The Right to Roam:
A Strategy to Reconnect a Continental Wildlife Pathway in the Frontenac Arch

June 19, 2023

Proposed location for a wildlife overpass on Highway 401 near Escott-Rockport Road, Mallorytown (taken by R. Danby)

Contributors

This report was prepared by the following authors on behalf of the Algonquin to Adirondacks Collaborative (A2A):

Katherine Black, Senior Ecologist, Blazing Star Environmental
Ryan Danby, Associate Professor, Queen's University; Advisor, A2A Road Ecology Committee
Ori (John) Urquhart, Principal, Blazing Star Environmental; Advisor, A2A Road Ecology Committee

Acknowledgements

Funding for the preparation of this report was provided by Parks Canada. The report is a project of the A2A Road Ecology Committee whose members provided invaluable feedback on numerous versions of this report, including Cameron Smith (A2A), Sheldon Lambert (Thousand Islands National Park), Mandy Karch (Ontario Road Ecology Committee), and Josh van Wieren (Thousand Islands National Park). Cayla Darling (Blazing Star Environmental) and Ryan Danby created maps for the report. Amy Hall (Carolinian Canada Coalition) conducted a literature review and drafted a template for this report while she was at Blazing Star Environmental. Mandy Karch led the preparation of an initial report for Highway 401 that was presented to the Ontario Ministry of Transportation; that report was integral to the present study. Mary Beth Lynch and Michael Gemmell of Thousand Islands National Park kindly reviewed an early draft. Trevor Kinley (Parks Canada) provided detailed comments related to the proposed mitigation strategy, including construction feasibility and engineering considerations. David McConnachie (A2A) provided feedback on communications aspects of the report. A2A would like to thank those that assisted with data collection and reporting for supporting studies conducted on Highway 401, County Road 2, and the Thousand Islands Parkway, including Ryan Danby, Ori Urquhart, Mandy Karch, Evelyn Garrah, Clayton Shearer, Rory Tanner, Fred Scheuler, Joshua Jones, and Ewen Eberhardt.

Table of Contents

Table of Figures

List of Tables

Abbreviations

A2A – Algonquin to Adirondacks Collaborative
NHS – Natural Heritage System
MTO – Ontario Ministry of Transportation
OHN - Ontario Hydrological Network
OMNRF – Ontario Ministry of Natural Resources and Forestry
ORN - Ontario Road Network
SWWV – Sustaining What We Value
TINP – Thousand Islands National Park
TIP – Thousand Islands Parkway
UNESCO – The United Nations Educational, Scientific, and Cultural Organization

Executive Summary

The Algonquin to Adirondacks (A2A) region has been identified as a priority habitat link in the Eastern Wildway, a north-south continental wildlife pathway that extends from the state of Georgia in the south to the boreal forest in the north (Wildlands Network, 2019; Figure 1). The A2A region is the least degraded north-south pathway east of Lake Superior and its narrowest point, known as the Frontenac Arch, provides an optimal location for wildlife to cross the St. Lawrence River. However, a warming climate may limit ice formation on the river in winter, potentially limiting routes of passage over this major waterbody to islands between Gananoque and Brockville. As a result, this region is at risk of becoming the only continental north-south link between the United States and Canada from the head of the Great Lakes to the Atlantic Ocean. It is therefore essential to maintain this landscape connection.

A significant challenge to maintaining landscape connectivity in the Frontenac Arch is the presence of three major roads on the Canadian side of the St. Lawrence River: Highway 401, the Thousand Islands Parkway, and County Road 2. These roads pose a substantial barrier to wildlife movement, are a major cause of wildlife mortality in this globally significant region, and with wildlife trying to cross these roads, pose a threat to vehicular traffic and to human safety. **A single survey of Highway 401 from Gananoque to just west of Brockville in June 2017 found more than 670 dead animals** (Urquhart et al., 2018). **This is a substantial underestimate of roadkill on this highway as it only represents animals that could be documented; many more go undetected, especially small animals.** Creating structures for wildlife to cross over and under these roads is an urgent national issue within Canada and has international implications. The A2A region is the pinch-point of the vitally important biological pathway that stretches almost the entire length of eastern North America and is critical in maintaining longer-term and broader scale landscape connectivity.

This report demonstrates the magnitude of this problem and presents a bold strategy to help restore ecosystem connectivity in this continentally important region. The mitigation strategy would simultaneously reduce significant wildlife mortality, contribute to the recovery of populations of species at risk, and increase motorist safety.

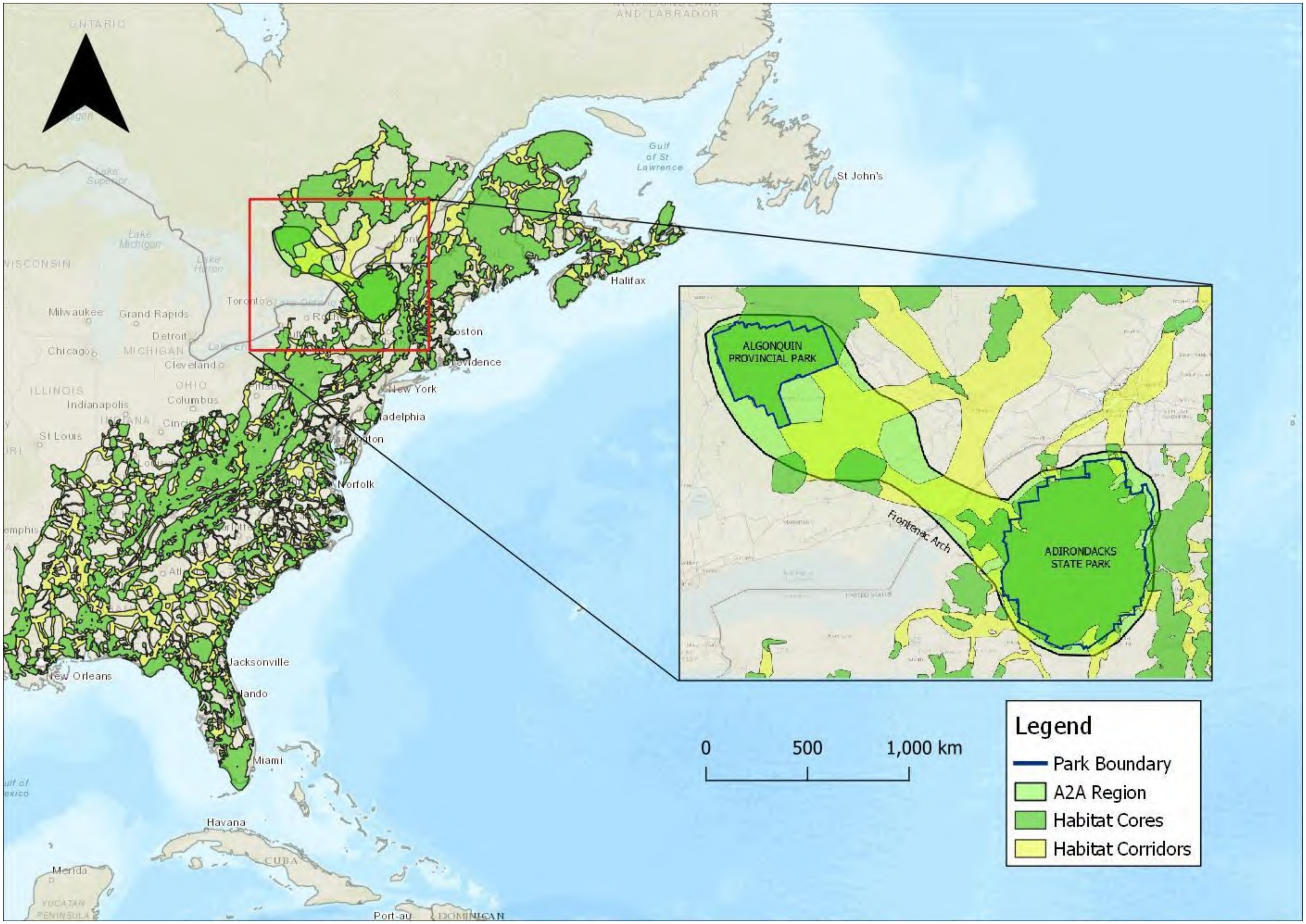


Figure 1: Map showing the A2A region within the Eastern Wildway.

This report is intended for road management agencies (e.g., Ontario Ministry of Transportation (MTO)) and key conservation partners to aid in the development and implementation of the recommended mitigation strategy. The strategy focuses on an area extending from Gananoque to the western edge of Brockville in Ontario, and from the Canada-United States border northwards past County Road 2. We identify priority areas for mitigation along Highway 401, the Thousand Islands Parkway, and County Road 2 within the Ontario portion of the Frontenac Arch that correspond with three wildlife pathways fragmented by the three roads. These pathways from west to east are 1) Landons Bay to Lansdowne, 2) Rockport to Waterton, and 3) along Jones Creek (Figure 2).

All three roadways captured in this report cause significant wildlife mortalities, but Highway 401 has the most traffic and presents the greatest barrier to wildlife movement. It is therefore prioritized for remediation. **We present a mitigation strategy that, if implemented, would facilitate safe movement of wildlife across this 50 km stretch of highway, dramatically reducing vehicular collisions with wildlife and significantly improving driver safety.** We propose that three wildlife overpasses be constructed along an approximately 10 km stretch of Highway 401 in association with the two western wildlife pathways (i.e., Landons Bay to Lansdowne and Rockport to Waterton; Figure 2). We also recommend replacing the existing culvert at the Jones Creek crossing at Highway 401 with a dedicated wildlife underpass. These infrastructure upgrades should be accompanied by the installation of appropriate wildlife fencing to ensure that animals are directed towards safe crossings. The proposed infrastructure improvements are the minimum required to help restore landscape connectivity and achieve a significant reduction in wildlife mortality. All three overpasses and the Jones Creek underpass are necessary to provide sufficient spatial opportunities for safe wildlife crossing of Highway 401.

In addition to the four major wildlife crossing structures, this report recommends smaller mitigation actions along Highway 401, the Thousand Islands Parkway, and County Road 2. These include replacing and retrofitting existing culverts in alignment with maintenance schedules and strategic placement of wildlife fencing. We also recommend more general mitigation measures that should be applied to infrastructure improvements for all three roadways, such as developing monitoring and maintenance plans, installing signage, and raising public awareness.

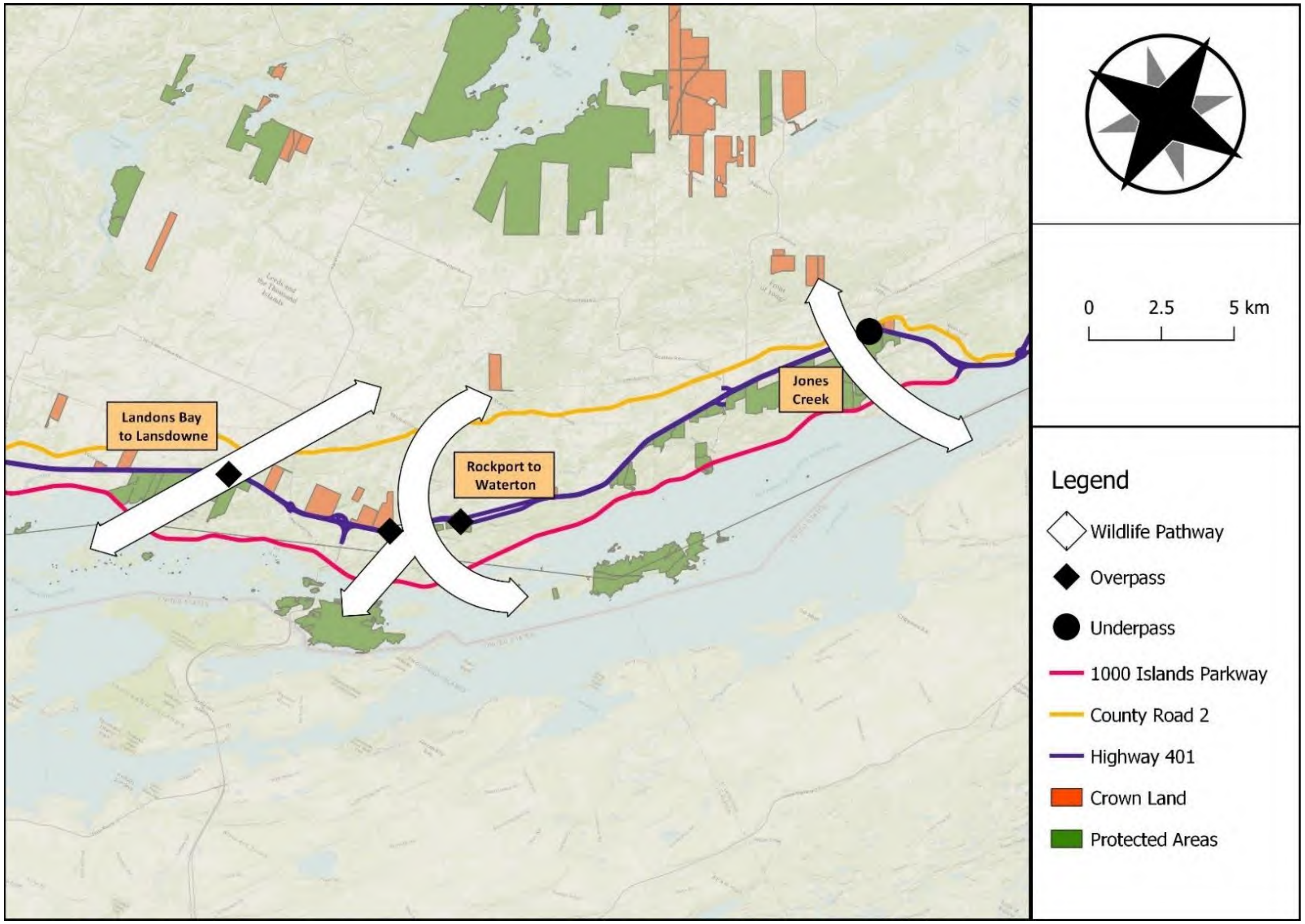


Figure 2: Map showing the three wildlife pathways[1] fragmented by Highway 401, the Thousand Islands Parkway, and County Road 2, and road areas proposed for major mitigation along Highway 401. See Figure 17 (p. 58) for a more detailed visual of the split in the Rockport-Waterton pathway.

[1] Coarse arrows in maps used to demarcate wildlife pathways throughout this report represent tracts of relatively continuous natural habitat, including connected wetlands, forests, watercourses, and riparian areas. Arrows do not reflect exact movement patterns or migratory routes of wildlife. Instead, they are analogous to links in chains of connected habitats among which animals may be linked via dispersal or genetics.

The rationale for the proposed mitigation strategy is based on:

- The location and severity of known wildlife road mortality hotspots based on data and knowledge gained from 11 studies conducted over the past 18 years (including seven years of primary research conducted on behalf of A2A) combined with additional field data and modelling.
- The location and configuration of identified wildlife movement pathways and habitat linkages per natural heritage mapping and modelling.
- The location of protected areas and areas that may be designated for protection so that infrastructure improvements are paired with land preservation.
- The ecology of numerous wildlife taxa in the region, their known movement patterns, and home range sizes. Animals with smaller home ranges and/or limited mobility need more closely spaced crossing structures.
- Topographic and water barriers to wildlife movement, including steep slopes and large wetland complexes. An example is the large wetland complex that forces a split in the Rockport-Waterton wildlife pathway shown on the preceding map (Figure 2) and on Figure 17 (p. 58).
- The proposed locations of overpasses on Highway 401 would connect movement pathways that are blocked by both roads and natural barriers.
- The location of rock cuts along Highway 401 to facilitate overpass construction.
- An increasing worldwide experience with wildlife-road crossing infrastructure and the scope and scale of mitigation projects that have been implemented in Canada.

The proposed mitigation strategy is quite feasible considering what has been accomplished along the Trans-Canada Highway in Banff and Yoho National Parks (i.e., 42 underpasses and seven overpasses along 88 km), the Right Honourable Herb Gray Parkway in Windsor (11 overpasses over 11 km), and Highway 69 in Central Ontario (one overpass, one underpass, and three reptile tunnels over 10 km).

The proposed infrastructure improvements represent a small step toward restoring connectivity relative to conditions before Highway 401 was built. We are proposing a few hundred metres of restored connectivity in an area that formerly had 50 km of connectivity. Regardless, implementing all the recommendations would result in massive benefits to Ontario’s biodiversity and beyond by substantially reducing road mortality, restoring movement pathways, supporting vulnerable species at risk, and enabling genetic diversity. Implementing the full suite of recommended actions would also reduce safety risks to drivers related to wildlife-vehicle collisions, along with associated economic costs to society.

Our recommendations are a tool for resiliency and climate change adaptation. Wildlife movement routes will certainly become more limited as land development increases, habitat loss accumulates, and species shift ranges and movement patterns in response to climate change. Wildlife in the region will continue to be funnelled to narrow, remaining tracts of habitat and barriers imposed by roads will be exacerbated. The planned widening of Highway 401 to six and eventually eight lanes in portions of the region will further reduce connectivity and increase wildlife mortality. Building wildlife crossings is essential for maintaining future ecosystem health, biodiversity, and climate change resiliency.

Statement of Limitations

This report provides mitigation recommendations for the three major roadways within each of the three priority wildlife pathways: the Landons Bay to Lansdowne route, the Rockport to Waterton route, and the Jones Creek route. This statement of limitations acknowledges important considerations associated with our recommendations.

We must recognize complete passage of wildlife with zero mortality cannot be achieved. However, with thoughtful mitigation, connectivity can be increased and wildlife mortality can be substantially reduced, particularly for the section of Highway 401 that crosses the Frontenac Arch.

The areas targeted for infrastructure reform within each of the wildlife pathways are partly based on identified wildlife mortality hotspots. We acknowledge that these areas may not capture previous hotspots where substantial road mortalities in the past have depressed populations. It is possible that road mortalities may be small in areas with the most significant historical impacts to populations (Eberhardt et al., 2013). To address this, our mitigation strategy also targets wildlife pathways with the best and most intact habitat, which should restore and reconnect populations that may have historically declined due to roadkill. By targeting both optimal habitat adjacent to roadways and identified mortality hotspots, the recommended infrastructure improvements should substantially reduce mortality that could cause further wildlife population declines and possible extirpations.

Recognizing the financial and construction challenges of major modifications to Highway 401, extensive consideration was given to choosing areas that are critical to achieve our goal of major road mortality reduction. The locations of proposed major infrastructure improvements align with protected lands or opportunities for land acquisition by conservation organizations and/or road agencies.

Lastly, this report does not provide a detailed review of the engineering feasibility associated with the recommended infrastructure improvements. However, it does incorporate feedback solicited from a road ecologist that works in highway engineering and is very familiar with constraints associated with designing and building wildlife crossing infrastructure (Trevor Kinley, Parks Canada). It also considers existing site features that may reduce construction challenges, such as upgrades to existing culverts, and areas with high rock cuts on both sides of Highway 401 that could support a wildlife overpass. Regardless, road managers and engineers will need to be consulted to advise on the technical aspects of proposed infrastructure changes. It will be especially important to consider future construction plans such as road widening projects (i.e., Highway 401 expansion) when designing the details of infrastructure improvements to ensure the continued function of mitigation measures.

