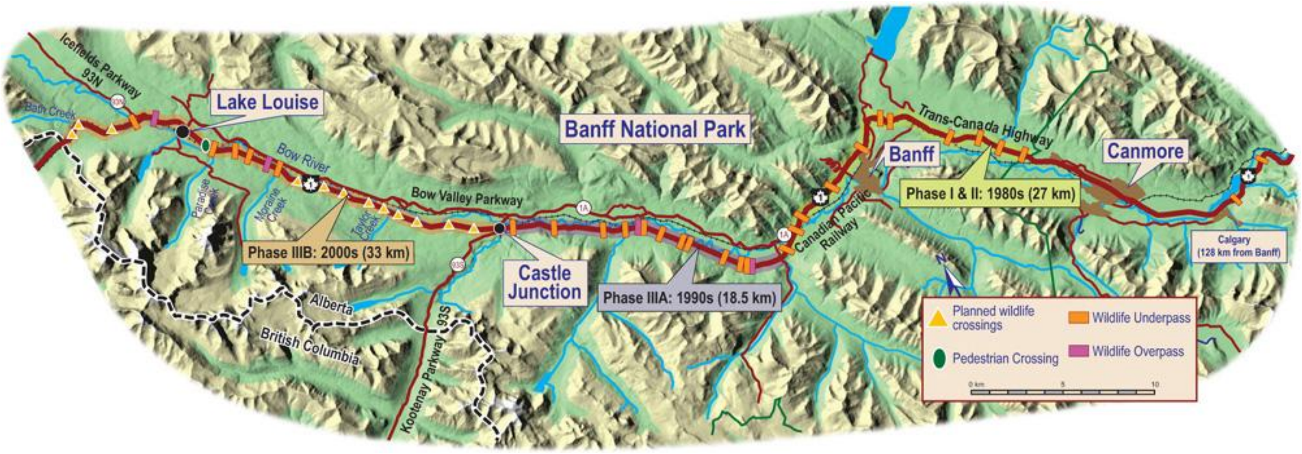


Figure 5.2: Map of Banff wildlife crossings, Phases I-IIIB.
Source: Parks Canada, 2010.

The Banff wildlife crossings are made up of a diversity of structures which accommodate wildlife that prefer proximity to riparian drainage areas, open areas, and those requiring cover (Clevenger et al., 2002; Parks Canada, 2012l). The five structure types are:

1) Creek bridge underpass
[3 m high x 11 m wide spanning waterway]
2) Elliptical, metal culvert underpass
[4 m high x 7 m wide]
3) Prefabricated concrete box underpass
[2.5 m x 3 m]
4) Open-span concrete bridge underpass
[3 m high x 11 m wide]
5) 50 m wide overpass
(Parks Canada, 2012k; see Figure 5.3)

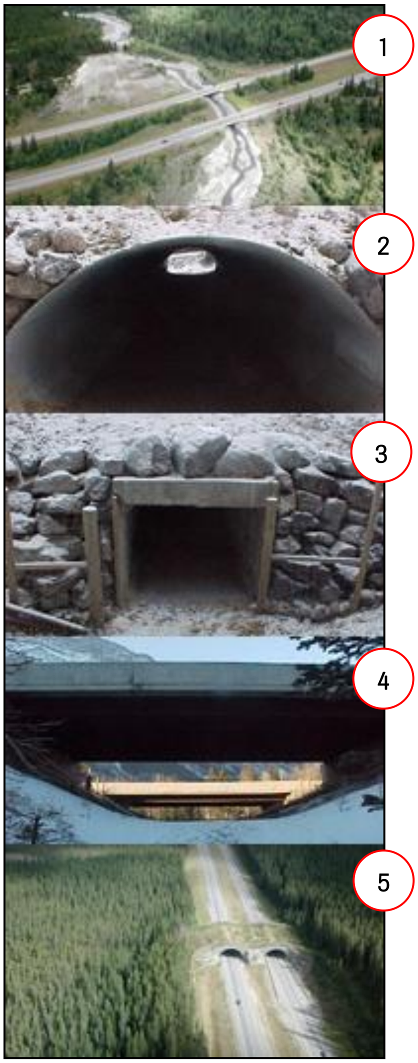


Figure 5.3: Banff wildlife crossing types. Credit: Tony Clevenger.
Source: Parks Canada, 2011.

BWCP primary investigator Anthony Clevenger maintains that the placement of wildlife crossings is critical to their functional success. Recommendations include situating wildlife crossings in proximity to natural travel corridors such as riparian areas to maximize habitat quality, adding stump walls or berms to facilitate crossings by multiple species, and maintaining an unobstructed view through the crossing at grade level to encourage animal use. Furthermore, human use disturbances should be minimized around crossing structures, which may include the relocation of foot trails and restricted underpass use (Clevenger et al., 2002).

The future location of wildlife crossings will be based on Geographic Information System (GIS) models that simulate the movement of five large mammal species (wolf, grizzly and black bears, elk, and moose) and predict likely crossing locations. The models' accuracy will be verified by independent data derived from animal tracking through radio telemetry, snow tracking, observations, and roadkill occurrences (Ford et al., 2010; Parks Canada, 2009c). GIS-based modelling may include habitat linkages, regional and local scale movement, road crossings, and mortality models (Clevenger et al., 2002).

Implementation

Parks Canada has been responsible for managing the construction and maintenance of the wildlife crossings and provided funding support for the BWCP research and monitoring from 1996 to 2002 through its Highway Service Centre (Ford et al., 2010). In 2002, Parks Canada ceased financial contributions towards project research and provided only basic monitoring funding for crossing structures (Clevenger, 2003; Ford et al., 2010). In addition to external grant applications by primary investigator Anthony Clevenger, other funding for continued monitoring and research was secured in 2005 through an international public-private partnership between Parks Canada, the Western Transportation Institute (WTI) at Montana State University, and the Woodcock, Wilburforce, and Kendall foundations (Clevenger, 2003; Clevenger et al., 2009; Ford et al., 2010). From 2005 to 2009, partnership funding consisted of a 2-to-1 match for every dollar contributed by Parks Canada (Clevenger et al., 2009). Considering the obstacle of discontinued funding, Clevenger believes Parks Canada should capitalize on the opportunity to lead pioneering research and, at the least, act as a key player and continue basic monitoring funding (Clevenger, 2003).

Part of Parks Canada's management of the wildlife crossings requires assuring their conformity with BNP's protection of natural heritage as set out in the *Banff National Park Management Plan* (Parks Canada, 2010). The Plan provides a framework for all Park planning and decisions and employs five strategies which describe its overall management approach. Key Strategy 5.2.1 concerns connecting and reconnecting people, landscapes, wildlife populations, and waterways including the management of transportation corridors to connect ecosystems (Parks Canada, 2010). Directions 5.2.1.4 and 5.2.1.6 provide for the maintenance and restoration of secure wildlife corridors and for the design and maintenance of highways and railroads to enhance safe wildlife movement (Parks Canada, 2010). In Direction 5.3.1.7, the Plan expressly supports the design and implementation of highway crossing structures as conservation measures and learning opportunities within the Park (Parks Canada, 2010). Importantly, the Plan sets out direction for the engagement of stakeholder and interest groups in scientific programming and research, volunteer and citizen science involvement, and the utilization of media and visitor engagement strategies for the dissemination of research and monitoring findings. Area concepts outline specific objectives for geographic areas within the Park, including the minimization of road-related mortality and increase of visitor awareness of crossing structures in the Lower and Middle Bow Valley. Key actions include the development of "drive through awareness" products which target park visitors and the development and installation of graphic media and interpretive exhibits at wildlife overpasses to facilitate visitor learning, helping to increase understanding and support for mitigation (Parks Canada, 2010).

Concerning the management of lands adjacent to crossing structures, the Plan outlines the management of land use activities in the town sites of Banff and Lake Louise which are also subject to the *Canada National Parks Act* (Parks Canada, 2010). Land directly adjacent to crossing structures is part of BNP and managed by Parks Canada while wider Y2Y corridor lands reconnected by crossing structures may require the cooperation of private landowners which may be facilitated through incentives (Anderson & Jenkins, 2006). These can include obtaining buy-in from industrial interests and ranchers via income and inheritance land tax breaks through conservation easements or monetary compensation for livestock loss to predators (Anderson & Jenkins, 2006).

Stakeholder and public engagement has been effectively employed in the BWCP; the transfer of technology and increase of community awareness are identified project objectives (Ford et al., 2010). Information dissemination to an audience that includes transportation planners and land and wildlife managers will facilitate well-founded decision-making and political support for similar projects worldwide (Clevenger, 2003; Clevenger et al., 2002). The BWCP's focus on public education and outreach has provided an increased understanding of the function and efficacy of crossing structures, helping to leverage support for continued government funding and similar mitigation projects across the Y2Y and North America (Ford et al., 2010). To this end, Phase IIIB employed public participation strategies including open houses, site tours, special presentations, a Stakeholder Advisory Committee, and the Canadian Environmental Assessment agency public participation process (Parks Canada, 2012f). Key tools for education and outreach consist of monitoring data from track pads, still and video camera images, and the results of genetic analyses (Ford et al., 2010).

Monitoring

Parks Canada has taken a long-term approach to monitoring wildlife-vehicle collisions and crossing structure use, maintaining monitoring operations in the Park since 1996 (Parks Canada, 2012a).

Initial monitoring lacked indicators or criteria established prior to mitigation construction through which to assess the performance of crossing structures (Ford et al., 2010). A set of six criteria for mitigation effectiveness were later developed and examine the reduction of both road-related mortality and barrier effects on habitat connectivity, genetic interchange, the fulfillment of biological requirements, allowance of dispersal and recolonization, and long-term maintenance of metapopulation and ecosystem processes. Participating agencies responsible for mitigation supervision are recommended to agree on indicators or criteria prior to project commencement (Clevenger et al., 2002).

The numerical and spatial distribution of wildlife-vehicle collisions are monitored by Parks Canada staff travelling along the TCH. Data including the date of road mortality, GPS coordinate and descriptive location, species, number of individuals, and physiological information from necropsies are stored in a central database (Ford et al., 2010). Roadkills tended to occur close to vegetative cover and far from crossing structures and were less likely on roads with a raised grade (Parks Canada, 2012f).

Parks Canada wardens, highway maintenance crews and study staff are also responsible for the regular survey of fencing for any defects that may allow wildlife passage. Defects are flagged and their locations recorded using GPS; repairs are made by splicing page-wire to the existing fence or using solid materials including rocks to close smaller gaps. Furthermore, one-way gates have been gradually replaced by swing gates which are safer as escape mechanisms for wildlife. A fence repair log has been kept since July 2000, indicative of the adaptive management approach employed in the study that monitors for problems and applies solutions based on monitoring results (Clevenger et al., 2002).

Clusters of wildlife-vehicle collisions have been observed to occur where fencing ends. The study has recommended the following adaptive approaches to mitigate this ongoing problem: implementing speed reduction zones with warning signage; increasing motorist education in the Park; increasing lighting and positioning crossing structures at fence ends; and using triggered infra-red beams to alert drivers when wildlife is detected near the roadway (Clevenger et al., 2002).