1 Introduction

1.1 Landscape Connectivity and Biodiversity

Protected areas are critical for the conservation of biodiversity, but alone are inadequate, and managing them on an individual basis is insufficient (Lemieux et al., 2021). Instead, management based on the principles of landscape connectivity is now held as the most appropriate and effective approach to biodiversity conservation, especially in highly settled regions where natural areas are heavily fragmented and multiple landowners are involved (Lepczyk et al., 2017).

Connectivity is frequently defined as "the degree to which a landscape facilitates or impedes the movement" of wildlife and biodiversity (Taylor et al., 1996). Animal movement is often the focus of landscape connectivity, but it also facilitates other biological processes such as gene flow, dispersal, and migration. It can also augment important ecosystem services such as flood mitigation, erosion control, and carbon sequestration (OECD, 2019).

Connectivity includes both structural and functional components (Ament et al., 2014). Structural connectivity refers to the physical relationship among habitat elements. For instance, a landscape where forest patches are linked together by riparian pathways and hedgerows will have higher structural connectivity than a landscape where the patches are separated from each other. Functional connectivity describes the degree to which landscapes facilitate or impede the movement of organisms and processes. For instance, a landscape where animals move among populations to interbreed has higher functional connectivity than a landscape where animals are isolated from each other.

Adequate connectivity within or among ecosystems is necessary to support healthy, resilient areas that are rich in biodiversity. Processes such as dispersal and gene flow are critical for ecosystem resilience, especially in the face of climate change (Alberti et al., 2020). Connectivity occurs at multiple scales; from a wetland complex fragmented by a road to migration routes that span across continents. Both small- and large-scale habitat connections provide crucial links for species and ecosystem survivability (Clevenger, 2012).

There are two basic approaches for increasing ecosystem connectivity: (1) focus on conserving or increasing areas that facilitate movement, and (2) mitigate the impact of landscape features that impede movement (Ament et al., 2014). The most effective results are achieved when both strategies are implemented together. This combined approach is the strategy embraced by the Algonquin to Adirondacks (A2A) Collaborative, an international, multi-partner, and multidisciplinary organization aimed at protecting and enhancing the ecological integrity of the A2A region (Figure 1). The A2A region contains the best and the most intact remaining habitat for biodiversity movement across the Great Lakes-St. Lawrence system (Miller & Bell, 2021). In this report we focus on areas that facilitate movement across the narrowest part of the Frontenac Arch, a significant ecological pathway within the A2A region (Figure 1), and propose mitigation to existing landscape features to improve wildlife movement and connectivity at the local and landscape scale.

1.2 The Frontenac Arch: An Internationally Important Ecoregion

The Frontenac Arch is a southern extension of the ancient Canadian Shield, which stretches across the St. Lawrence River to connect with the Adirondack Mountains in New York State. It supports a disproportionately high number of intact forests and wetlands relative to adjacent landscapes to the east and west. As a result, it can support viable populations of area-sensitive species that are absent in other regions. The region sits at a biogeographic crossroad, a junction of five forest systems: the Great Lakes-St. Lawrence, the Carolinian, the Atlantic Coastal, the Appalachian, and the boreal. It hosts many species that are near or at their geographic range edge, yielding a unique composition of species (UNESCO, 2018; Frontenac Arch Biosphere, 2022). Consequently, the Frontenac Arch contains several rare ecosystems and species at risk that warrant specific conservation attention (Government of Canada, 2021; MECP, 2020; Figure 3).

The Canadian portion of the Frontenac Arch was designated a World Biosphere Reserve by the United Nations Educational, Scientific, and Cultural Organization (UNESCO) in 2002. Biospheres are designated areas that serve as living laboratories to explore nature-based solutions to better manage biodiversity and to promote sustainable interactions between people and ecological systems (UNESCO, 2023). Included within the region are over 18,000 ha of protected areas including two provincial parks (Frontenac and Charleston Lake), a national park (Thousand Islands), and numerous other conservation reserves maintained by organizations such as the Nature Conservancy of Canada, Ontario Nature, and the Thousand Islands Watershed Land Trust (Miller & Bell, 2021). The Thousand Islands Ecosystem has been designated an Important Amphibian and Reptile Area and the Frontenac Park Ecosystem as an Important Bird and Biodiversity Area (Canadian Herpetological Society, 2019; Important Bird Areas Canada, 2022). Strategies for conserving or restoring connectivity among these various protected areas are an urgent priority as pressure for land development increases and incremental loss of habitat accumulates.

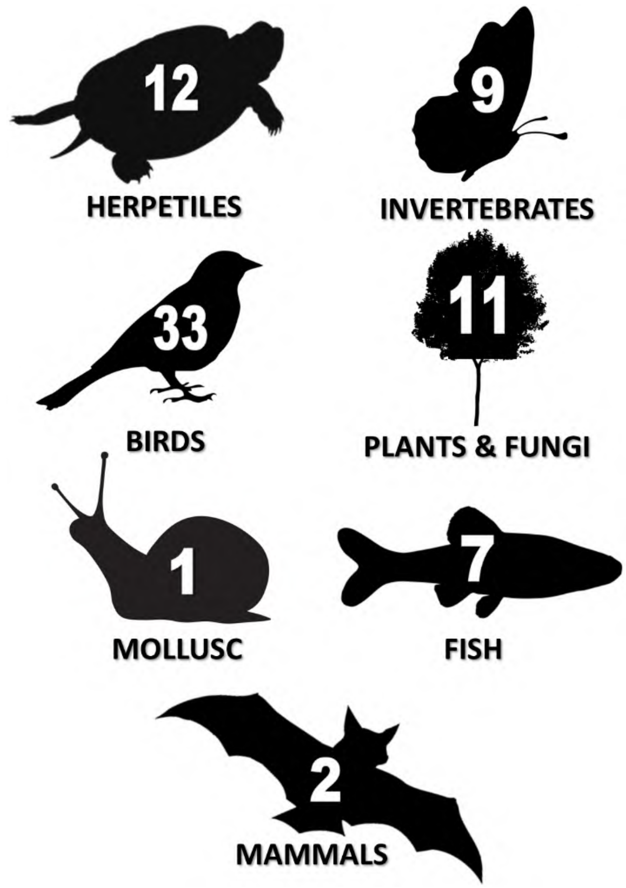


Figure 3: Infographic showing the number of taxa listed under the provincial *Endangered Species Act* and federal *Species at Risk Act* with ranges that overlap with the Ontario portion of the Frontenac Arch region. Species at risk range information was obtained from OMNRF (2023) and Environment and Climate Change Canada (2022).

The Frontenac Arch is the core link of the A2A pathway and serves as an ecological connection between landscapes to the north, including Algonquin Provincial Park in Ontario, and landscapes to the south, including Adirondack State Park in New York (Keddy, 1995; Stephenson, 2001). At a broader scale, the A2A pathway represents “the most extensive, least degraded north-south pathway east of Lake Superior” (Miller and Bell, 2021), and serves as a continental-scale pathway connecting the boreal forests of northern Canada to the eastern temperate forests of the Appalachian Mountains that extends into the southeastern United States (Figure 1). This broader continental pathway that encompasses the A2A region and spans along eastern North America is known as the Eastern Wildway (Wildlands Network, 2019). The role of A2A in both structural and functional connectivity has been made evident in several continental habitat analyses (e.g., Barnett and Belote, 2021; Pither et al., 2021).

The Great Lakes and the St. Lawrence River are substantial geographic barriers to the movement of terrestrial wildlife in eastern North America, and significant urban and agricultural development in this region further reduces connectivity (e.g., Marrotte et al., 2020). With climate change, ranges of species are expected to shift north through the Great Lakes (e.g., Walker et al., 2002; Francl et al., 2010), making habitat connectivity across the continent vital for some species' survival and more important than ever.

However, existing geographic barriers and other constraints to movement that will be further exacerbated by climate change will pose a major challenge to range shifts. For example, a warming climate may limit ice formation on the St. Lawrence River in winter, with potential routes of passage over this major waterbody limited to islands during a much-shortened ice-on season. The rate of adaptation to climate change will vary among species and persistence will likely depend on ability to disperse across the landscape, causing further challenges for less mobile species. As an essential ecological pathway, the Frontenac Arch is critical in supporting the movement of alleles (i.e., genes), resources, migratory species, and species with large home ranges (Lemieux et al., 2021). Maintaining and enhancing the pathway functionality of the Frontenac Arch is therefore crucial in facilitating biodiversity movement along eastern North America in response to climate change.

The St. Lawrence River crosses the Frontenac Arch in a southwest to northeast direction. This divide is bridged somewhat by Thousand Islands National Park, with the islands and mainland properties acting as important stepping-stones for the movement of animals and plants across the river. However, parallel to the St. Lawrence River in Canada there are three major roadways: the Thousand Islands Parkway, Highway 401, and County Road 2 (formerly Highway 2). Highway 401 is a divided four-lane expressway often with a concrete barrier in the middle, while the Thousand Islands Parkway and County Road 2 are both two-lane regional arteries. All three roadways, especially Highway 401, present a significant obstacle to wildlife movement as they each completely bisect the region and support high traffic volumes (Table 1).

Table 1: Average daily traffic volumes for the Thousand Islands Parkway, Highway 401, and County Road 2 at three locations along the Frontenac Arch (adapted from Eberhardt et al., 2013; MTO, 2016; Leeds and Grenville, 2018; BT Engineering, 2021).

Location	Highway	Annual Average Daily Traffic (AADT)
Gananoque	Thousand Islands Parkway	2,186
	Highway 401	31,110
	County Road 2	5,400
Mallorytown	Thousand Islands Parkway	2,080 (June to October only)
	Highway 401	34,300
	County Road 2	3,258
Sherwood Springs	Thousand Islands Parkway	2,538
	Highway 401	30,400
	County Road 2	1,351

The Thousand Islands Parkway, Highway 401, and County Road 2 are major contributors to wildlife mortality by way of direct vehicular collisions (Garrah et al., 2015; Danby et al., 2016; Urquhart et al., 2018; Appendix A). A survey of Highway 401 from Gananoque to just west of Brockville in June 2017 resulted in finding more than 670 dead animals (Urquhart et al., 2018). Each location was visited once, on a single day. This is a substantial underestimate of roadkill on this highway as it only represents animals that could be documented at that time. Many more go undetected, especially small animals, and many die days and weeks following the survey. In the days before the survey, many dead animals were likely removed by scavengers and road crews or deteriorated beyond identification.

Measures to reduce mortality have been suggested independently for each of the three roadways, and some have been implemented. However, a strategy that considers the collective impacts of all three roads, the distribution and configuration of natural habitat along the Frontenac Arch, and appropriate techniques to restore landscape connectivity are currently lacking for this continentally important wildlife pathway.

1.3 Road Effects on Wildlife and Landscape Connectivity

In 2003, there were 1,042,200 km of paved and unpaved public roads in Canada (Transport Canada, 2007). Nearly 30% of all paved public roads (120,000 km) are in Ontario, and most are in the densely populated southern portions of the province where almost all lands excluding lakes and protected areas fall within 1.5 km of a road (OMNRF, 2016).

The impacts of roads and traffic on wildlife are one of the largest threats to biodiversity worldwide (van der Ree et al., 2015b). Roads result in numerous indirect and direct impacts to wildlife including habitat fragmentation and loss, traffic disturbance, barriers to gene flow, changes to habitat quality, wildlife mortality, and increased spread of invasive species and disease.

Roads reduce population and landscape connectivity by fragmenting natural habitats and acting as a barrier to movement (Clark et al., 2010; Holderegger & Di Giulio, 2010; Proulx et al., 2014). Roads create an abrupt linear edge around habitats with a variety of effects that can extend well beyond the road edge (Laurance, 2006). Noise disturbance associated with traffic can reduce the abundance, density, and diversity of breeding birds adjacent to roads, potentially due to acoustic interference with bird songs (Reijnen et al., 1997; Rheindt, 2003; Parris & Schneider, 2009). Similarly, some species of bats are known to alter their flight paths to avoid areas where high vehicle noise interacts with the soundscape (Bennett & Zurcher, 2012). Roads have also been shown to change movement patterns and induce biological and social changes in small rodent populations (Goosem, 2001; Fuentes-Montemayor et al., 2009). Some species do not or are unable to avoid traffic, while others may avoid crossing roads, severely limiting their movement through landscapes and denying them access to critical habitats and resources. In Canada, Blanding’s turtle (*Emydoidea blandingii*; Proulx et al., 2014), woodland caribou (*Rangifer tarandus caribou*; Dyer et al., 2001), and white-footed mouse (*Peromyscus leucopus*; Merriam et al., 1989) have all demonstrated road avoidance behaviour despite variation in mobility, life-history traits, and home range sizes among these species. Despite exhibiting an aversion to roads, these species are still at risk of roadkill, particularly Blanding’s Turtle and other herpetiles (Ashley & Robinson, 1996; MacKinnon et al., 2005; Choquette & Valliant, 2016).

Aversion of roads can result in smaller populations isolated by fragmented habitat, leading to a higher risk of extinction due to random environmental events (Jaeger & Fahrig, 2004). Without exchange of individuals, there is a risk that these populations can become genetically isolated and suffer from the effects of inbreeding depression (Jackson & Fahrig, 2011). For example, Keller et al. (2005) and Zachos et al. (2007) found evidence of negative genetic effects due to roads on ground beetles (Carabus violaceus) and red deer (Cerphus elaphus), respectively. Both studies found that effective population sizes were lowered, making a population more vulnerable to inbreeding and genetic drift (Holderegger & Di Giulio, 2010).

Additional indirect effects of roads on wildlife include those related to hydrology and water quality. Roads that intersect wetland habitats can impede lateral flows, causing ponding in upstream locations and lowering of the water table in downstream locations (Vu, 2019). Increased erosion during road construction can cause a release of sediment into surrounding aquatic ecosystems (Taylor & Owens, 2009). Pollutant-laden water from roads can enter watercourses and wetlands via run-off (Mayer et al., 2011). The extensive use of road salts in de-icing can be toxic to aquatic and semi-aquatic organisms (Arnott et al., 2020). For example, high chloride concentrations in roadside ditches and wetlands can reduce embryonic and larval survival of amphibians (Karraker et al., 2008) and alter amphibian community structure by excluding salt intolerant species (Collins & Russell, 2009).

The primary direct impact of roads on wildlife is mortality due to vehicular collisions (Forman & Alexander, 1998; Ashley et al., 2007; Hill et al., 2019). On an annual basis in Canada, there are more than 25,000 collisions with large mammals such as ungulates (Traffic Injury Research Foundation, 2012), and it is estimated that approximately 14 million birds are killed by vehicles during the breeding season (Bishop & Brogan, 2013). Many at-risk reptile and amphibian species do not readily avoid roads or traffic and will become immobile in response to the threat of an oncoming vehicle, making them more susceptible to collisions (Carr and Fahrig, 2001; Mazerolle et al., 2005; Bouchard et al., 2009). In a study of a 3.6 km section of a causeway adjacent to Big Creek National Wildlife Area on Lake Erie, reptiles and amphibians comprised approximately 95% of road mortalities (Ashley & Robinson, 1996). Roads may attract wildlife, further increasing the likelihood of collisions. For example, roads and roadsides can act as a travel pathway (James & Stuart-Smith, 2000), and provide access to food (Hager, 2009), nesting sites (Murphy et al., 2022), minerals such as salt (Fraser & Thomas, 1982), and thermoregulation habitat (Camacho, 2012).

Wildlife-vehicle conflicts also present a significant risk to human safety. In Canada, Ontario is the province with the most wildlife-vehicle collisions (Transport Canada, 2020). Here there are approximately 14,000 wildlife-vehicle collisions per year (Transport Canada, 2020). However, this is a highly conservative estimate as it likely only reflects collisions with large animals that result in insurance claims. Reported wildlife-vehicle collisions result in approximately 400 human injuries per year in Ontario (Moorhouse, 2023) and about 20 human fatalities each year across Canada (Transport Canada, 2020). These accidents can be due to direct collisions or attempts to avoid hitting wildlife (e.g., swerving). Keeping animals off roads is a priority to maintain a safe and efficient road network.

In addition to human safety concerns, road accidents involving wildlife incur major economic costs to society. It is estimated that wildlife-vehicle collisions cost Canadians more than $800 million per year (Desjardins Insurance, 2021). This includes costs mostly related to vehicle damage and does not account for indirect costs such as emergency services and other medical fees, traffic delays, insurance premium increases, long-term disability, lost workdays due to injury, social impacts to road users, or the loss of important natural resources (Traffic Injury Research Foundation, 2012). Wildlife-vehicle collisions are a significant burden to society and the natural environment, and solutions are required to mitigate wildlife interactions with roads.

1.4 Solutions to Reduce Wildlife Road Mortality

There is growing experience with techniques for mitigating the ecological impacts of roads and these techniques are being evaluated and improved on an ongoing basis (OMNRF, 2016). These mitigation measures are often divided into two main categories: (1) those intended to influence motorist behavior, including signage, reductions in traffic volume or speed, and temporary road closures; and (2) those intended to influence animal behavior, including roadside fencing, animal crossing structures, and habitat enhancement to attract animals away from roadways (Rytwinski et al., 2016).

Signage installed at locations where wildlife is frequently seen or where wildlife-vehicle collisions are concentrated (e.g., deer crossing signs) is a common traffic management strategy. However, a review by Huijser et al. (2016) found that standard wildlife warning signs are largely ineffective in reducing wildlife-vehicle collisions because drivers tend to become complacent about them. In contrast, signs that are place- and time-specific can be highly effective. For instance, Sullivan et al. (2004) found that deer collisions were reduced by 50% when static signs were temporarily replaced with signs equipped with reflective flags and flashing lights during the migration season. They also found that these signs were effective for reducing vehicle speed, which likely contributed to the reduced collisions. A study by Donaldson and Kweon (2019) on the efficacy of dynamic signage along a 27 km stretch of highway in Virginia supports these conclusions. The authors also calculated that the reduction in vehicle damage would result in a savings from $700,000 to $1,400,000 over 15 years, not to mention the potential saving of human lives that would occur.

Reducing traffic volumes and even temporarily closing roads is a management approach that has been adopted in some areas to reduce wildlife-vehicle collisions and improve connectivity (Huijser and McGowen, 2010). In Ontario, Burlington's King Road, Richmond Hill's Stouffville Road, and Kitchener's Stauffer Drive are all closed during periods of peak salamander migration. Parks Canada has implemented daily closures of a popular 17 km stretch of road between 8pm and 8am in Banff National Park, improving wildlife habitat quality and reducing vehicle collisions in the process (Whittington et al., 2019). Closing major highways on the Frontenac Arch is neither possible nor desirable, and while traffic reduction may reduce wildlife-vehicle collisions, mitigation measures targeting animal behaviour are required to effectively restore connectivity (Huijser et al., 2016).