Monitoring of crossing structures examines annual trends and patterns of species use and provides some comparison of species response to structure types. This baseline information is considered necessary for evaluating structure function and factors that encourage species passage (Clevenger et al., 2002). The key task in monitoring crossing structures is determining the rate of crossings made by species over time (Ford et al., 2010). Wildlife usage data is obtained from track recordings made at 2 metre wide track pads consisting of a 3-4 cm deep mix of sand, silt, and clay (Clevenger et al., 2002; Ford et al., 2010; Parks Canada, 2012d). The pads have been visited every three to four days with researchers recording the species, direction of movement, number of individuals, and evidence of human activity during each visit (Clevenger & Waltho, 2000; Ford et al., 2010). Additionally, 10,000 DNA bear hair samples were collected between 2005 and 2009 (Ford et al., 2010). More recent monitoring has been supplemented by motion-sensitive cameras which provide information on elements including time of passage and animal behaviour in addition to being more reliable, cost-effective, and less invasive than tracking alone (Clevenger et al., 2009; Ford et al., 2010).

In interpreting data, the observation of wildlife passage counts and comparison between species should be considered alongside population size to more accurately judge how a crossing structure performs among species. The Banff study cautions against interpreting a low number of passages as wildlife avoidance and high numbers as preference of crossing structures, as wildlife populations and habitat quality differ in their distributions where structures are located (Parks Canada, 2012g).

Image 5.4: Banff wildlife monitoring images. Top to bottom: Grizzly sow and cubs on Redearth overpass; Wolf pup in Pilot underpass; Deer at Redearth Creek underpass. Credit: Anthony Clevenger, WTI/Parks Canada.
Source: Parks Canada, 2011.

Results of monitoring between 1996 and 2003 show that elk were most frequently detected, then deer, wolves, sheep, and coyotes. Phase I and II underpasses were used by wolves 2986 times, by cougars 587 times, by black bears 526 times, and by grizzly bears 36 times for a total of 37,507 passes by all species (Clevenger, 2003; Parks Canada, 2012h). Phase IIIA structures showed a total of 11,175 passes by all species with evidence of a steady increase in passage by carnivores, pointing towards a period of wildlife adaptation after structure construction (Clevenger, 2003; Parks Canada, 2012h).

The time of day of wildlife usage generally matched species activity patterns. A tentative comparison of species preference for structure type determined that grizzly bears, wolves, and ungulates preferred overpasses, cougars preferred underpasses, and black bear showed no preference (Parks Canada, 2012h). Wildlife responded differently to crossing structure features; while carnivores preferred structures close to riparian drainage areas, ungulates avoided them. Phase IIIA monitoring was completed without animals having much time to adapt to structures as in earlier phases and found contrary results to an earlier study by Clevenger and Waltho (2000). While Phase I and II monitoring showed that crossing structure dimensions have little effect on species usage probably because animals had adapted to their use, Phase IIIA gave evidence that passage by grizzly bears, wolves, elk, and deer tended towards structures that were high, wide, and short in length while black bears and cougars favoured more constricted spaces. These observations matched species behaviours and life history traits of preferences towards more open areas versus those with cover (Clevenger et al., 2002; Clevenger & Waltho, 2005; Parks Canada, 2012l).

The project aims to present its monitoring and research findings as widely as possible in international and peer-reviewed journals, books, and conferences and provide training courses and student research support towards the provision of a greater professional understanding and knowledge base around wildlife crossings and road ecology (Ford et al., 2010).

Project Outcomes

As of 2009, data on 600 roadkill locations had been collected (Parks Canada, 2009d). Wildlife-vehicle collisions have declined by 80% for all large mammals and by more than 95% for ungulates (Parks Canada, 2009a). Since 1996, more than 200,000 crossings by 11 species of large mammals have been monitored (Parks Canada, 2012e).

Year-round monitoring has enabled thorough examination of the efficacy of the Banff crossing structures. Clevenger et al. (2002) assert that the Banff wildlife crossings are maintaining landscape connectivity and genetic interchange for the study's focal species, as species passage frequencies have been found to reflect species abundance and distribution. There has been no awareness of any species consistently avoiding structure use. Importantly, wildlife passage has been observed during critical seasons of breeding and migration (Clevenger et al., 2002).

Additional research is required to further establish species usage patterns and test study methodologies. Future studies will seek to determine the number and proportion of passage by radio-marked individuals and determine whether mitigation contributes to the maintenance of viable wildlife populations. Lastly, research on more cost-effective wildlife crossing design is suggested, with attention to ecological and technical requirements including construction methods and time and estimated costs and maintenance. There is a need for rigorous testing of established mitigation practices and for research, development, and testing of innovative measures to advance progress in mitigation practice (Clevenger et al., 2002).

Lessons Learned

Though not comprehensive, the following presents some of the notable lessons learned for wildlife crossing mitigation through the Banff study.

Owing to the evolving data between phases over the length of the monitoring program, the Banff study monitoring results inform the adaptive management of mitigation design and streamline planning processes for wildlife crossings (Ford et al., 2010). Phase IIIB planning and design has been based on GIS movement models and the monitoring results of previous phases which show the importance of tracking species behaviour changes in crossing structure usage over time and space, with the consideration of multiple species responses. The study asserts that continuous long-term monitoring is needed to determine the efficacy of design characteristics for multiple species and to allow species to adapt to crossing structures (Clevenger et al., 2002).

In addition to establishing extensive data on wildlife crossing usage by large mammals, the Banff study also found that drainage culverts can facilitate safe passage for small- to medium-sized animals and are most effective at frequent intervals (Clevenger et al., 2002). Importantly, to maximize connectivity for multiple species across transportation corridors, projects should include a diversity of crossing structure types and sizes. Mitigation should also include the management of human use activities around crossing structures and the broader landscape, as human activity at or adjacent to crossing structures was an important negative factor affecting wildlife use, primarily in carnivores (Clevenger & Waltho, 2005; Ford et al., 2010; Parks Canada, 2012l). This may be facilitated through increased public education and outreach through the distribution of information materials at tourism centres along highways or park visitor centres and entrances. Signage and interpretive exhibition materials may be located at crossing structures, especially overpasses, to maximize the visibility of mitigation efforts and infrastructure and increase driver awareness (Clevenger et al., 2002).