Roadside fencing is intended to prevent animal entry onto roadways to reduce wildlife-vehicle collisions (Huijser et al., 2016). It has longstanding use in applications related to large mammals with the dual benefit of both wildlife and motorist protection. For instance, the Government of New Brunswick (2010) has installed over 300 km of fencing to prevent moose (*Alces alces*) from entering onto provincial highways. Increasingly the application of fencing is being expanded to include smaller animals and is frequently installed in areas where mortality "hotspots" are found and the collision rate is disproportionally high relative to adjacent areas (Beebee, 2013; Clevenger et al., 2001). In southern Ontario, wildlife exclusion fencing has been progressively adopted by provincial and national parks, local governments, and conservation organizations to address reptile and amphibian road mortality hotspots. Perhaps most notably, at Long Point in Norfolk County, there has been a substantial reduction of reptile road mortality since the Long Point Causeway improvement project began in 2006 (EKI, 2020). The project included installation of over 4 km of roadside fencing designed for exclusion of herpetofauna (amphibians and reptiles) in combination with culverts that allow safe movement of wildlife under the road (Long Point Causeway Improvement Project, 2015).

Wildlife crossing structures are intended to increase population connectivity by providing safe passage of animals from one side of a road to another and allowing them access to resources and mates without the threat of vehicle collision, thereby improving population viability (Van der Ree et al., 2015a). Like fencing, crossing structures vary in their design. Large overpasses and underpasses are typically installed for large mammals and have proven successful in many locations (Clevenger & Waltho, 2005; Corlatti et al., 2009). Some of the best-known examples have been built in western North America, where species such as grizzly bear (*Ursus arctos horribilis*), elk (*Cervus canadensis*), and cougar (*Puma concolor*) are targeted. The 88 km stretch of the Trans-Canada Highway that passes through Banff and Yoho National Parks now has 49 wildlife crossing structures, including 42 underpasses and seven overpasses, all accompanied by wildlife fencing (Atlas Obscura, 2023; T. Kinley, personal communication). These crossing structures have increased demographic and genetic connectivity of wildlife (Sawaya et al., 2013 & 2014), and have reduced wildlife-vehicle collisions by more than 80% (CBC News, 2022). However, the success of wildlife crossing infrastructure varies for different species depending on landscape setting and structure design (Stewart et al., 2020), suggesting that there is no perfect design for all species in all circumstances.

Two large overpass projects have recently been built in Ontario with funding by the provincial government. The first, located on Highway 69 in central Ontario, incorporates a 30 m wide overpass in tandem with 10 km of wildlife exclusion fencing, a large wildlife underpass, and three reptile tunnels. Monitoring indicates that the infrastructure has resulted in an 87% decrease of vehicle collisions with moose and white-tailed deer (*Odocoileus virginianus*; EKI, 2020). The overpass is used by these species as well as black bears and smaller mammals like coyote and fox (EKI, 2020). The second project is a set of structures associated with the Right Honourable Herb Gray Parkway in Windsor, which considered the movement and habitat needs of local at-risk snake species. To connect habitat on either side of the Parkway, the 11 km road was lowered to 8 metres below-grade. The road now passes alongside earth berms and through 11 tunnels ranging from approximately 120 m to 240 m wide that are covered with natural prairie vegetation, providing overpass habitat connections across the multilane expressway that total over 1,400 m (Rajlic et al., 2016).

Underpasses designed as wildlife passages for smaller animals have also been used successfully in many locations (Aresco, 2005; Baxter-Gilbert et al., 2015). Colley et al. (2017) detected a significant reduction in road mortality of the threatened massasauga rattlesnake (*Sistrurus catenatus*) on stretches of road where ecopassages had been installed in Killbear Provincial Park, Ontario. Similarly, Boyle et al. (2021) found that dedicated ecopassages improved connectivity for turtles under a roadway in Presqu'ile Provincial Park, Ontario, and reduced the number of turtles and amphibians found on the road. However, there has been less success in using pre-existing drainage culverts as wildlife underpasses. In a study in southern Quebec, Brunen et al. (2020) found that ordinary drainage culverts are unsuitable as substitutes for purposely designed wildlife passages for mammals.

Fencing and crossing structures can individually reduce roadkill but are much more effective when implemented in combination. Fences when used without crossing structures can reinforce the fragmentation of wildlife into smaller populations that is initiated by roads. For this reason, there is now a consensus among scientists and practitioners that fences should be paired with effective wildlife crossing structures whenever possible (van der Ree et al., 2015a). Similarly, crossing structures may not always be sufficient on their own. For instance, Read and Thompson (2021) found that turtles would use drainage culverts to cross two-lane roads in southern Ontario, but only when fences were installed to direct the animals towards the culverts. Cunnington et al. (2014) found the same for frogs on the Thousand Islands Parkway. Similar evidence exists for larger animals. Donaldson and Elliott (2021) found that white-tailed deer increased their use of a large box culvert by 410% when 1.6 km of fencing was added, and use of a bridge underpass increased 71% with the addition of fencing. They estimated that the combination of fencing and underpasses along this short stretch of road would result in vehicle damage cost savings of >$2.3 million over 25 years. Similarly, a meta-analysis by Rytwinski et al. (2016) estimated that the combination of fencing and crossing structures can reduce road mortality of large mammals by 83%.

Ultimately, advances in road ecology have contributed to the development of effective solutions to mitigate wildlife-vehicle collisions. The combined goals of improving wildlife movement and reducing mortality can be competing, but well-designed mitigation plans can achieve both. Existing information on wildlife mortality hotspots along roadways can be used to develop and implement targeted measures to restore wildlife connectivity. Numerous studies identifying high-risk areas for wildlife and associated habitat areas along roadways within the Frontenac Arch have already been completed. This report uses the results of this work to recommend major and minor mitigation measures for the Thousand Islands Parkway, Highway 401, and County Road 2.

2 Frontenac Arch Community Responds to Significant Wildlife Road Mortalities

Due to the ecological importance of the Frontenac Arch region, many studies have been conducted to identify the best methods to conserve its species, ecosystems, and landscape connectivity. These efforts have been spearheaded by local organizations such as A2A, Thousand Islands National Park, Thousand Islands Watershed Land Trust, Queen's University, Carleton University, Turtles Kingston, Leeds and Grenville Turtles, and the Ministry of Natural Resources and Forestry.

This massive community effort to conserve the local landscape led to the realization that the Thousand Islands Parkway, Highway 401, and County Road 2 present a major barrier to wildlife movement and cause substantial mortality, including to several species at risk. Over the past 18 years, each road has been the focus of studies aimed at understanding the magnitude and spatial distribution of wildlife-vehicle collisions (Figure 4). Two multi-year field mitigation trials were implemented in 2009 and 2019 to assess the efficacy of fence-culvert systems. Results from these projects were used to inform the approach and recommendations that we present in this report. The relevant studies are described briefly in Appendix B.

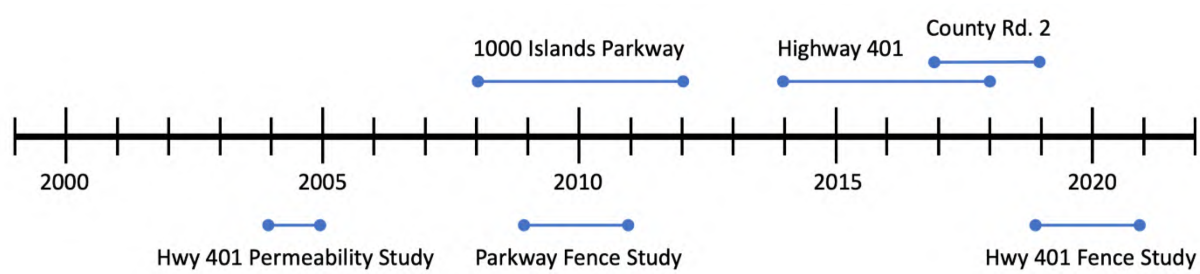


Figure 4: Timeline representing road ecology studies of the Thousand Islands Parkway, Highway 401, and County Road 2. The top part of the timeline represents road mortality studies, and the bottom part reflects studies of mitigation measures including wildlife fencing and crossing structures.

3 Our Approach to Identifying Priority Areas for Mitigation

Our approach to our goal of identifying priority areas for mitigation integrates information from the numerous previous studies described in Appendix 1 combined with new data and modelling analyses (Figure 5). We identify key wildlife movement pathways that interact with the three roadways of interest and recommend specific solutions to ensure these landscape connections retain migration functionality. The study area focused on an area extending from Gananoque to the western edge of Brockville, and from the Canada-United States border northwards past County Road 2. Our geospatial analysis was conducted using a tessellated network of 2-hectare hexagons (described below under "Scenario Mapping").

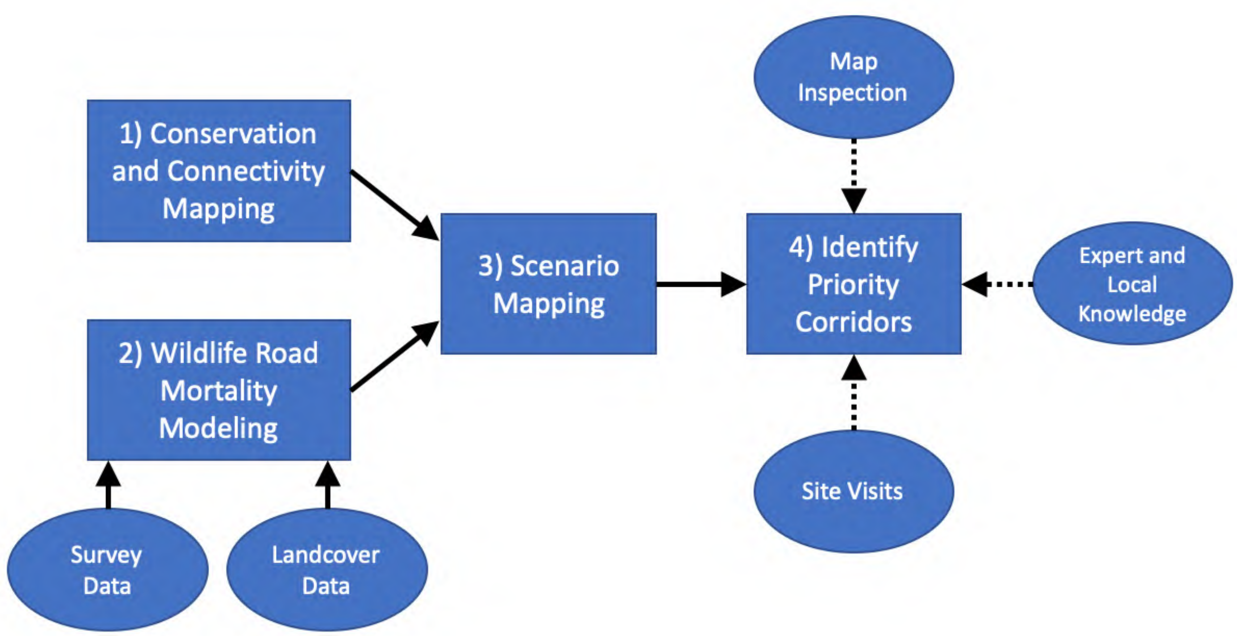


Figure 5: A representation of the process used to identify the priority areas for mitigation. The numbered boxes (1-4) are indicative of the discrete methodological steps that are described in this section. Circles represent major inputs into each step of the process and are described in their respective section. Solid arrows are indicative of quantitative and geospatial process inputs, while dashed arrows represent qualitative inputs.

3.1 Conservation and Connectivity Mapping

There have been several efforts to map and analyze conservation priorities at landscape and regional scales within the study area. The products of three such efforts were used as primary input data sources in our analysis. These are described individually in the following sections along with an explanation of how their respective datasets were incorporated into our analysis.

3.1.1 6E10 Natural Heritage System ("Sustaining What We Value")

Sustaining What We Value (SWWV) was a collaborative, multi-partner project that identified a Natural Heritage System (NHS) for Leeds and Grenville County and portions of Lanark and Frontenac Counties. The project used an integrated systems approach that: (1) engaged diverse stakeholders as decision-makers throughout the process; (2) used a science-based approach to inform stakeholder decisions on targets for what to include in the NHS; (3) was based on regional ecological boundaries; and (4) used an objective, decision-support tool (Marxan software) to minimize the extent of land needed to achieve natural heritage goals (SWWV, 2011). The output of the process was a preferred NHS comprised of core areas, pathways, and linkages among them. On the southern portion of the Frontenac Arch, the preferred NHS contained a large number of core areas and pathways on the mainland along the north shore of the St. Lawrence River with some connections to areas north of Highway 401 (Figure 6). Hill and Grenadier Islands were also identified as core habitat areas. Linkages and other features were also prominent north of Highway 401.

All the products produced under the SWWV project were consolidated into a digital information package including all the source and derived GIS map layers used to support the analysis as well as GIS map layers for the preferred NHS option. We acquired this package from the OMNRF and used it as part of our analysis. The components of the NHS were mapped for our area of interest and sections of road that intersected the NHS were identified.

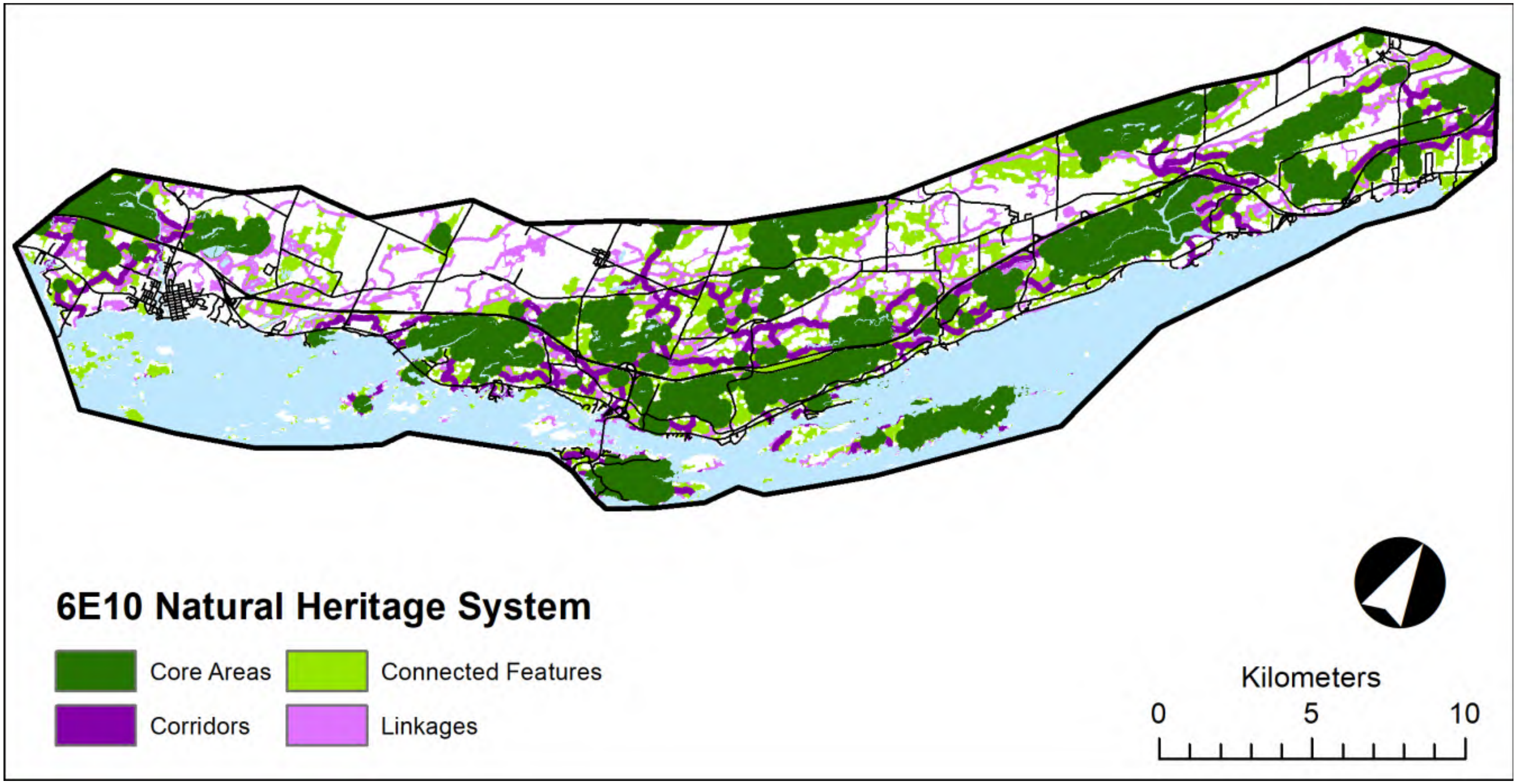


Figure 6: The Natural Heritage System (NHS) identified as part of Sustaining What We Value (SWWV, 2011). Only portions of the NHS that overlap with our study area are identified in this map. Categories have been aggregated to indicate core areas and well-connected natural areas (greens) and linear habitat features acting to connect these (purples).

3.1.2 A2A Regional Connectivity Mapping and Natural Heritage System

Building on SWWV's mapping work, A2A set out to enlarge the scope of the NHS mapping to include areas between Adirondack State Park and Algonquin Provincial Park in partnership with the Natural Heritage Information Centre of the OMNRF. This project used a "core and linkage" approach modified from the SWWV methodology. The key divergence from the SWWV method was that "all blocks of natural cover were identified for potential connections in the A2A study area rather than generating priority areas from Marxan first as cores and then connecting them across the landscape" (Henson & Tellier, 2014, pg. 4). The key components of this system were: Core Areas, Primary Connection Zones, Least Cost Paths, and Riparian Linkages. After these components were identified, all areas within them were assigned a score based on a suite of surrogates for biodiversity, ecosystem functions, and anthropogenic constraints. Higher scores represented potentially more important or less constrained natural areas while lower scores represented less important or more constrained areas. Results on the Frontenac Arch were somewhat similar to the SWWV results in that core areas were prominent along the north shore of the St. Lawrence River south of Highway 401 (Figure 7).

We mapped the components of the A2A NHS for our area of interest and identified sections of road that intersected either cores or connections (Figure 7). Comparison of the 6E10 and A2A systems indicated that the A2A system was more suitable for an analysis of road ecology due to the identification of Primary Connection Zones across roadways. As such, the A2A system was more central in our scenario development. For ease of data handling, we also reclassified the A2A NHS scores from 0 to 51 and assigned values to a tessellated network of 2-hectare hexagons (Figure 8). Higher scores represent areas with a higher NHS value.