5.3 DISCUSSION OF FINDINGS

By examining case study information using the content analysis categories and thematic criteria derived from this report's literature review, it is possible to draw cross-case conclusions that suggest best practices common to the I-75 and Banff projects.

It is evident that planning for the location of wildlife crossings along a transportation corridor is not an arbitrary practice. In both the I-75 and Banff projects, needs assessment tools were employed to determine where wildlife movement was being impeded and where it would be best facilitated. The consideration of impediments drew in part from roadkill data that suggested a consistent pattern of road mortality at locations where wildlife made crossing attempts. The consideration of optimal crossing points was informed by analyses of habitat linkages and animal movement data that provided insight to which habitat animals were using and which were of highest habitat quality to best meet wildlife requirements.

In both projects, wildlife crossings were used to restore linkages between fragmented habitats to facilitate connectivity within a wider landscape corridor or series of protected areas for wider wildlife movement. Ensuring that wildlife crossings link habitats to fulfill the biological needs of species, rather than leading nowhere, is critical to the maintenance of population viability - a common objective of wildlife crossing projects. To this end, adjacent land management is necessary in order to maximize the efficacy of wildlife crossings beyond the mitigated right-of-way, including the limitation of human disturbance in or adjacent to structures to prevent wildlife use deterrence. If not already in public ownership, adjacent corridor management related to both projects discussed the use of incentives or compensation for private landowners and local governments in acquiring land for conservation purposes.

Though initially designed for focal species, the consideration of wildlife crossing use by multiple species was eventually recommended in the I-75 project and integrated into mitigation planning in the Banff project's subsequent phases, based on adaptive management processes. As such, wildlife crossing design guidelines and post-construction evaluation should consider effects on and use by multiple species in order to maximize crossing structure efficacy and the significant financial investment necessary for project implementation. Though monitoring studies of the I-75 underpasses showed use by multiple species beyond the Florida panther focal species, it is through monitoring of the Banff project's diversity of structures that differences in wildlife use of crossing structures are made apparent. As such, wildlife use preferences should be considered in selecting wildlife crossing designs that are best suited to the needs of local focal species but also feature elements that encourage use by multiple species.

Both projects emphasized the importance of mitigation design that combined wildlife crossing structures with continuous fencing to provide the most comprehensive design solution addressing project goals of landscape connectivity *and* the reduction of wildlife road mortality. Fencing inspection and repair were considered paramount to ensure crossing structures were being used and wildlife were being kept off the roadway.

Importantly, the use of fencing as an absolute barrier to roadway access was recommended in the I-75 project and implemented in the Banff project in combination with contingency features such as one-way swing gates to address the situation of wildlife becoming trapped between fencing in the right-of-way.

The successful implementation and maintenance of both projects benefited from projects champions (whether an individual or an organization), explicit roles and responsibilities for agencies and players involved, and public support campaigns or initiatives. Continued project support by the public and relevant agencies can enable project improvements and continued monitoring. To this end, education efforts and the dissemination of information derived from monitoring data can relay wildlife crossing structure use success and species status updates back to the public and funding agencies. Information dissemination can help to sustain interest in the project, influence the development of similar projects elsewhere, and justify the use of public funds for wildlife mitigation. Drive-through-awareness efforts in Banff and Florida seem to be particularly effective methods through which to raise awareness and communicate the location, function, and efficacy of crossing structures.

The implementation of wildlife mitigation in Banff also benefits from the integration of mitigation planning in the *Banff National Park Plan*, which delineates construction priorities in geographic areas of the Park and support of monitoring activities and the dissemination of findings. As such, wildlife crossings are made a mandatory consideration as legitimate practices for mitigating the impacts of transportation corridors within the Park and their management is made a priority with specific timelines. Parallels can be drawn between the BNP Plan and Ontario’s natural heritage policies, the implementation manual for which suggests the use of wildlife crossings for road mitigation. The direction for implementing wildlife crossings may be communicated more strongly if integrated into the individual plan and policy documents for the Greenbelt, Niagara Escarpment, and Oak Ridges Moraine planning areas.

Finally, adaptive management comes across as an effective and necessary management approach to wildlife crossing project success and long-term efficacy. It provides for management flexibility to address habitat and climate changes and allows for tactical improvements to wildlife crossing functionality and impediments to wildlife use. Adaptive management can also help to inform future projects and provide the highest return on investment by managing mitigation for maximal species use.

The cessation of monitoring after two years of post-construction evaluation is a common practice in many mitigation projects (Clevenger et al., 2002). However, the Banff project gives clear justification for continued, long-term monitoring in order to illuminate the emergence of changing wildlife usage patterns and preferences as wildlife adapt to crossing structures. Adaptive management as facilitated by long-term monitoring also provides for more comprehensive, cumulative data on wildlife crossing rates, giving a more accurate picture of mitigation efficacy and the fulfillment of project goals. To this end, the development of criteria is important to determine desired project outcomes, guide data collection, manage crossing structures, and evaluate project success.

While already an established practice in the Banff project, adaptive management is recommended by Jansen et al. (2010) for the I-75 project, especially useful for replicating wildlife mitigation on adjacent roads. The use of photography and video images are purported in both projects as the most effective monitoring methods through which to determine wildlife crossings rates and wildlife behaviour and as tools for disseminating information and building public interest by providing visual evidence of wildlife use.

6.0 CONCLUSION & RECOMMENDATIONS

The problem of habitat fragmentation is one that requires implementable strategies in the short-term that can function and improve landscape connectivity for the long-term. Pressures on the natural environment including human development, the connection of developed areas and populations, and the efficient movement of people and goods are increasing. In some cases, these needs may be in direct competition with the conservation of wildlife habitats and populations. As such, the effects of habitat fragmentation require immediate mitigation measures to maintain or restore the connectivity and viability of natural heritage to conserve the ecological integrity of changing landscapes. Wildlife crossings may potentially act as constructed corridors to provide habitat linkages where transportation development and related land use activities have severed them.