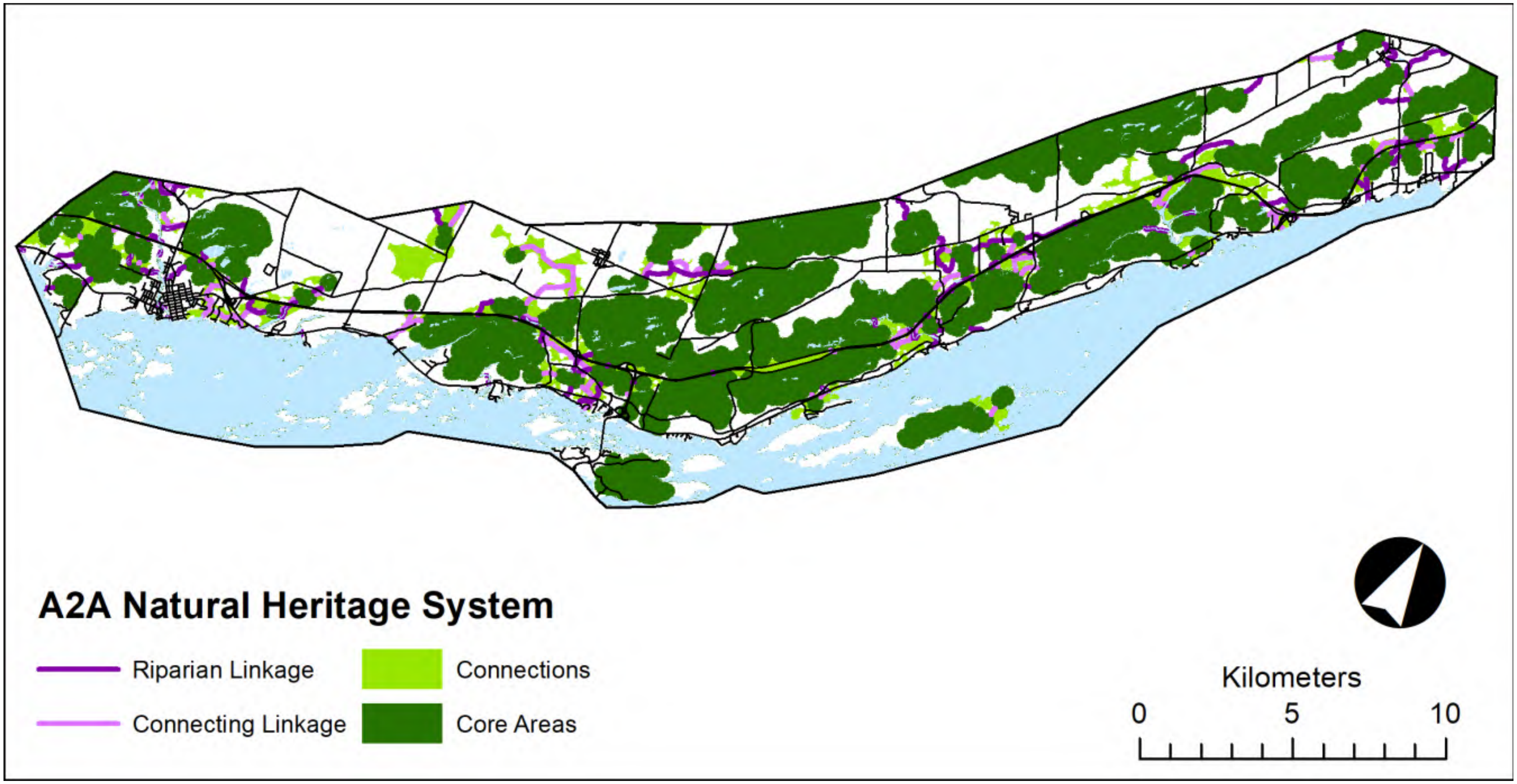


Figure 7: The natural heritage system (NHS) identified as part of A2A's conservation mapping exercise in 2014. Only portions of the NHS that overlap with our study area are identified.

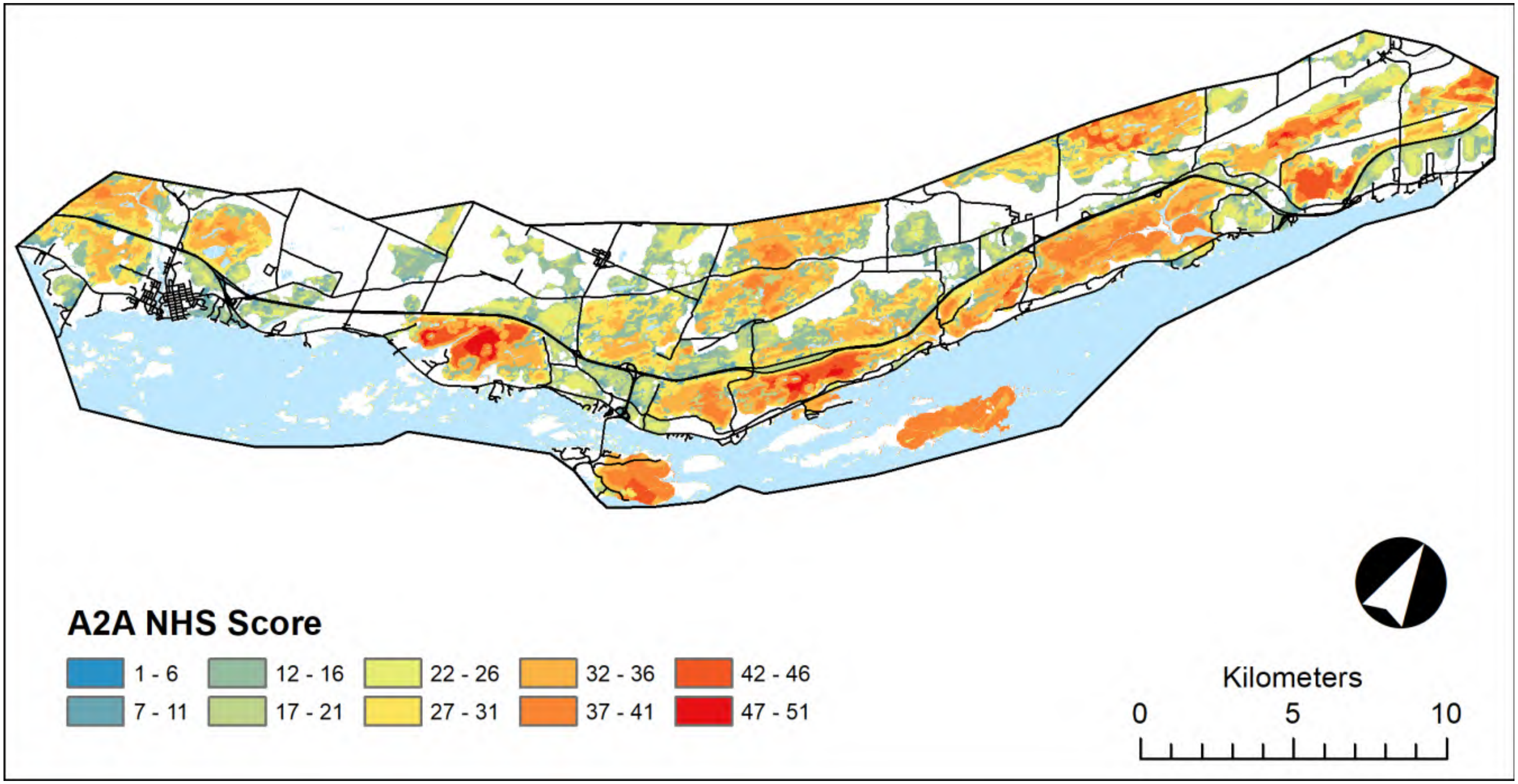


Figure 8: Scores allocated to areas within the Algonquin to Adirondacks Natural Heritage System based on biodiversity values, ecosystem services potential, and anthropogenic constraints. Scores were classified for the purposes of this study. Higher scores represent areas with a higher natural heritage system value.

3.1.3 Landscape Connectivity ("Circuitscape Analysis")

This project was conducted by the OMNRF's Wildlife Research and Monitoring Section. The primary objective was "to evaluate the relative differences in wildlife landscape connectivity throughout the Ontario portion of the Great Lakes drainage basin" and "identify pathways of probable wildlife movement where land use planning and management can focus on conserving natural heritage systems" (Bowman & Cordes, 2015, pg. 1). The project followed the methods of Koen et al. (2014) which had focused on eastern Ontario. Both studies used the software package, Circuitscape, to model connectivity. The software adapts algorithms from electronic circuit theory to model animal movement and gene flow across a gridded network of landscape resistance. The result is a cumulative current (or current density) map analogous to the probability of use by random walking animals (Bowman & Cordes, 2015). Higher values in the data represent a greater propensity of an area for connectivity and wildlife movement. The data were generated at a resolution of 100 m. We clipped the current density data to the extent of our study area and then reclassified the data from 0-50. As would be anticipated, current density (a surrogate for connectivity) was highest in areas of natural terrestrial landcover types (e.g., forests), but other patterns also emerged. In our study area, small pockets of high connectivity exist between the Thousand Islands Parkway and Highway 401 at Jones Creek, LaRue Creek, and Landons Bay. Another pocket occurs just to the north of Highway 401 along the Gananoque River (Figure 9).

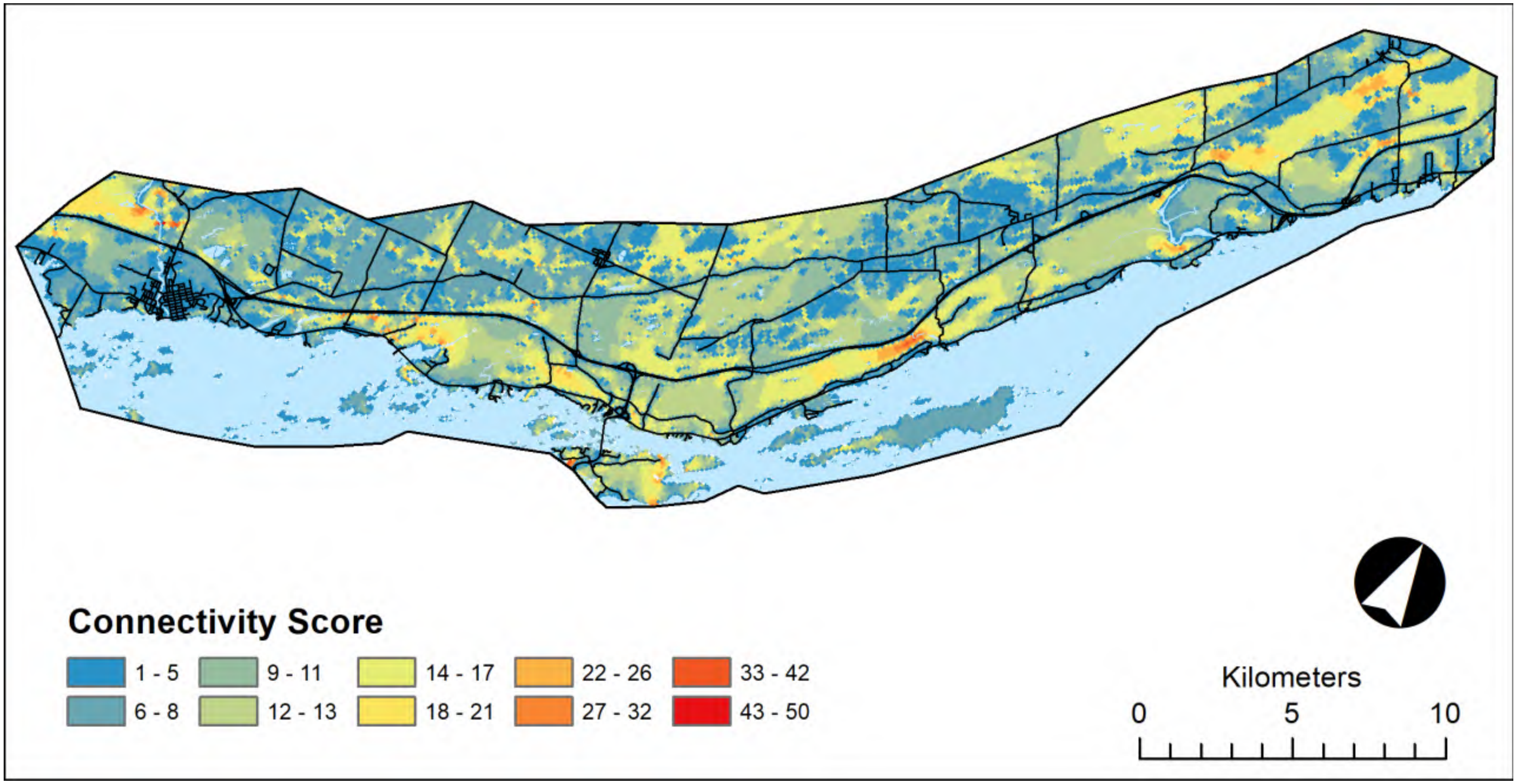


Figure 9: Current density map for eastern Ontario by Koen et al. (2014) derived from a cost surface using Circuitscape software. High values have less resistance and facilitate connectivity. Low values have higher resistance and less connectivity.

3.2 Wildlife Road Mortality Modelling

As described previously, several projects have collected road mortality data in the region, including concentrated efforts along the Thousand Islands Parkway (2008-2011), Highway 401 (2014-2017), and County Road 2 (2016-2017). Comparable data were collected on all three highways (including species, location, alive or dead, sex, size, and age class, etc.).

Jones (2018) used data from the Thousand Islands Parkway surveys in 2008 and 2010 and the County Road 2 surveys in 2016 and 2017 to assess environmental factors that contribute to the location of herpetile-vehicle collisions. He developed a suite of statistical models that identified these factors at local and landscape scales. The local scale was identified as areas within 50 m of a site (equivalent to an area of ~0.75 ha) while the landscape scale was identified as being within 250 m of a site (equivalent to an area of ~20 ha). Models were developed for turtles, snakes, and frogs on both roadways, as well as specifically for midland painted turtle and northern watersnake, the most common turtle and snake species, respectively. Regression tree analysis, with collision density as the dependent variable and the various environmental data as the independent variables, was used specifically so that significant threshold values in the environmental data could be identified and used for management purposes. Results identified several variables that were important for different reptile and amphibian taxa on the two different roads. However, wetland and water-related variables were most important for virtually all taxa on both roads and were important at both scales of analysis.

We identified the variable which was selected as the first order split and most influential in each of Jones' (2018) models as well as its specific threshold value (Table 2). These values were then used to predict locations along all roadways in our study area that could experience high levels of mortality. In several instances Jones (2018) identified different thresholds for the same variable due to the same variable being included in multiple models. For these variables we used the most restrictive (least inclusive) threshold given that our intent was to identify priority sites.

Table 2: Critical landscape thresholds associated with high herpetile road mortality on the Frontenac Arch, as calculated by Jones (2018) and implemented here.

Variable	Description	Threshold
Landscape Connectivity	Circuitscape score	≥ 0.000681
Swamp	Percent of 20 ha landscape comprised of swamp	>21%
Deciduous Forest	Percent of 20 ha landscape comprised of deciduous forest	≥ 49
Water	Percent of 20 ha landscape comprised of water	≥ 26%
Open Wetland	Percent of 20 ha landscape comprised of marsh and aquatic wetland	>20%
Habitat Diversity	Shannon Diversity Index (SHDI) of 20 ha landscape	≥ 1.8
Distance to Water	Distance to a water body	<320m
Distance to Water Crossing	Distance to a road-stream intersection	<53m

Landcover data from the 6E10 mapping exercise (SWWV, 2011) were used to derive the key metrics required to implement the model. The data are 10 m resolution and categorize the landscape into several different classes including marsh, open wetland, swamp, coniferous forest, deciduous forest, mixed forest, undifferentiated forest, agricultural, roads, urban, and water. FRAGSTATS v4 (McGarigal et al. 2014) was used to process the landcover data. A 250 m radius circular moving window analysis was implemented on each landcover class to generate maps of proportional cover for each class. A map of landcover diversity based on Shannon's Diversity Index (SHDI) was generated using the same process.

The Ontario Road Network database (ORN) was intersected with the Ontario Hydrological Network database (OHN) to identify locations where streams and waterbodies are crossed by roadways. A <distance> function was applied to this point map to generate a continuous raster field with these values. Similarly, a <distance> function was used to generate a raster field representing the distance of any point on the landscape to the nearest stream or waterbody. The results are presented in Figure 10.

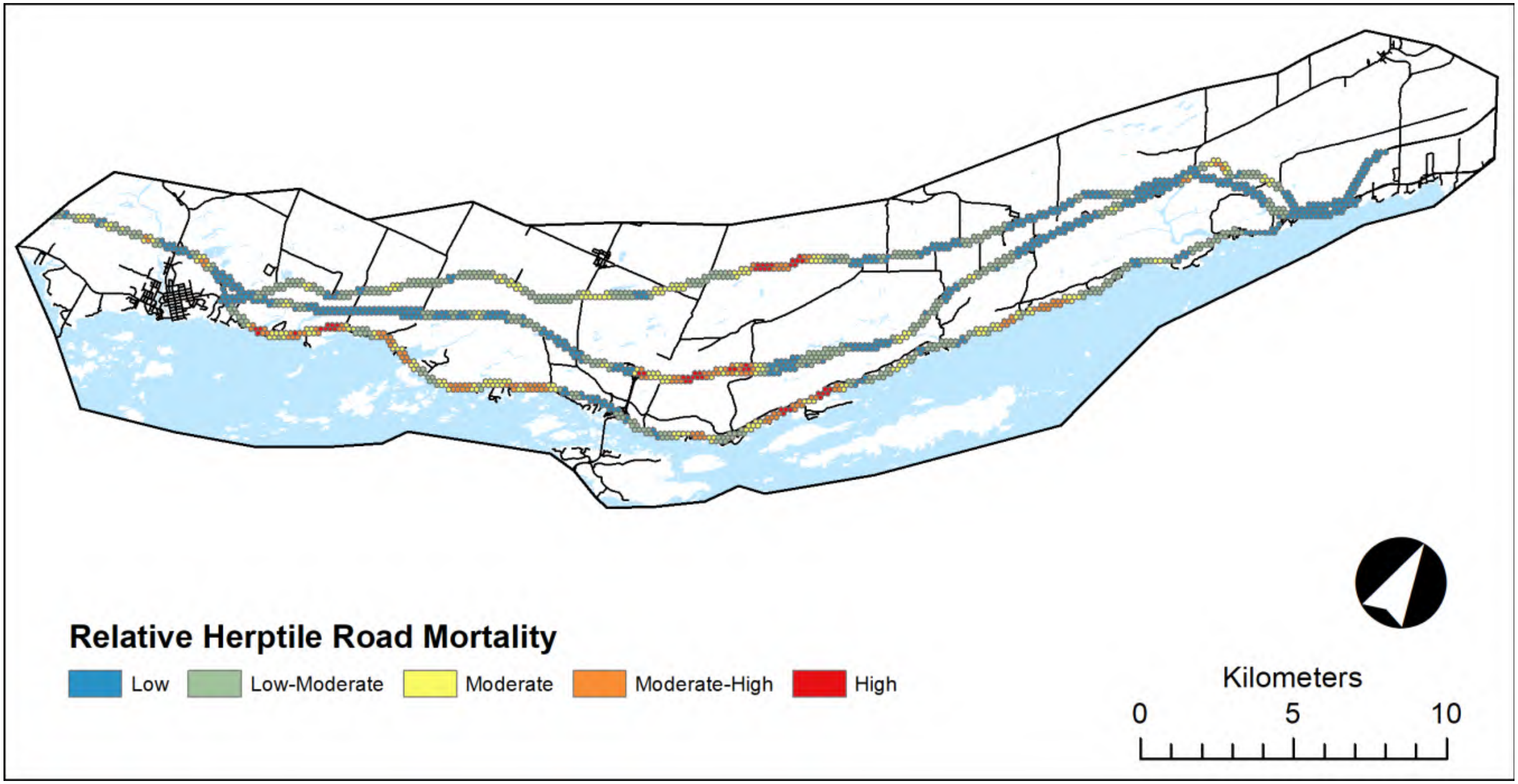


Figure 10: Normalized score of herpetile-vehicle collision density along County Road 2, Highway 401, and the Thousand Islands Parkway as observed from extensive field surveys conducted in 2016-17, 2014-15, and 2008-11, respectively. "TINP lands" represent areas of Thousand Islands National Park. Scores are unitless. Higher values represent locations with high levels of mortality; lower values are areas with low levels of mortality. Each roadway was normalized separately.