In Ontario, such conservation priorities are integrated into the management of natural heritage systems. They are explicitly supported through provincial policy provisions and plans that seek to protect a series of interconnected natural areas for the connectivity of landscapes, habitats, and wildlife populations, among other ecological functions. The linkage function of wildlife crossings supports the intent of provincial natural heritage policies; the structures are also expressly considered as viable mitigation measures for restoring connectivity in NHSs in the *Natural Heritage Reference Manual* (MNR, 2010). As such, provincial direction and public agency support by MNR enables the integration of wildlife crossings into transportation planning in Ontario. This may be aided by even stronger policy language towards long-term protection of NHSs and explicit directions for incorporating wildlife crossings in specific areas identified as requiring mitigation in the Greenbelt, Niagara Escarpment, and Oak Ridges Moraine plans.

NHSs are good candidates for the implementation of wildlife crossings because they are already established corridors with supportive policies for connectivity in place. However, challenges to maintaining connectivity are widespread. As of 1995, 88% of roads in the Niagara Escarpment planning area lay within natural, protected, and rural land use areas while the Oak Ridges Moraine planning area is facing significant population increases and development pressures (Fenech, Taylor, Hansell & Whitelaw, 1995). Moreover, significant forthcoming regional highway developments and expansions are threatening to encroach into the Niagara Escarpment and Greenbelt. The current planning and assessment of development alternatives for the Niagara to GTA and GTA-West transportation corridors provides the opportunity to integrate conservation needs, the use of wildlife crossings, and a long-term vision for landscape connectivity in support of the continued viability of NHSs.

The following recommendations are based upon an extensive literature review and information derived from two case studies representing international best practices in wildlife mitigation. They represent lessons for the integration of wildlife crossings in planning for Ontario's natural heritage systems.

① **Conservation needs and the restoration or maintenance of connectivity in NHSs should be incorporated early in the planning process and integrated into transportation corridor designs.**

Regional or provincial planning must first consider environmental planning and the preservation of existing connectivity between landscapes. Root causes of fragmentation should be addressed, including socio-economic processes of population growth, land use and infrastructure development, and potential environmental conflicts (Anderson & Jenkins, 2006). Importantly, planning decisions should consider cumulative effects of development on natural heritage areas, features, and systems, especially that of transportation corridors on wildlife and landscape connectivity including the provision of access to once remote, undisturbed areas (Beckmann & Hilty, 2010; Forman et al., 2003).

Lister (2012) suggests that transportation planning should consider a network of wildlife crossings along all key migration corridors, towards a continental vision for connectivity. The Ontario Road Ecology Group (2010) also supports the idea of big-picture planning in Ontario based on a unified connectivity vision, reflective of the intent of provincial policies for NHSs. The consideration of a regional or provincial network of wildlife crossings and connected corridors is particularly relevant considering the current planned development and expansion of Ontario highways. Planning for future highways should first avoid comprising the ecological integrity of existing NHSs and linkages before incorporating reactive mitigation measures to remedy landscape severances.

The 2007 Ontario Roads and Ecopassages Forum resulted in the compilation of a series of goals towards the ecologically sound design and planning of road networks and their mitigation by wildlife crossings (Toronto Zoo, 2007a). A dialogue between road ecologists, biologists, urban planners, and road engineers resulted in the compilation of a series of goals. Notably, participants suggested that all road projects be considered as opportunities for ecological restoration or improvement, that mitigation structures be included early in the design process, and that natural heritage criteria are needed in the planning process for roads (Toronto Zoo, 2007b&c). These goals clearly identify the opportunity to incorporate conservation concerns in to the transportation planning process, in order to prevent impacts or address the negative effects of roads on wildlife and landscape fragmentation using wildlife mitigation in transportation design. To this end, forum participants identified a suite of existing tools available in Ontario, including the PPS, the *Natural Heritage Reference Manual*, municipal official plans, natural heritage system mapping by

MNR and Conservation Authorities, transportation master plans, and endangered species legislation. As such, practitioners and decision-makers in Ontario are in a good position to make ecologically sound transportation planning decisions that fully consider wildlife mitigation for sustained landscape connectivity and wildlife population viability.

Collaboration between public agencies, as in the cooperation between MTO and MNR in the planning of the Highway 69 animal overpass, is integral for the integration of conservation concerns in related planning processes and the success of wildlife mitigation projects. In the 2007/08 Annual Report to the Legislature, the Environmental Commissioner of Ontario (ECO) suggests that public agencies should be ultimately responsible for ensuring conservation concerns be considered during the road planning process and that mapping and other conservation resources are available and up-to-date (ECO, 2008). The ECO ultimately recommends that MTO and MNR collaborate early in the transportation planning process to identify where mitigation is required and to monitor existing wildlife crossings and wildlife-vehicle collisions in a more centralized manner than is currently practiced (ECO, 2008).

② **Wildlife crossing design and mitigation guidelines should be developed with sensitivity and specificity to the habitat and landscape features in Ontario's NHSs and the consideration of multiple species needs.**

Design guidelines should incorporate best practices from international case studies including: crossing structure placement at locations adjacent to high habitat quality and linkage to a wider landscape corridor; limiting human disturbance; structure design and maintenance of vegetation for unobstructed views for wildlife; and incorporating a diversity of structures to encourage multiple species use. As learned from the I-75 and Banff projects, the installation of crossing structures should always be combined with continuous fencing on both sides of a mitigated roadway in order to guide wildlife to structures and protect public safety by preventing wildlife from entering the roadway and suffering road mortality. Contingency provisions should be included in fencing design to allow wildlife to escape, should they be caught between fencing.

Guidelines should be specific to Ontario landscapes and wildlife identified for targeted mitigation. They should be regularly updated to reflect advancements in wildlife crossing design, including cost-effective materials, construction, and maintenance and the development of flexible or modular designs that can be adapted to respond to changing conditions (Lister, 2012).