3.3 Scenario Mapping

The accumulated data were used to derive six different scenarios that represent priority areas for road ecology mitigation activities in the study area. The criteria used to define each scenario are detailed in Table 3. The scenarios are presented in Figures 11 and 12.

Table 3: Criteria used in scenarios mapping. Six scenarios were developed using Boolean logic implemented in ArcGIS based on input data derived from a suite of maps, observational data, and modelled relationships described in this report.

Scenario	Boolean Criteria
1	[higher than average roadkill on each of HWY #2, HWY #401, and TIP] **AND** [located within a core area or connecting linkage of the A2A Natural Heritage System]
2	[higher than average roadkill on each of HWY #2, HWY #401, and TIP] **AND** [located within a core area or connecting linkage of the A2A Natural Heritage System] **- OR -** [meet at least one of the following landcover thresholds: swamp > 21%, deciduous forest ≥ 49%, water ≥ 26%, open wetland ≥ 20%, SHDI ≥ 1.8]
3	[higher than average roadkill on each of HWY #2, HWY #401, and TIP] **AND** [Sites located within a core area or connecting linkage of the A2A Natural Heritage System] **- OR -** [meet at least one of the following landcover thresholds: swamp > 21%, deciduous forest ≥ 49%, open wetland ≥ 20%, SHDI ≥ 1.8]
4	[higher than average roadkill on each of HWY #2, HWY #401, and TIP] **AND** [located within a core area or connecting linkage of the A2A Natural Heritage System] **- OR -** [meet at least one of the following landcover thresholds: swamp > 21%, deciduous forest ≥ 49%, open wetland ≥ 20%, SHDI ≥ 1.8] **AND** [within 60m of a stream crossing]
5	[higher than average roadkill on each of HWY #2, HWY #401, and TIP] **AND** [located within a core area or connecting linkage of the A2A Natural Heritage System **OR** higher than average circuitscape values **OR** within a core area of the 6E10 Natural Heritage System]
6	[higher than average roadkill on each of HWY #2, HWY #401, and TIP] **AND** [higher than average A2A Natural Heritage System score] **AND** [meet at least two of the following landcover thresholds: swamp > 21%, deciduous forest ≥ 49%, water ≥ 26%, open wetland ≥ 20%, SHDI ≥ 1.8] **AND** [within 60m of a stream crossing]

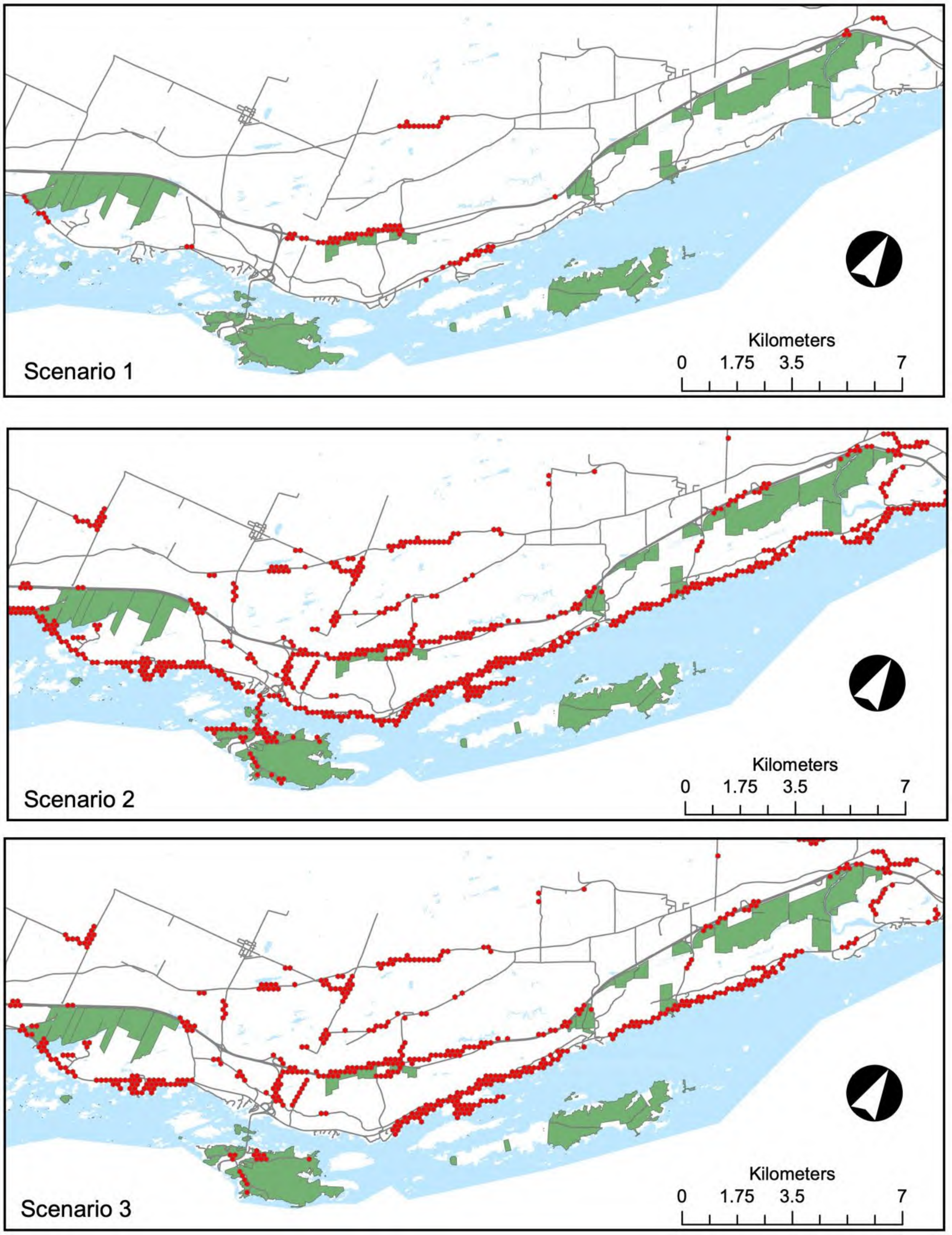
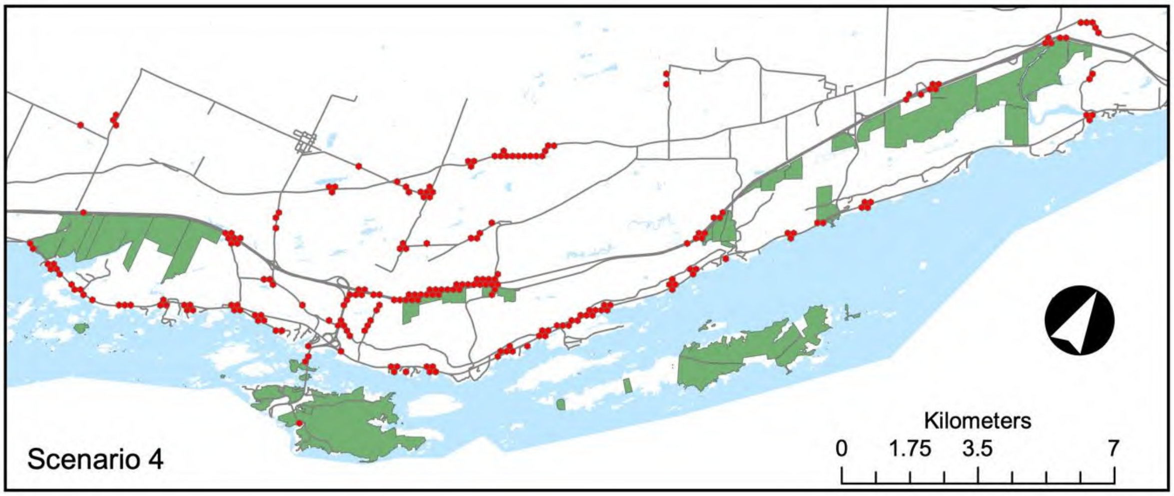
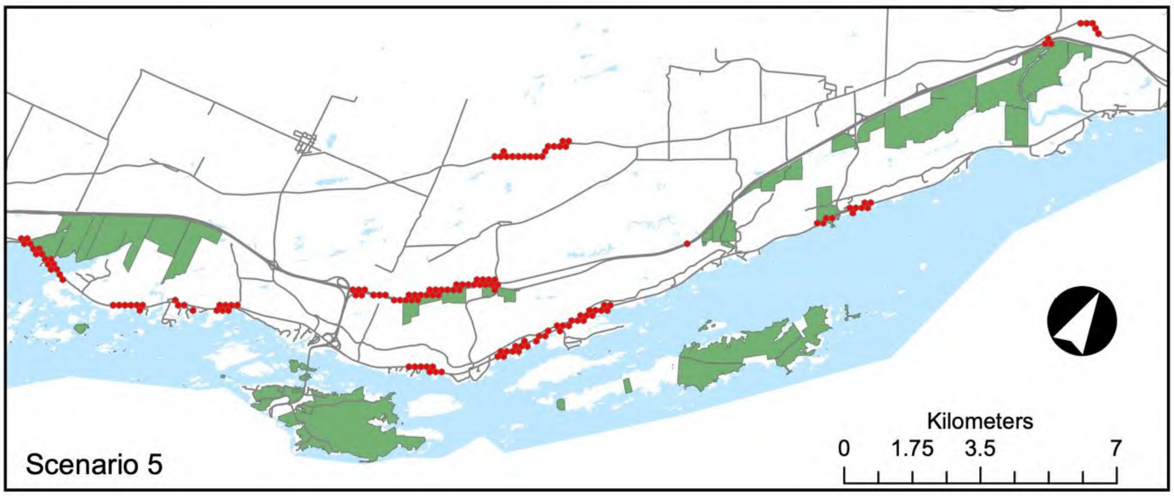


Figure 11: Scenarios 1-3 for road ecology priorities in the study area. Criteria used in identifying each scenario are presented in Table 3. Each scenario is a binary classification. Sites are either included or excluded in each of the scenarios; there is no scaling or scoring of a site's significance within a scenario. Green represents protected areas.





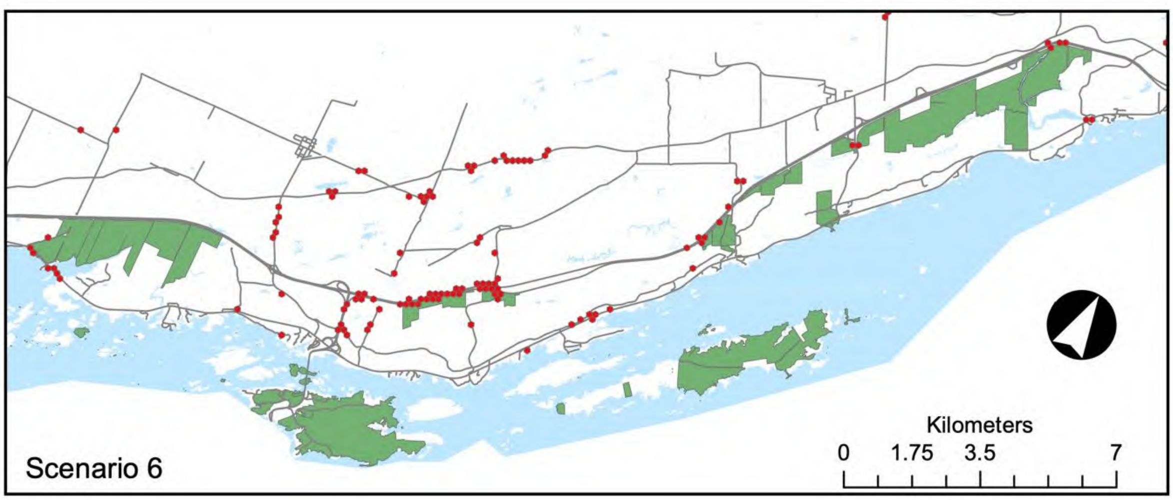


Figure 12: Scenarios 4-6 for road ecology priorities in the study area. Criteria used in identifying each scenario are presented in Table 3. Each scenario is a binary classification. Sites are either included or excluded in each of the scenarios; there is no scaling or scoring of a site's significance within a scenario. Green represents protected areas.

A tessellated network of 2 ha hexagons was generated to serve as the primary analytical surface for scenario generation. This approach is often preferred in conservation applications (see Birch et al., 2007). Networks of 1 ha and 5 ha hexagons were also tested, but processing data using a 1 ha network was computationally too intensive for the extent of the study area, and 5 ha hexagons were too large to provide sufficient level of detail for the purposes of this study. Incidentally, the long diagonal axis of a 2-ha hexagon is 175 m, which is close to the 200 m distance identified by Garrah et al. (2015) as the optimum scale for identifying wildlife mortality hotspots on the Thousand Islands Parkway.

It is important to keep in mind that the scenarios were derived with the intent of being used as inputs in the overarching process illustrated in Figure *5*. In this sense, they identify the collective set of areas that the study team considered as priority areas for intervention in reducing the potential for wildlife-vehicle collisions and restoring ecological connectivity across roadways. But they are not ranked in order of significance. Each scenario simply reflects the criteria used to generate it. Scenario 1 is not more favourable than Scenario 2, etc. However, there certainly are scenarios that are more inclusive or exclusive than others.

3.4 Identification of Priority Wildlife Pathways

To identify priority wildlife pathways, scenario mapping was reviewed in conjunction with high resolution satellite imagery (Google Earth), drainage mapping, and cadastral (property boundary) mapping.

Attention was placed on Scenarios #1 and #5 as they emphasized the co-occurrence of wildlife road mortality on just these three roads with connectivity of the surrounding landscape (see criteria in Table 3). Two clusters of priority areas were apparent on Highway 401 in Scenarios 1 and 5: one east of Highway 137, and one at Jones Creek. The two road mortality hotspots previously identified on County Road 2 were also apparent in both these scenarios. Clusters were not as discrete along the Thousand Islands Parkway, though Landons Bay and Thompson’s Bay were clear in both scenarios (Figures 11 and 12).

Scenarios #2, #3, #4, and #6 included all the region’s roadways. They confirmed the importance of the areas identified in Scenarios #1 and #5, but they also helped identify other areas where remedial action should be considered. Depending on the scenario these ranged from long stretches of road to isolated areas.

High resolution satellite imagery was inspected to gain more detailed observations of priority areas that were not possible from our coarser resolution input maps. This was accompanied by dedicated site visits in fall 2020, and informed by existing knowledge of County Road 2, Highway 401, and Thousand Islands Parkway that we gained through regular repeated surveys conducted as part of our prior studies in the region (Figure 4). This "ground-truthing" was necessary for identifying the range of remedial options conceivable for each site, including existing infrastructure and habitat features that may support wildlife crossing. Drainage maps from the Source Protection Information Atlas (MECP, 2022) were also reviewed to further inform the locations of watercourse crossings and associated infrastructure, and cadastral maps were inspected to understand the nature of property divisions and ownership in the area. We were interested in determining the spatial relationship between the priority areas for mitigation and current protected areas as well as other land use types.

4 Priority Wildlife Pathways for Mitigation and Recommendations to Restore Connectivity

4.1 Overview of the Recommended Strategy

This report identifies three wildlife movement pathways that should be prioritized for mitigation based on existing landscape connections and wildlife mortality hotspots along County Road 2, Highway 401, and the Thousand Islands Parkway. These pathways are described below from west to east and correspond with ecological pathways previously identified by other landscape modelling studies conducted for the A2A region (i.e., SWWV, 2011; Henson & Tellier, 2014; Bowman & Cordes, 2015; Roch, 2015). Recommendations to help restore connectivity and substantially reduce wildlife road mortality are provided below for each of the three major roadways within each of the wildlife pathways. A summary of proposed mitigation measures and their locations is provided in Appendix C.

Each of our recommendations is targeted at a specific location that, if implemented, will immediately improve connectivity at the local scale by allowing for safer movement of animals across roadways. We have also explicitly considered the surrounding landscape in identifying mitigation locations to enhance connectivity at a broader scale. The three pathways we identify are comprised of tracts of relatively continuous natural habitat, including connected wetlands, forests, watercourses, and riparian areas. Larger mammals such as white-tailed deer, moose, black bear, coyote, and fisher may move beyond these pathways. Species with smaller ranges might not, but dispersal or mating of individuals serves to link them together. For example, Howe et al. (2007) demonstrated genetic linkages between subpopulations of gray ratsnake (*Pantherophis spiloides*) in LaRue Mills on the south side of Highway 401 to as far north as Charleston Lake Provincial Park. This represents population connectivity at a scale greater than 10 km for a species with a typical home range radius of only 1 km (OMNRF, 2012). Our identified wildlife pathways are therefore analogous to links in chains of connected habitats. Wildlife may not travel a distance greater than one link in the chain, but over time, their genetics will travel along the chain through multiple links. The implementation of the recommended mitigation strategy will therefore contribute to enhancing ecological connectivity at broader scales like the A2A region and the Eastern Wildway.

The proposed spatial distribution of crossing structures aims to strike a balance of known movement patterns and home range sizes of a variety of wildlife taxa in the region. There are no strict rules or formulae for determining the minimum number of crossing structures required, or how closely spaced they should be, to mitigate road mortality for multiple wildlife groups. The strategy recommended here likely underestimates the number of crossing structures needed for wildlife taxa with small home ranges such as herpetiles, which typically require closely spaced passage opportunities (OMNRF, 2016), but will likely support the movement of the region’s larger mammals. For example, fishers have an average home range size of 27 km^2 and are anticipated to need a wildlife crossing structure every 5.2 km along Highway 401 (Roch, 2015). However, placing structures at points of highest landscape connectivity, like this strategy does, is better than distributing them evenly (Roch, 2015).