③ **All wildlife mitigation projects should feature an adaptive management approach supported by long-term monitoring activities to ensure accurate post-construction evaluation of mitigation efficacy.**

Funding should be allocated for monitoring activities at the outset of a wildlife crossing project to ensure post-construction evaluation of mitigation efficacy and the collection of data to inform adaptive management decisions. Project goals and monitoring criteria should be developed to assess mitigation success and should ideally consider wildlife crossing rates, roadkill reduction, and the maintenance of habitat connectivity alongside biological species requirements including seasonal movements, dispersal, genetic interchange, and recolonization. Monitoring activities should be sustained for the long-term to allow species to adapt to crossing structures and provide more accurate usage data. An adaptive management approach informs knowledge gaps and best practices for other projects, allows for the assessment of mitigation improvement opportunities and management responses to changing ecological conditions, and ultimately ensures that public expenditures are being put to good use.

④ **Information dissemination, public education initiatives, and efforts towards public support building should be prioritized and continued after project construction.**

Lastly, efforts should be made to build public support for wildlife mitigation projects prior to and following implementation in Ontario. Public education initiatives targeted at increasing awareness of road impacts on habitat fragmentation, wildlife-vehicle collisions, and wildlife population viability are useful in building project support, aiding fundraising activities, and creating political will for project implementation by MNR or MTO. The dissemination of post-construction monitoring data helps to sustain project interest and funding by communicating successes. Communication strategies may target driver behaviour on Ontario roads, and may include the distribution of informational pamphlets at Ontario Highway Service Centres (ONroutes), Ontario Travel Information Centres, and park entrances, installation of interpretive displays at wildlife crossings, and provision of warning signs and systems. The wider dissemination of project data in academic journals, media, and via the internet will help to increase awareness of emerging road ecology principles, the importance of connectivity in NHSs, and the efficacy of wildlife crossings in mitigating the impacts of roads on our natural heritage.

The Role of Planning in Wildlife Mitigation

This research examined the contribution of key processes and players in the design, implementation, and monitoring of wildlife crossings, which include the roles of various branches of government, planners, engineers, ecologists, environmental stewardship organizations, and community members. A literature review outlined the translation of theoretical knowledge into practical mitigation practices related to the concept of corridors, the scholarly debate surrounding their efficacy in restoring habitat linkages between severed landscapes, and their relationship to wildlife crossings. Case studies consolidated extensive project reports into a streamlined structure which outlined design considerations, implementation processes and challenges including engaging effective partnerships, and the components of successful monitoring programs. As such, this report highlights successful strategies used in real-world projects requiring multi-disciplinary collaboration which can be used by planners and other professionals in order to maximize the success of future wildlife crossing projects. This information may be useful for the proactive consideration of wildlife crossings at initial stages of transportation planning and infrastructure design or retrofit.

Planners can advocate for the integration of conservation needs early in the transportation planning process (Bissonnette & Cramer, 2008). In their capacity as experts on land management and development, planners can emphasize the need for investment in wildlife mitigation infrastructure and related improvements for public safety (Lister, 2012). To implement wildlife crossing projects that address local landscape-level needs, planners can facilitate the development of needs assessment protocols or conduct assessments to delineate needs for road mortality reduction and landscape connectivity using a variety of tools, including GIS-based modelling and habitat connectivity analyses. Furthermore, planners can conduct research on design guidelines, cost-effective mitigation techniques, and best practices like those of the I-75 and Banff projects. This should include the consideration of existing infrastructure retrofits for wildlife needs and the availability of new crossing structure technologies to provide cost-effective solutions justifying the investment of public funds. Lastly, while the integration of wildlife mitigation in the transportation planning process requires significant interagency and interdisciplinary cooperation, planners can coordinate adaptive management processes and multi-disciplinary project teams to help streamline planning processes and inform decision-making on mitigation improvements or the replication of projects in other areas. In Ontario, planners have the capacity, tools, and policies in place with which to prioritize the connectivity of natural heritage systems at the forefront of transportation planning processes and designs, towards a province-wide corridor system and leadership in wildlife mitigation.