Our mitigation strategy involves installation of three wildlife overpasses along an approximately 10 km stretch of Highway 401. While enlarged culverts may be suitable for the passage of some smaller species, overpasses will enable safe passage of larger animals. Due to its significantly high traffic volumes, Highway 401 acts as a nearly impenetrable barrier for large mammals, which are unlikely to even attempt to cross (Seiler, 2003). The movement of larger animals is essential for maintaining broad-scale ecological connectivity, particularly because they tend to disperse greater distances and have extensive spatial requirements for survival (Haskell et al., 2002; Jetz et al., 2004). Without the three recommended overpasses, larger species that reside in the area at low densities, such as bobcats and fishers, are at significant risk of extirpation through population isolation, limiting genetic diversity and reproductive capacity to replace individuals killed on roads. Other species that use the region occasionally, including moose, black bears, and lynx, are currently prevented from establishing resident populations due to the lack of local connectivity. This causes further isolation of their population centres in the Algonquin region to the north and the Adirondack region to the south.

The locations of our recommended infrastructure upgrades align not only with mortality hotspots, habitat linkages, and home range sizes, but also with protected areas or areas with potential to become protected. These include lands owned by Parks Canada (Thousand Islands National Park) and other conservation organizations[2], land with opportunity for acquisition by conservation organizations, and land with potential to be designated for conservation purposes (i.e., provincial Crown land). The intention here is to pair infrastructure improvements with land preservation so that animals are guided through suitable habitat areas that will not be subject to significant land development or alteration in the future. Wetland and forest cover outside of these protected areas currently receives some manner of protection by private landowners and municipal and provincial planning policies.

4.1.1 Fence Considerations

Crossing structures must be accompanied by wildlife fencing to direct animals towards safe passage. Animals inherently do not want to use crossing structures; it is largely fencing that directs them towards structures. Designing crossing structures so that they are attractive to a variety of wildlife species will increase likelihood of use, as will animal experience with them. The very high traffic volumes on Highway 401 will likely cause larger animals to hesitate to cross and pace along fences, increasing the odds of them eventually finding and using a crossing structure. However, many animals, especially those new to crossing structures, simply follow fences to their ends and cross there, resulting in mortality hotspots at fence ends (Clevenger et al., 2001). Fence segments should therefore be as long as possible, with fence lengths less than 5 km expected to be ineffective for large mammals (Huijser et al., 2016). This fence-end mortality effect is anticipated to be trivial for long (i.e., >5 km) fences because more animals are likely to use crossing structures along their length (Huijser et al., 2015; 2016).

To be effective for large mammals, fencing associated with crossing structures on Highway 401 should consist of chain-link or knotted-woven wire game fence approximately 2.4 m (8 ft) tall and should be at least 5 km long on each side of the highway. The bottom 60 cm of the fence should have fine mesh so that it is effective against herpetiles and small to medium sized mammals (Clevenger & Huijser, 2011). Metal fence posts should be used instead of wood

[2] Maps in this report do not include properties affiliated with Thousand Islands Watershed Land Trust. Several of these properties are privately owned and are not publicly mapped due to privacy and liability concerns.

to prevent breakage under snow or damage by snow plows. Considering their significantly lower traffic volumes, fence recommendations for the Thousand Islands Parkway and County Road 2 are more location- and species-specific than those for Highway 401 (details below). Regardless, in all instances, fences should be as long and tall as feasible and impermeable against as many species as possible.

4.2 Landons Bay to Lansdowne Pathway

The westernmost pathway identified for mitigation supports wildlife movement from the Landons Bay area northeast through connected habitat that extends to Charleston Lake Provincial Park and beyond (Figure 13). The Landons Bay area was identified as one of the most ecologically important areas in the region, achieving close to the maximum possible NHS scores (SWWV, 2011). Landons Bay is a likely destination for wildlife moving across the St. Lawrence River at the westernmost limits of the Frontenac Arch. Wildlife are bottlenecked by urban sprawl from Kingston, extensive agricultural development surrounding Gananoque, and are pushed northeast. The St. Lawrence River has an inlet extending north into Landons Bay where it connects to a large wetland complex that crosses Highway 401 just south of Ebenezer. This watercourse funnels wildlife from various protected areas including Thousand Islands National Park and Wellesley State Island Park, both of which are known for their rich biodiversity. Wildlife can utilize the island stepping-stones to cross the St. Lawrence River and are guided north through wetland connections before reaching Highway 401, which bisects this habitat.

Where Highway 401 crosses this pathway near Landons Bay Creek marks an essential crossing location for a wide diversity of species that are funnelled here from provincially and nationally significant habitat, making it a critical link in the Algonquin to Adirondacks connection. Thousand Islands National Park has significant land holdings on the south side of Highway 401 within the Landons Bay to Lansdowne route (Figure 13), presenting an opportunity to couple infrastructure improvements with land conservation to ensure the effective enhancement and maintenance of this wildlife movement pathway. The lands south of the highway are known for their ecological diversity and

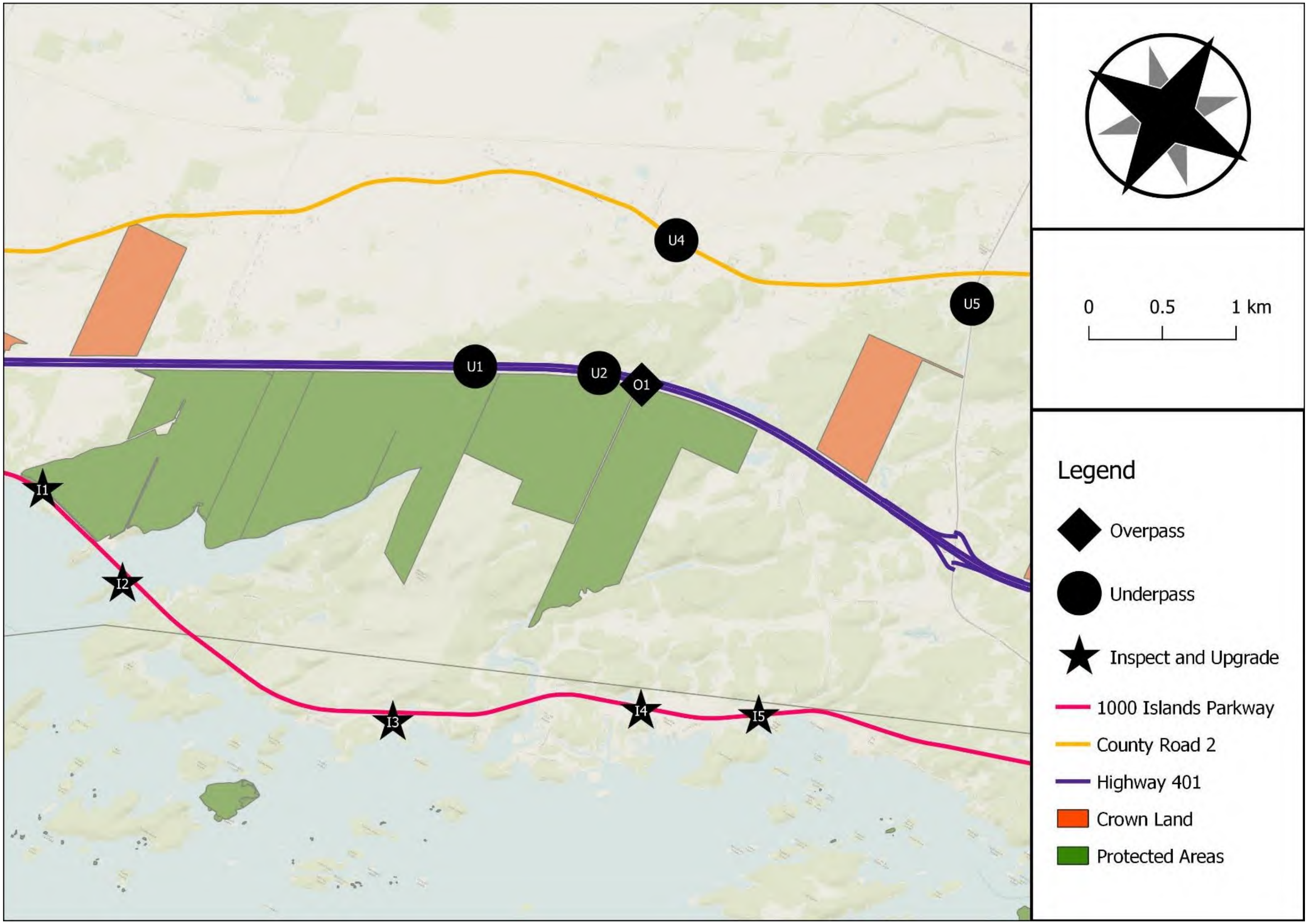


Figure 13: Landons Bay to Lansdowne pathway and recommended locations for mitigation.

comprise an Area of Natural and Scientific Interest (Ross, 2004). Similar habitat exists north to northeast of Highway 401 within the pathway, including on Crown land, but is more fragmented.

A box culvert currently exists at Landons Bay Creek where it crosses Highway 401 and may be suitable for the passage of small and medium-sized mammals, but with potential for significant improvements (Figure 14). This culvert (MTO ID 002204010006) is 2.4 m tall, 2.4 m wide, and 73.8 m long, with an openness ratio (height x width divided by length) of 0.078. An openness ratio of 0.05 is the minimum required for small and medium-sized mammals that are adapted to nocturnal and/or tunnel-like conditions, while larger openness ratios are needed for common herpetiles and at-risk herpetiles (0.1 and 0.25, respectively; Gartner Lee and EcoPlans, 2009). A smaller culvert along this stretch of Highway 401 (MTO ID 002204010030) has low suitability for the passage of herpetiles due to its small size. This culvert is 0.6 m tall, 0.6 m wide, and 28.4 m long, with an openness ratio of 0.013. This culvert also lacks continuity at the highway median and this separation increases travel distance and traffic noise (Ross, 2004). The corresponding area was identified as a location of moderate road mortality for vertebrates along Highway 401 (Danby et al., 2016).

Figure 14: Photo of the existing box culvert at the Landons Bay Creek-Highway 401 crossing.

High road mortality can also be seen on the Thousand Islands Parkway within the Landons Bay to Lansdowne route where the road bisects wetland complexes, specifically the following wetlands from west to east: Halsteads Creek Marsh at Halsteads Bay, the provincially significant Landons Bay Wetland, and the provincially significant Ivy Lea Wetland Complex at Knight's Creek. These complexes extend northeast to run between the Thousand Islands Parkway and Highway 401 before crossing the expressway and continuing northward. Where the Parkway intersects these wetlands, crossings vary from small culverts to larger box culverts and the large bridge over Landons Bay. Despite being approximately 460 m long, the Landons Bay bridge has a single open water underpass that is only 20-30 m wide, limiting safe wildlife passage to a relatively narrow area. Thousand Islands National Park owns protected land directly along the Parkway that encompasses Halsteads Creek Marsh and lands north of Landons Bay that span to Highway 401. Land affiliated with the Ivy Lea Wetland Complex receives some level of protection given the wetland's provincially significant status, though this protection may be temporary.

The bisection of the Landons Bay to Lansdowne migration route by County Road 2 was not identified as a mortality hotspot. Mortality risk along County Road 2 in this area ranged from "lowest" to "medium" (Figure 13). Three locations of moderate road mortality risk were identified: near Kidd Road South in Ebenezer, Reynolds Road in Lansdowne, and Railway Street/Grahams Road in Lansdowne (Figure 13). These areas are associated with a watercourse, wetlands, and forest patches that span both sides of the road.

4.2.1 Recommended Mitigation Measures

4.2.1.1 Recommendation #1: Install overpass with fencing on Highway 401 (O1)

An overpass should be installed over Highway 401 to connect Landons Bay on the south side of the highway to the wetland complex on the north side (Figure 13). Rock cuts of approximately the same elevation on both sides of the lower-lying roadbed would facilitate the construction of an overpass here (Figure 15). Overpasses function as large landscape bridges over highways to enable the passage of a diversity of wildlife, including large mammals, birds, bats, and herpetiles, and are more likely to be used if they incorporate habitat characteristics (Clevenger & Huijser, 2011). They also provide a route for wildlife species that may be deterred from underpasses due to their relatively damp and dark conditions (Danby et al., 2016).

Figure 15: Photo of rock cuts along Highway 401 at the proposed overpass location within the Landons Bay to Lansdowne pathway.

The overpass should be at least 40 m wide to over 100 m wide, with the size depending on site characteristics and engineering feasibility (Clevenger & Huijser, 2011; Smith et al., 2015). The overpass should reflect a continuum of adjacent connecting habitat by utilizing similar substrate and vegetation composition and structure (Clevenger & Huijser, 2011). To attract a variety of species, the overpass should include a mix of open and treed habitat. Trees and shrubs should be planted, particularly at the approaches to the overpass, to provide cover and act as barriers to vehicle lights and noise (City of Surrey, 2021). Cover for smaller fauna such as brush piles and rocks should also be included along the overpass. If feasible, stepping-stone amphibian habitat (i.e., scattered, shallow ponds) could be incorporated using impermeable substrates in certain areas to retain rain and meltwater (Clevenger & Huijser, 2011). Fencing per specifications above should be used to guide animals towards the overpass.

4.2.1.2 Recommendation #2: Retrofit existing tall box culvert on Highway 401 and install fencing (U1)

The existing tall box culvert on Highway 401 at Landons Bay Creek was originally designed for the passage of livestock and therefore considered the movement of larger animals to and from Landons Bay (Ross, 2004). However, well-defined wildlife trails have been observed adjacent to the culvert with fewer signs of animals leading into the culvert (Ross, 2004), suggesting that mammals in the area are more inclined to travel around the underpass. This may be because it is not tall enough for large mammals such as deer, which usually require a minimum clearance height of 3 m (Gartner Lee and EcoPlans, 2009). To encourage use of the underpass, fencing should be installed to direct animals towards the culvert and should follow the specifications provided above.

Landscaping of the culvert floor should also be undertaken to improve footing (Ross, 2004). Incorporation of natural ground cover such as native soil, mulch, deadfall, and/or rocks could achieve this while also attracting smaller mammals, which may be deterred by the open, dark space of the culvert (Forman et al., 2003). Beaver activity in the area may flood the underpass, potentially making it impassable for terrestrial wildlife. Terrestrial shelves (>0.5 m wide elevated walkways) should be added to both sides of the tunnel with access ramps from adjacent upland habitat to promote multiple passage options (Clevenger & Huijser, 2011).

4.2.1.3 Recommendation #3: Replace existing small culvert on Highway 401 and install fencing (U2)

The undersized culvert along Highway 401 within the Landons Bay to Lansdowne pathway should be replaced to make it suitable for herpetile passage. In general, underpasses designed for herpetiles should either be a) culverts that have large enough openings to maintain moisture, temperature, and lighting similar to exterior conditions (e.g., concrete box or bottomless arch culvert), or b) smaller tunnels with surface grates that allow light penetration and promote air flow (Clevenger & Huijser, 2011; Danby et al., 2016). The former approach is preferred as it limits herpetile exposure to traffic noise, vehicle lights, road contaminants, and abrasives (e.g., gravel) associated with grates (Ross, 2004; Kintsch & Cramer, 2011). Sound attenuating walls could be placed above the culvert entrances to further reduce vehicle noise (Clevenger & Huijser, 2011). A larger culvert would promote a multi-species strategy by providing passage for numerous and larger wildlife species beyond herpetiles, such as small and medium-sized mammals. A single culvert that spans the approximately 60 m width of Highway 401 at this location should be used to prevent separation at the median. This culvert should be at least 4 m in diameter to achieve an openness ratio above 0.25 (Gartner Lee and EcoPlans, 2009). Fencing following the specifications above should be installed in combination with the culvert to funnel wildlife into the underpass.

If site conditions cannot accommodate a culvert diameter of approximately 4 m, lighting should be provided to increase visibility. Most wildlife species, including amphibians, are less willing to enter a passage if there is minimal light penetration or if interior lighting differs from the exterior (Forman & Hesperger, 1996; Jackson, 1996; Woltz et al., 2008). The use of underpasses typically significantly increases when light levels are improved, whether ambient, reflected, or artificial, so long as they mimic natural lighting and day cycles (Jackson, 1996; Woltz et al., 2008; City of Surrey, 2021). A simple approach could be to include sun-synchronous artificial lighting or reflective lighting.

The substrate of the underpass should reflect natural terrain, which can also help maintain moisture and humidity. Substrate materials should be fine enough that they do not impede the movement of small animals like amphibians (City of Surrey, 2021). Cover objects for small animals should be included for refuge and protection from predators (Clevenger & Huijser, 2011). If the culvert would retain water year-round, a ramp and shelf design should be incorporated for terrestrial species.

4.2.1.4 Recommendation #4: Investigate existing crossing structures on Thousand Islands Parkway, replace/retrofit as necessary, and install fencing (I1-I5)

Further studies should be conducted to catalogue existing crossing structures along the Thousand Islands Parkway within the Landons Bay to Lansdowne Route. This includes documenting existing conditions of crossing infrastructure (e.g., openness ratio) and associated habitat areas, assessing suitability for wildlife passage, and identifying improvement opportunities. Alternatively, the agency responsible for maintaining the Parkway should consult road ecology experts before maintenance works to consider improvement opportunities on a case-by-case basis. At a minimum, permanent exclusion fence should be installed along the Thousand Islands Parkway where it traverses the wetlands described above in conjunction with existing crossings. Figure 13 identifies five areas of moderate to high mortality along the Parkway (I1 through I5) where inspections and upgrades are required in conjunction with the installation of fencing.

Exclusion fence should be designed to funnel animals towards crossings and suitable habitat. It is critical that fencing is installed in association with appropriate crossings since poorly placed fencing on its own can further isolate wildlife. Given that multiple taxa were observed dead in considerable numbers on the Parkway in the Landons Bay to Lansdowne pathway (Garrah et al., 2015), fences should be designed to exclude a variety of wildlife groups, including herpetiles and mammals. To achieve this, a fence should span both sides of the road for segments as long as possible, and road areas next to wetlands should be prioritized. Fencing should be made of material that excludes small animals but allows water penetration (e.g., fine hardware cloth or concrete, vinyl, or aluminum with small cracks), be buried below ground 15-20 cm, and have a minimum aboveground height of 2 m (Clevenger & Huijser, 2011; OMNRF, 2016). This height is intended to exclude larger mammals along with the threatened gray ratsnake, which is an excellent climber and was observed dead along the Parkway by Garrah et al. (2015). The fence should also have an overhanging lip extended away from the road to prevent snakes from climbing over it. The ends of the fence should curve away from the road in a U-shaped fashion to guide animals back into habitat rather than towards the road (OMNRF, 2016).

Since a 2 m tall fence could arguably reduce the aesthetics of the Thousand Islands Parkway, the fence could be installed in a depressed area along the roadside, effectively lowering the fence height relative to the road and making it less conspicuous. Installing the fence further from the road, like at the bottom of the embankment slope or roadside ditch, may also help prevent damage from road operations such as resurfacing and snow removal. Landscaping around the fence could also help it blend in with its surroundings (Clevenger & Huijser, 2011; OMNRF, 2016). Regardless, potential issues related to aesthetics are significantly outweighed by the benefits of wildlife fencing (e.g., increased road safety and less wildlife death) and are typically associated with overwhelming public support (T. Kinley, personal communication).

4.2.1.5 Recommendation #5: Install underpass on County Road 2 with fencing (U3)

The intersection of County Road 2 with Railway Street/Grahams Road is surrounded by patches of discontinuous to continuous forest interspersed with agricultural land and rural properties. No watercourse crossings were observed in this area. The addition of a wildlife underpass near 44.405408, -75.993036 would connect forest patches on either side of County Road 2 that are linked to a forest corridor that spans all the way to Charleston Lake Provincial Park. This underpass should be designed for the passage of small to medium-sized vertebrates with a diameter of >2 m to achieve an openness ratio of approximately 0.25 (Gartner Lee and EcoPlans, 2009). The substrate of the underpass should mimic natural soils and conditions. The incorporation of cover material will encourage use by amphibians and small mammals (Clevenger & Huijser, 2011). A guiding fence or retaining wall along the road that is 60 cm or more above ground will be crucial in directing herpetiles towards the culvert (OMNRF, 2016). At a minimum, the fence should span the length of continuous forest habitat on both sides of the road (approximately 200 m) but may have to be adjusted to account for private land ownership.

4.2.1.6 Recommendation #6: Replace/retrofit existing small culverts on County Road 2 and install fencing (U4 and U5)

The area of County Road 2 near Kidd Road South is associated with a shallow, narrow drain crossing at 44.385754, -76.0414641 (U4). Habitat on either side of the road is dominated by agricultural lands and therefore the drain likely acts as a funnel for wildlife, particularly aquatic and semi-aquatic species like herpetiles and muskrats. The crossing at County Road 2 consists of a small plastic culvert. Assuming a tunnel length of approximately 20 m based on the width of County Road 2, this culvert should be replaced with a 2.5 m diameter culvert to promote the passage of herpetiles and other small and medium-sized vertebrates (Gartner Lee and EcoPlans, 2009). It should be large enough to span the channel and its riparian area to capture the entire movement pathway. A culvert that is 2.5 m in diameter should promote air flow and light penetration at the entrances. The culvert should be prefabricated concrete rather than steel due to the high thermal conductivity of steel (i.e., will be cold during spring migration). The substrate should preferably be native soils or sandy loam or pea gravel to facilitate anuran passage (Clevenger & Huijser, 2011; Pomezanski, 2015). Drainage improvements surrounding the culvert may be required to prevent flooding at the culvert entrances, which may deter amphibians. Providing cover material within the culvert will encourage use by amphibians and small mammals (Clevenger & Huijser, 2011). Incorporation of a guiding fence or wall along approximately 100 m of both sides of the road that is 60 cm or more above ground will be crucial in directing herpetiles towards the culvert (OMNRF, 2016). The fence length may have to be adjusted to account for private land ownership.

South of the intersection of County Road 2 and Reynolds Road is a large wetland complex that spans both sides of Reynolds Road (approximately 44.391395, -76.016944; U5). Reynolds Road likely has multiple drainage culverts south of County Road 2 in areas with open water wetlands and channels. Wildlife movement likely occurs in an east-west/west-east fashion here over and under Reynolds Road, following the intact pathway of wetlands and forests south of County Road 2. Mortalities observed along County Road 2 within this area are most likely associated with animals moving to and from these habitats, or the remnant forest patch northwest of the County Road 2 – Reynolds Road intersection, though the latter is less likely. Habitat north of County Road 2 is highly fragmented and consists mostly of agricultural land with scattered relic forest patches. Connections between the optimal habitat on either side of Reynolds Road south of County Road 2 should therefore be prioritized for mitigation. As proposed for the Thousand Islands Parkway within the Landons Bay to Lansdowne route, crossings on Reynolds Road should be upgraded when feasible and permanent exclusion fence should be installed in conjunction with crossings. This fencing should be designed to mostly exclude herpetiles and small mammals, and therefore the height should be at least 60 cm above ground and should use a wildlife-impermeable material such as small gauge hardware mesh (OMNRF, 2016). Fencing should span the length of adjacent wetland habitat, at a minimum.

4.3 Rockport to Waterton Pathway

The pathway from Rockport to Waterton (Figure 16) is potentially the most critical link in the Algonquin to Adirondacks connection. It is the centre of the Frontenac Arch pathway with the greatest diversity of species, the highest rates of road mortality, and the greatest impact on at-risk turtle and snake species. Both field data and predictive modelling for all three major roadways have identified the Rockport to Waterton route as the highest priority area to mitigate. Restoring this habitat connection is critical to prevent at-risk herpetile populations from becoming genetically isolated and to avoid further population decline due to road mortality.

Resilient land mapping indicates that the Rockport to Waterton route is highly intact and therefore facilitates high landscape connectivity, diversity, and capacity to maintain ecological function as the climate changes (Nature Conservancy of Canada, 2022). It also identifies pinch-points between the Thousand Islands Parkway and Highway 401 near Rockport and between Highway 401 and County Road 2 near Waterton where landscape flows are concentrated in a narrow area (Nature Conservancy of Canada, 2022). The pathway and associated pinch-points are clearly visible from aerial imagery due to extensive land use alterations for agriculture, industry, and urban development in the surrounding area. Urban sprawl from Ottawa in the east and Kingston and Peterborough in the west has created a bottleneck that filters wildlife into this narrow tract of remaining connected habitat. In addition to containing provincially significant wetlands, this remaining habitat has significant patches of forests that are more than 125 years old (Thousand Islands National Park, unpublished data).

Within the Rockport to Waterton Route, there have been devastating impacts to at-risk herpetiles and other vertebrates along Highway 401 between exit 661 (Highway 137) and Escott-Rockport Road, resulting in the two most significant hotspots in the study area. This is in part due to the intact wetland complexes adjacent to the highway here combined with insufficient wildlife crossing infrastructure. To date, MTO has taken an important first step in

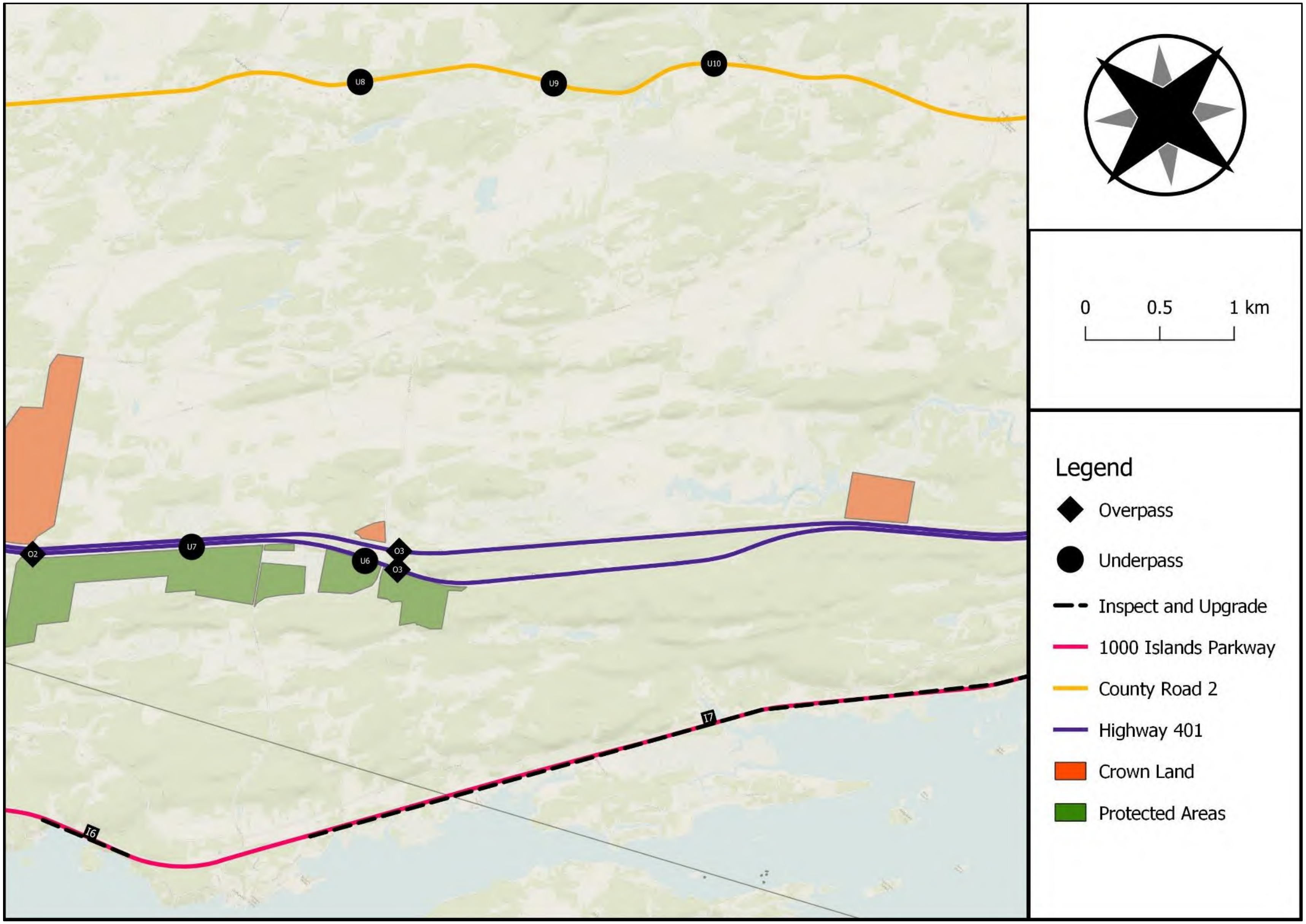


Figure 16: Rockport to Waterton pathway and recommended locations for mitigation.

installing wildlife fencing along a portion of the highway in this area and sponsored research and monitoring to assess the effectiveness of this fencing. Approximately 1 km of fencing was installed on both sides of the highway between Darlingside Drive and Escott-Rockport Road (approximately 44.38664, -75.96531 to 44.39383, -75.95460; Figure B3). This fencing has significantly reduced mortality and generated recommendations on how to further reduce mortality through fencing improvements (Baker & Danby, 2021). However, this area needs substantially greater upgrades to be restored to a successful movement pathway. Thousand Islands National Park owns land on the south side of Highway 401 directly adjacent to two major hotspots identified within the Rockport to Waterton route (Figure 16), ensuring that wetlands and forests here will be protected. There is also a mixture of private and general use provincial Crown land to the north that encompasses wetland and forest habitat.

A 3 km stretch of the Thousand Islands Parkway along Thompson's Bay within the Rockport to Waterton route was previously identified as the most significant mortality hotspot along the Parkway (Figure B4). This portion of the Parkway runs along the provincially significant Grenadier Island Wetland Complex, with substantial mortalities of turtles, snakes, frogs, and birds observed in multiple years (Garrah et al., 2015). Our analyses suggest that this hotspot extends further than 3 km and reflects the length of the wetland along the road. Another high mortality area was identified along the Parkway near Redstone Isle. Here the Parkway is bound by open water of the St. Lawrence River to the south and intact wetlands and forests to the north.

County Road 2 between Blue Mountain Road in Mitchellville and Escott-Rockport Road in Escott was identified as a mortality hotspot for herpetiles. Here the road passes through wetlands and forests that are part of a large pathway of natural habitat that extends between Charleston Lake Provincial Park and the St. Lawrence River. This portion of County Road 2 crosses three tributaries of LaRue Creek in the following locations from west to east: a box culvert at 44.421285, -75.969732, a small culvert at 44.4287213, -75.957134, and a bridge at 44.435847, -75.947850.

4.3.1 Recommended Mitigation Measures

4.3.1.1 Recommendation #1: Install two overpasses with fencing on Highway 401 (O2 and O3)

We propose the installation of two overpasses corresponding with the two most critical hotspots along Highway 401 within the Rockport to Waterton route (Figure 16). These overpasses would be within approximately 2.5 km of one another, reflecting a two-way split in this wildlife movement pathway

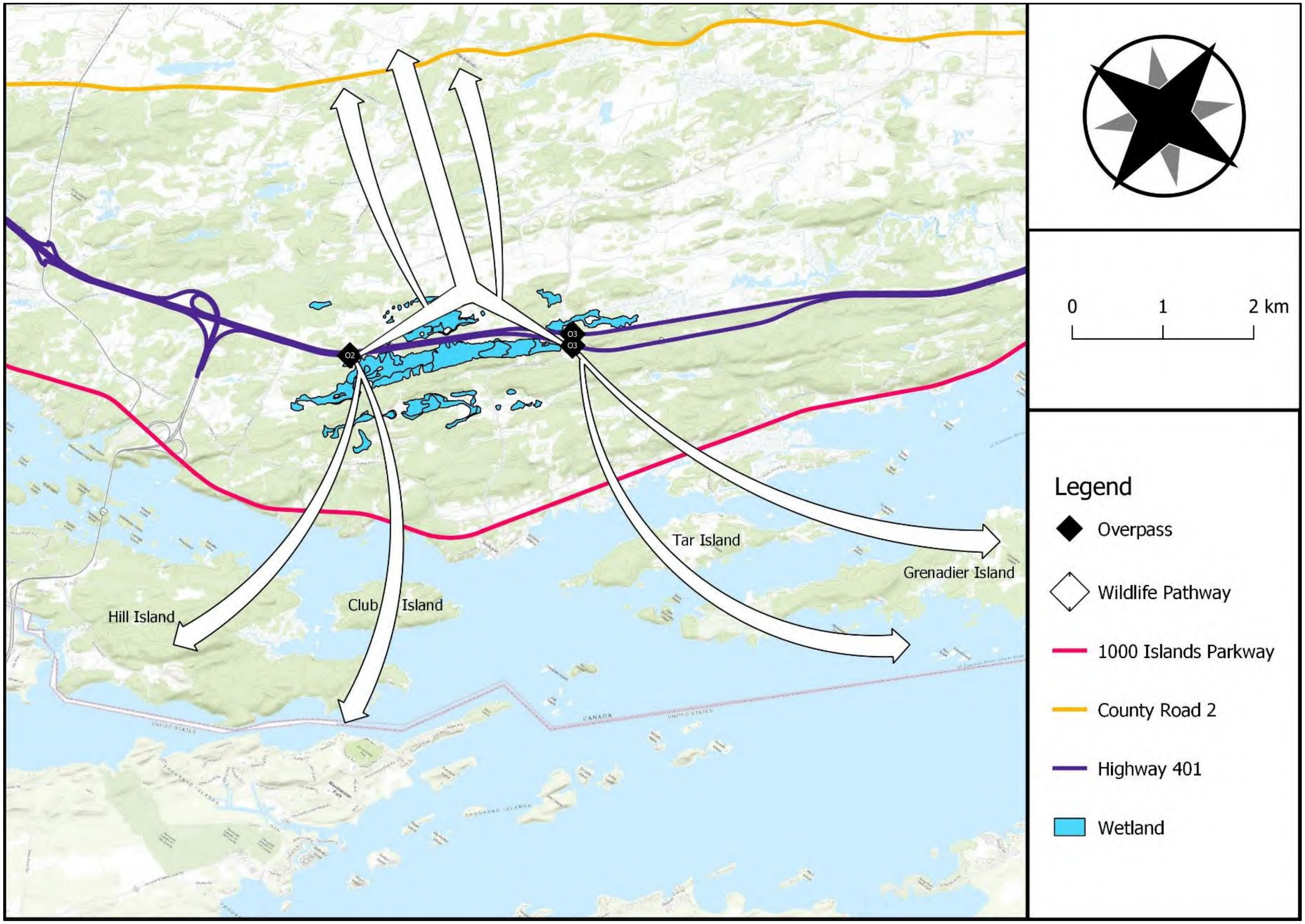


Figure 17: Proposed locations of overpasses on Highway 401 within the Rockport to Waterton pathway. Map shows wetland cover adjacent to Highway 401 between the two overpasses, which causes a split in wildlife movement along the broader pathway.

south of Highway 401 that then merges into one pathway north of the highway towards Charleston Lake Provincial Park (Figure 2, Figure 17). The southern split corresponds with a massive wetland complex immediately south of the highway, which likely poses a barrier to terrestrial species (Figure 17). Here terrestrial species are likely funnelled to upland forested areas on either side of the wetland complex. This split continues south of the wetland complex, with a western route leading towards Hill and Wellesley Islands and an eastern route leading towards Tar and Grenadier Islands (Figure 17). The split towards Hill Island is supported by white-tailed deer tracking data for the area, which show movement between this island and the mainland via Huckleberry Island (Sucharzewski, 2022). The eastern split aligns with local knowledge of movement patterns for deer and turtles, which have been observed moving between the mainland and Grenadier Island (S. Lambert, personal communication). Turtle tracking data have also demonstrated movement within the southern portion of this eastern split, from the north side of Grenadier Island to Thompson's Bay and from the south side of Grenadier Island towards the U.S. (Devlin, 2004).

The western overpass should be built west of the wetland complex and existing fence where there is dry land on both sides of the highway and a rock cut on the north side of the highway (approximately 44.386749, -75.965242; O2). The eastern overpass should be east of Escott-Rockport Road adjacent to upland forest that connects to the wetland complex (approximately 44.400171, -75.940820; O3). There are rock cuts on either side of the highway at this location (Figure 18) which should facilitate the engineering and construction of an overpass.

Figure 18: Photo of rock cuts along Highway 401 at the proposed western overpass location within the Rockport to Waterton pathway.

These overpasses should follow design guidelines provided above for the proposed Highway 401 overpass within the Landons Bay to Lansdowne pathway. The design of the eastern overpass would need to accommodate the lane split and land divide of Highway 401 near Escott-Rockport Road. The lane split here likely contributes to wildlife mortality by imposing increased barriers to connectivity (i.e., two parallel roads lined with rock walls). The design of the eastern overpass should therefore consist of two shorter aligned overpasses with the middle land divide fully fenced. This overpass would run parallel to and in proximity with Escott-Rockport Road; measures to ensure connectivity along Escott-Rockport Road should also be considered to ensure that animals can safely reach the overpass.

4.3.1.2 Recommendation #2: Replace existing culverts on Highway 401 and install additional fencing (U6 and U7)

Culverts along the stretch of Highway 401 between Highway 137 and Escott-Rockport Road consist of two large box culverts (U6 and U7) and corrugated steel pipes that support drainage of the provincially significant LaRue Mills Creek Wetland Complex on both sides of the highway (details in Danby et al., 2016). We propose that these culverts be upgraded to improve the movement of herpetiles and small and medium-sized mammals. The box culverts are prone to flooding (Figure 19) and therefore should be replaced with larger culverts (>3 m diameter) to accommodate drainage and sufficient light penetration. They should also include terrestrial shelves (>0.5 m wide elevated walkways) on both sides of the tunnel with access ramps from adjacent upland habitat to incorporate “dry” passage options (Clevenger & Huijser, 2011).