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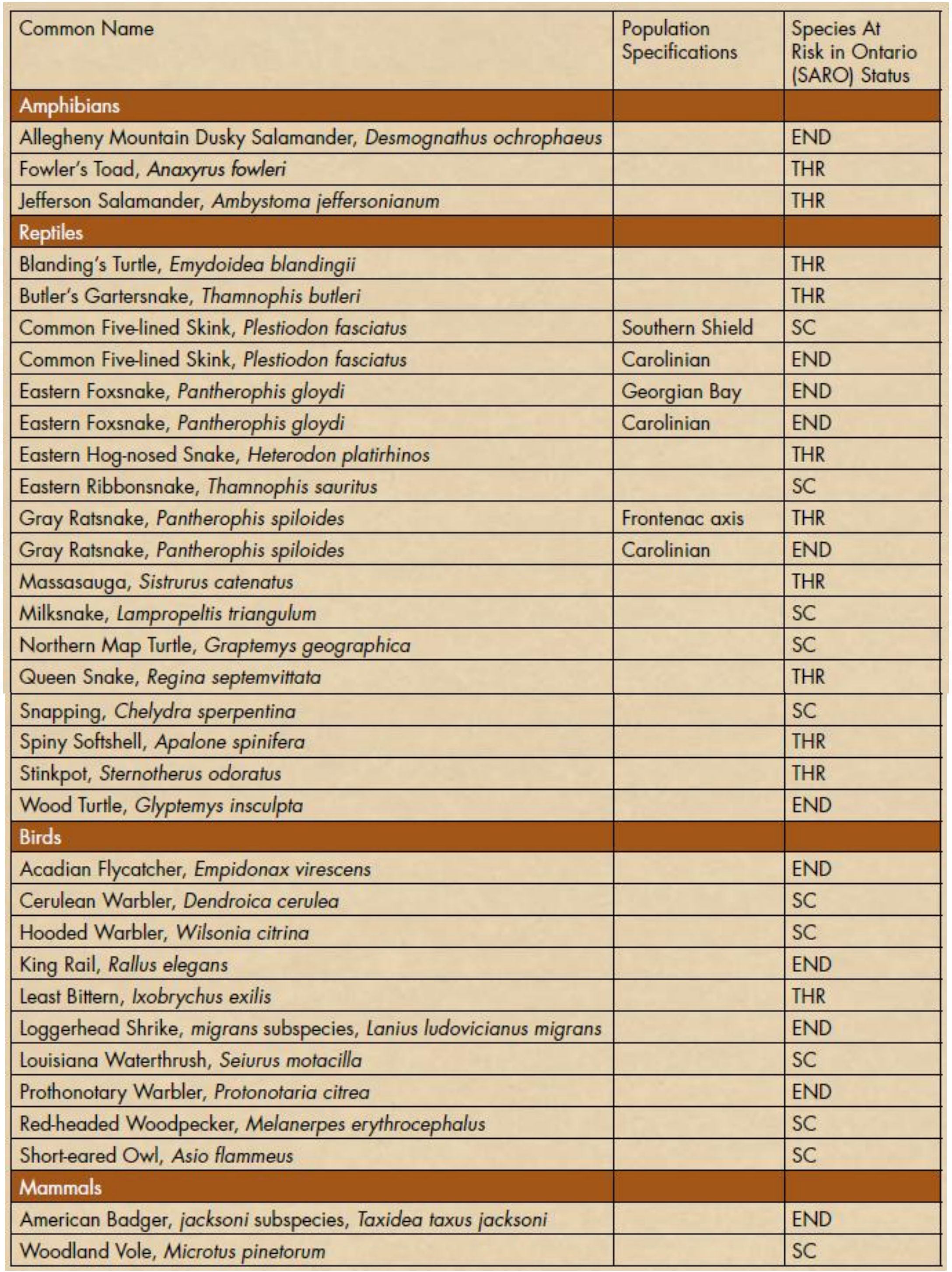
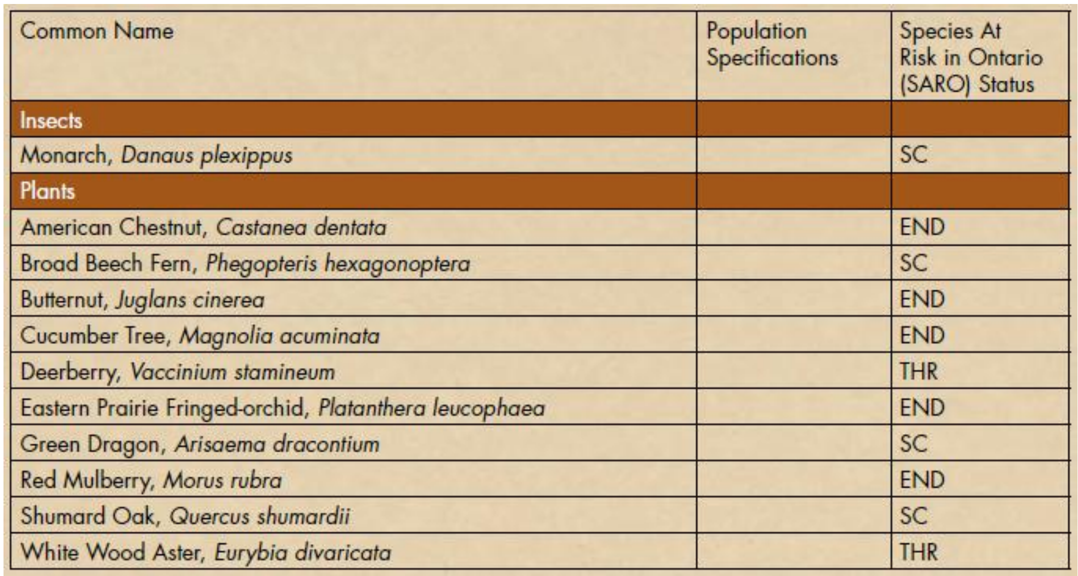
APPENDIX

1.0 ONTARIO SPECIES AT RISK THREATENED BY ROADS

*SARO Status: Extirpated (EXP); Endangered (END); Threatened (THR); Special Concern (SC)
(Source: OREG, 2010)



Common Name	Population Specifications	Species At Risk in Ontario (SARO) Status
Amphibians		
Allegheny Mountain Dusky Salamander, *Desmognathus ochrophaeus*		END
Fowler's Toad, *Anaxyrus fowleri*		THR
Jefferson Salamander, *Ambystoma jeffersonianum*		THR
Reptiles		
Blanding's Turtle, *Emydoidea blandingii*		THR
Butler's Gartersnake, *Thamnophis butleri*		THR
Common Five-lined Skink, *Plestiodon fasciatus*	Southern Shield	SC
Common Five-lined Skink, *Plestiodon fasciatus*	Carolinian	END
Eastern Foxsnake, *Pantherophis gloydi*	Georgian Bay	END
Eastern Foxsnake, *Pantherophis gloydi*	Carolinian	END
Eastern Hog-nosed Snake, *Heterodon platirhinos*		THR
Eastern Ribbonsnake, *Thamnophis sauritus*		SC
Gray Ratsnake, *Pantherophis spiloides*	Frontenac axis	THR
Gray Ratsnake, *Pantherophis spiloides*	Carolinian	END
Massasauga, *Sistrurus catenatus*		THR
Milksnake, *Lampropeltis triangulum*		SC
Northern Map Turtle, *Graptemys geographica*		SC
Queen Snake, *Regina septemvittata*		THR
Snapping, *Chelydra sperpentina*		SC
Spiny Softshell, *Apalone spinifera*		THR
Stinkpot, *Sternotherus odoratus*		THR
Wood Turtle, *Glyptemys insculpta*		END
Birds		
Acadian Flycatcher, *Empidonax virescens*		END
Cerulean Warbler, *Dendroica cerulea*		SC
Hooded Warbler, *Wilsonia citrina*		SC
King Rail, *Rallus elegans*		END
Least Bittern, *Ixobrychus exilis*		THR
Loggerhead Shrike, *migrans* subspecies, *Lanius ludovicianus migrans*		END
Louisiana Waterthrush, *Seiurus motacilla*		SC
Prothonotary Warbler, *Protonotaria citrea*		END
Red-headed Woodpecker, *Melanerpes erythrocephalus*		SC
Short-eared Owl, *Asio flammeus*		SC
Mammals		
American Badger, *jacksoni* subspecies, *Taxidea taxus jacksoni*		END
Woodland Vole, *Microtus pinetorum*		SC



Common Name	Population Specifications	Species At Risk in Ontario (SARO) Status
Insects		
Monarch, *Danaus plexippus*		SC
Plants		
American Chestnut, *Castanea dentata*		END
Broad Beech Fern, *Phegopteris hexagonoptera*		SC
Butternut, *Juglans cinerea*		END
Cucumber Tree, *Magnolia acuminata*		END
Deerberry, *Vaccinium stamineum*		THR
Eastern Prairie Fringed-orchid, *Platanthera leucophaea*		END
Green Dragon, *Arisaema dracontium*		SC
Red Mulberry, *Morus rubra*		END
Shumard Oak, *Quercus shumardii*		SC
White Wood Aster, *Eurybia divaricata*		THR

2.0 CONTENT ANALYSIS CATEGORIES & THEMATIC CRITERIA MATRIX

CONTENT ANALYSIS CATEGORIES & THEMATIC CRITERIA		
Category: WILDLIFE CROSSING DESIGN		
Theme	**Source**	**Data Source**
Design Objectives/Goals	Anderson & Jenkins (2006); Beckmann et al. (2010); Clevenger & Huijser (2009); Forman et al. (2003); Noss (2003); Ruediger & DiGiorgio (2007)	Content analysis of case study documents
Type & Design Specifications	Beckmann et al. (2010); Clevenger & Huijser (2009); Forman et al. (2003); O'Brien (2006); Ruediger & DiGiorgio (2007)	Content analysis of case study documents
Focal Species	Anderson & Jenkins (2006);Beckmann et al. (2010); Clevenger & Huijser (2009); Forman et al. (2003); Noss (2003); Ruediger & DiGiorgio (2007)	Content analysis of case study documents
Site Selection/Placement	Beckmann et al. (2010); Clevenger & Huijser (2009); Forman et al. (2003); O'Brien (2006); Ruediger & DiGiorgio (2007)	Content analysis of case study documents
Number of Crossings	Beckmann et al. (2010); Forman et al. (2003); O'Brien (2006); Ruediger & DiGiorgio (2007)	Content analysis of case study documents
Approaches	Beckmann et al. (2010); Clevenger & Huijser (2009); Forman et al. (2003); O'Brien (2006); Ruediger & DiGiorgio (2007)	Content analysis of case study documents
Habitat Features/Quality	Beckmann et al. (2010); Clevenger & Huijser (2009); Forman et al. (2003); O'Brien (2006); Ruediger & DiGiorgio (2007)	Content analysis of case study documents
Landscape Context/Connections	Noss & Harris (1986)	Content analysis of case study documents
Category: IMPLEMENTATION PROCESS		
Theme	**Source**	**Data Source**
Organizations/Institutions/Experts/ Partnerships Involved	Beckmann et al. (2010); Noss (2003); Ruediger & DiGiorgio (2007)	Content analysis of case study documents
Guiding Plans & Policies	Anderson & Jenkins (2006); Beckmann et al. (2010); Noss (2003); Ruediger & DiGiorgio (2007)	Content analysis of case study documents
Project Finance	Anderson & Jenkins (2006)	Content analysis of case study documents
Adjacent Land Management	Beckmann et al. (2010)	Content analysis of case study documents
Incentives	Anderson & Jenkins (2006)	Content analysis of case study documents
Obstacles	Anderson & Jenkins (2006)	Content analysis of case study

		documents
Stakeholder Engagement	Anderson & Jenkins (2006); Beckmann et al. (2010); Noss (2003); Whitelaw & Pollock (2005)	Content analysis of case study documents
Support Building	Anderson & Jenkins (2006)	Content analysis of case study documents
Role of Planners	Beckmann et al. (2010)	Content analysis of case study documents

Category: MONITORING PROGRAM STRUCTURE

Theme	Source	Data Source
Monitoring Body	Forman et al. (2010)	Content analysis of case study documents
Study Design	Clevenger & Huijser (2009)	Content analysis of case study documents
Length of Program	Clevenger & Waltho (2000); Grilo et al. (2008); Yanes et al. (1995)	Content analysis of case study documents
Frequency	Clevenger & Waltho (2000); Grilo et al. (2008); Yanes et al. (1995)	Content analysis of case study documents
Methods/Tools/Protocols	Clevenger & Huijser (2009); Clevenger & Waltho (2000); Ford et al. (2009); Grilo et al. (2008); Noss (2003); Yanes et al. (1995)	Content analysis of case study documents
Indicators/Measures of Success	Beckmann et al. (2010); Clevenger & Huijser (2009)	Content analysis of case study documents
Data Usage	Clevenger & Waltho (2000); Grilo et al. (2008); Yanes et al. (1995)	Content analysis of case study documents
Information Dissemination	Paige & Darling (2009); Noss (2003); Wieler (2007)	Content analysis of case study documents
Adaptive Management	Beckmann et al. (2010); Kintsch (2008); Lynch et al. (2008); Morghan et al. (2006); Noss (2003)	Content analysis of case study documents
Efficacy	Forman et al. (2003)	Content analysis of case study documents
Additional Research Required	Forman et al. (2003); Noss (2003)	Content analysis of case study documents