The corrugated steel pipes should be replaced with culverts at least 3 m in diameter with appropriate substrate and cover objects per specifications above. Use of these underpasses would be encouraged by fencing. The existing fencing on both sides of Highway 401 should be extended another approximately 3 km to fully span the stretch of highway between Highway 137 and Escott-Rockport Road, corresponding with the most significant wildlife mortality hotspots identified in this study. Gaps along the existing fence should be closed to prevent these openings from becoming unsafe passage areas for wildlife.

Figure 19: Photo of flooded box culverts (circled in red) on Highway 401 between Highway 137 and Escott-Rockport Road.

4.3.1.3 Recommendation #3: Investigate existing crossing structures on Thousand Islands Parkway, replace/retrofit as necessary, and install fencing (I6 and I7)

Future studies should aim to document culverts along the stretch of the Thousand Islands Parkway within the Rockport to Waterton route, along with their potential for wildlife passage and associated improvements. Existing culverts are likely undersized and should be upgraded to make them more conducive to wildlife passage. At a minimum, permanent fencing to guide herpetiles to existing crossing structures should be implemented, spanning the Redstone Isle area from 44.37484, -75.95015 to 44.37664, -75.94187 (I6) and the Grenadier Island Wetland Complex from approximately 44.42412, -75.89057 to 44.38444, -75.93197 (I7; Figure 16). Fencing design should follow recommendations provided for the Thousand Islands Parkway within the Landons Bay to Lansdowne route and should be tall enough (>2 m) to exclude gray ratsnake.

4.3.1.4 Recommendation #4: Retrofit existing box culvert on County Road 2 and install fencing (U8)

The existing box culvert on County Road 2 within the Rockport to Waterton route is suitable for herpetile passage based on size, air flow, and light penetration (Figure 20). Natural cover objects should be added in the tunnel and near the entrances to further encourage use by amphibians, snakes, and small to medium-sized vertebrates. Herpetile fencing should be installed adjacent to the road along the length of associated wetland habitat (at least 100 m long) and should follow specifications above to be effective for a variety of reptiles, including gray ratsnake (i.e., >2 m tall). Terrestrial shelves and access ramps should be added to promote use of medium-sized mammals.

Figure 20: Photo of box culvert on County Road 2 within the Rockport to Waterton pathway.

4.3.1.5 Recommendation #5: Replace existing culvert on County Road 2 and install fencing (U9)

The tributary crossing on County Road 2 at 44.4287213, -75.957134 (U9) is associated with wetland on both sides of the road and consists of a small, embedded culvert (Figure 21). It is significantly undersized for herpetile passage and should be replaced with a larger culvert (>2 m diameter). The culvert should be accompanied by at least 2 km of fencing along the wetland to guide amphibians, turtles, snakes, and other small to medium-sized vertebrates towards the underpass. Fencing should be of material that is impermeable to wildlife and at least 2 m above the ground (OMNRF, 2016).

Figure 21: Photo of the undersized culvert on County Road 2 within the Rockport to Waterton pathway.

4.3.1.6 Recommendation #6: Install fencing along existing bridge on County Road 2 (U10)

The bridge crossing on County Road 2 at 44.435847, -75.947850 (U10) corresponds with a rock-walled channel with relatively fast flows (Figure 22). These conditions likely deter herpetile presence but are likely to support other aquatic animals such as fish and muskrats. The simple and most appropriate solution here is to add a wildlife fence with a height >2 m tall along both sides of the bridge to guide animals towards the underpass (OMNRF, 2016). At a minimum, fencing should span the length of riparian habitat associated with the tributary, which is approximately 50 m long. There are two residences very close to the bridge that may limit fence length.

Figure 22: Photo of the bridge on County Road 2 that crosses a tributary of LaRue Creek.

4.4 Jones Creek Pathway

The easternmost pathway identified for mitigation efforts is the Jones Creek route (Figure 23). This area is arguably the most intact pathway of habitat moving north across the Frontenac Arch. Circuitscape analyses identified the Jones Creek pathway as a small pocket of high landscape connectivity between the Thousand Islands Parkway and Highway 401. It also has a high NHS score with great potential for habitat linkages on both sides of Highway 401. The large, provincially significant Jones Creek Marsh within this pathway connects with Charleston Lake Provincial Park through riparian and forested linkages. A meandering stream runs east from Charleston Lake Provincial Park passing by several small wetland complexes and eventually crosses under Highway 401 where it meets the St. Lawrence River at Jones Creek. This level of habitat connectivity is rare in southeastern Ontario and serves as a critical link in the Algonquin to Adirondacks connection.

In many locations, agricultural development north of Highway 401 creates connectivity challenges between the St. Lawrence region and areas further north. However, at Jones Creek, minimal agricultural development northwest of the Highway 401 crossing should allow wildlife to pass through relatively intact habitat on a migration path northwest. This area contains a relatively large expanse of intact forests and wetlands, but this habitat is severed by Highway 401 (Figure 24). As a result, this section of the highway is identified as a road mortality hotspot with the highest density of mortality east of Rockport (Danby et al., 2016). County Road 2 and the Thousand Islands Parkway intersect this pathway with relatively lower mortality risk to wildlife, although some remediation on these two roads is still required.

Thousand Islands National Park owns a significant portion of protected land within the Jones Creek route that spans from immediately south of Highway 401 to the Thousand Islands Parkway (Figure 23). Much of Jones Creek and its riparian area would receive some level of protection outside of Thousand Islands National Park lands through the provincially significant status of Jones Creek Marsh, though this protection may be temporary.

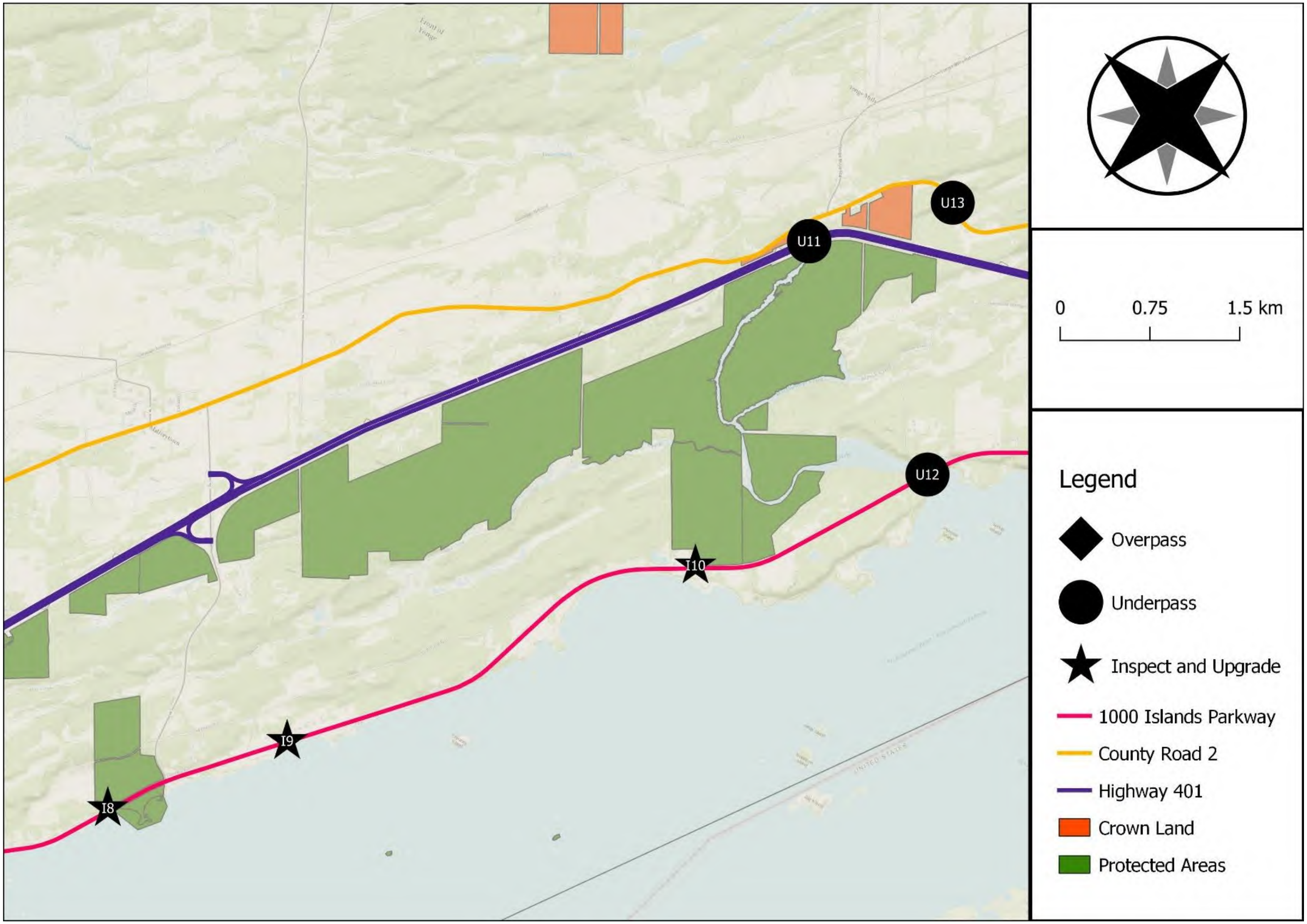


Figure 23: Jones Creek pathway and recommended locations for mitigation.

Figure 24: Aerial photo of the Jones Creek wildlife pathway where it is severed by County Road 2 and Highway 401 (© Thousand Islands National Park, 2023).

4.4.1 Recommended Mitigation Measures

4.4.1.1 Recommendation #1: Replace existing underpass on Highway 401 and install fencing (U11)

Jones Creek passes under Highway 401 near Yonge Mills Road through an arch-shaped concrete tunnel (U11; Figure 25). Flows of the creek are relatively swift here with riffles in the tunnel (Ross, 2004). The sound of the rushing water combined with the darkness of the tunnel may deter wildlife passage. There are well-defined deer and coyote trails leading to the northern entrance of the tunnel but there is uncertainty surrounding whether these animals use the underpass or are merely guided to it via the creek corridor (Ross, 2004). A narrow (<25 cm wide), elevated cement shelf runs along both sides of the culvert, conceivably providing opportunities for small to medium-sized mammals such as muskrats and raccoons to pass, but a wider and naturalized ledge would certainly increase this possibility (Ross, 2004).

Figure 25: Photo of Jones Creek underpass at Highway 401.

The existing arch-shaped tunnel should be replaced with a larger underpass. This could be a concrete bottomless arch, an open span bridge, or large bottomless box culvert. Regardless of the type of underpass, it should be at least 4.5 m tall and sufficiently wide to encompass the maximum riparian area of Jones Creek and a portion of adjacent upland habitat, with a minimum width of 12 m (Clevenger & Huijser, 2011). This size of underpass would allow light penetration, large animal passage, and the incorporation of natural terrestrial ledges by including the riparian zone and banks of the creek and adjacent upland habitat. Salvage material such as logs, root wads, and rocks should be used to incorporate cover objects and microhabitat features within the underpass. Fencing should be used to guide animals into the underpass following specifications in Section 4.1.1.

4.4.1.2 Recommendation #2: Retrofit Jones Creek bridge on Thousand Islands Parkway (U12)

The Thousand Islands Parkway crosses Jones Creek via a bridge at the creek's confluence with the St. Lawrence River (U12; Figure 26). This area was assessed as having a low wildlife mortality risk but should be remediated to prevent it from becoming a hotspot. The approximately 60 m long bridge accommodates an open water passage that is approximately 20 m wide. Recent bridge remediation work involved the addition of gravel and rip-rap at the footings of the bridge.

Figure 26: Photo of the Thousand Islands Parkway bridge at Jones Creek.

Fencing should be installed in association with the existing bridge to prevent wildlife from crossing the Parkway and to funnel animal movement through the underpass. Fencing should be made of material that is impermeable to wildlife and be at least 2 m tall to be effective for herpetiles including gray ratsnake (OMNRF, 2016). The adjacent area is known critical habitat for this species, which is typically observed on the road here. Private land ownership, steep slopes, and public access will have to be considered in the design and location of fencing. Since the area surrounding the bridge is often accessed by local anglers, the best solution may be to fence off the riparian area.

The bridge footings should be naturalized to the extent possible by incorporating native soil, plantings, and other natural cover objects (e.g., logs). Not only would this improve erosion control, but it would also enhance upland habitat associated with the underpass, encouraging use by terrestrial species in addition to aquatic and semi-aquatic species. Turtle hatchlings can get trapped when navigating across rip-rap, so amending the bridge footings by adding soil would further facilitate movement.

4.4.1.3 Recommendation #3: Investigate existing crossing structures on Thousand Islands Parkway, replace/retrofit as necessary, and install fencing (I8, I9, and I10)

Three areas of medium to high herpetile mortality risk were identified along the Thousand Islands Parkway within the Jones Creek pathway (I8 through I10; Figure 23). These locations are affiliated with the provincially significant Browns Bay Wetland Complex, which occurs on the south side of the Parkway. Location identifier I8 is also associated with the crossing of a tributary of the St. Lawrence River. These areas should be investigated, potentially as part of scheduled inspection and/or maintenance, to assess existing crossing structures and to determine appropriate remedial action. At a minimum, fencing should be installed in conjunction with crossings and should follow specifications previously provided for the Thousand Islands Parkway.

4.4.1.4 Recommendation #4: Replace culvert on County Road 2, install signage, and reduce speed limit (U13)

A significant herpetile mortality hotspot was identified along County Road 2 east of Yonge Mills Road within the Jones Creek migration pathway. This hotspot is associated with intact wetlands and forests on either side of County Road 2 along with a sharp bend in the road where visibility is poor (Figure B6, Figure 23). A watercourse crossing exists at 44.521918, -75.8179610 (U13) and consists of a small, embedded culvert (Figure 27) that should be replaced with a prefabricated concrete culvert >2 m in diameter to promote the passage of herpetiles and other small and medium-sized vertebrates (Clevenger & Huijser, 2011). The substrate should be native soils, sandy loam, or pea gravel to facilitate anuran passage (Clevenger & Huijser, 2011; Pomezanski, 2015). Drainage improvements surrounding the culvert may be required to prevent flooding at the culvert entrances, which may deter amphibians. Providing cover material within the culvert will encourage use by amphibians and small mammals (Clevenger & Huijser, 2011). Wildlife fencing >2 m tall should be installed to direct wildlife towards the underpass and should span the length of wetland habitat associated with this mortality hotspot (at least 250 m).

Figure 27: Photo of the undersized culvert on County Road 2 within the Jones Creek pathway.

Signage and a reduction in speed limit will be important along this curved stretch of County Road 2 to account for reduced visibility. The speed limit should be reduced to 60 km/hr from May 1 to October 31 to limit road mortalities during the active season for most wildlife (Urquhart et al., 2018). Wildlife crossing signs and/or wildlife habitat awareness signs should be placed 500 m before the identified hotspot and on both sides of the road to warn drivers of the oncoming road mortality risk (Urquhart et al., 2018).

4.5 General Mitigation Measures for Highway 401, Thousand Islands Parkway, and County Road 2

In addition to the specific mitigation measures proposed for each of the three major roadways above, the following general mitigation measures are recommended to support wildlife movement and landscape connectivity within the key migration pathways:

- The A2A Road Ecology Committee should obtain road project and maintenance schedules on an annual basis to facilitate collaboration on the design of upgrades to enhance wildlife passage. Similarly, road ecologists should be consulted early in the planning stages for new crossings and fencing to ensure that they are designed appropriately for wildlife. Road ecologists and road managers (i.e., MTO, St. Lawrence Parks Commission, municipalities) should meet annually to review mitigation plans.
- Where crossing infrastructure cannot be installed or replaced due to engineering feasibility or other constraints, work in partnership with road ecologists to consider alternatives such as retrofitting and remediating existing crossings.
- The design of wildlife passage infrastructure should consider future road improvements (i.e., road widening) to ensure longevity of crossings and to prevent disruptions to mitigation measures. Our recommendations are based on the current configurations of the three roadways of interest, but these designs are subject to change. For example, there are plans to expand Highway 401 to six lanes between Gananoque and Brockville, and a 4.5 km stretch within Brockville will be expanded to eight lanes (IN Engineering, 2020). Other stretches of Highway 401 east of the study area are also planned for expansion to eight lanes (MTO, 2021). Plans for mitigation should consider wider roads and increased traffic volumes, which will further exacerbate wildlife-vehicle conflicts in the absence of suitable wildlife crossing infrastructure.
- Monitoring and maintenance plans should be incorporated into infrastructure improvement strategies to ensure the efficacy and long-term functionality of mitigation measures. Well-designed mitigation measures that are not monitored and maintained can increase wildlife mortalities. For instance, Baxter-Gilbert et al. (2015) found that turtles chose to cross Highway 69 in Ontario through holes in damaged exclusion fence rather than through underpasses, increasing the number of turtles found dead on the road by 20% post-mitigation.
- Develop and support the execution of a land acquisition strategy to ensure that lands on either side of wildlife crossings are perpetually preserved. Coordinated implementation of the recommended mitigation measures on protected lands and with conservation organizations will

further aid in restoring wildlife connectivity across the Frontenac Arch. Consideration of land use surrounding the major roadways will be essential in maintaining the ecological integrity of landscape connections within the broader A2A pathway while pressure for land development increases and incremental loss of habitat accumulates.

- For wildlife mortality hotspots along all three roadways, minor mitigation measures such as improving signage (e.g., wildlife signs that flash during high-risk periods), adding rumble strips, installing optical speed bars, and permanently or temporarily reducing speed limits should be considered to influence driver behaviour (OMNRF, 2016). These mitigative actions should also be considered for municipal roads within the identified wildlife movement pathways. Electronic signs on road shoulders could include information on wildlife pathways and warnings during peak wildlife crossing times. Similar information could be broadcasted on local radio stations and traveller's information stations.
- Increasing public awareness on wildlife-road issues would inform people how they can help prevent animal-vehicle collisions. An education campaign would also improve public acceptance of the proposed mitigation measures (OMNRF, 2016). Raise awareness by partnering with experts, local naturalist groups, and conservation organizations such as Leeds and Grenville Turtles and Turtles Kingston. Involve citizens and volunteers through initiatives such as Kingston's Turtle Nest Protection Program and Lanark County's Observing, Understanding, Rescuing (OUR) Turtles. These programs involve roadside turtle monitoring, reporting on and transporting injured turtles, and installing nest protectors along roadsides.
- Routine highway maintenance such as road resurfacing and mowing road shoulders can directly kill wildlife, particularly turtles and snakes (Danby et al., 2016). Mowing outside of peak herpetile movement periods and raising the height of mower blades can help prevent this. Similarly, since turtles frequently nest in roadside habitats, resurfacing should be conducted outside of turtle nesting and hatching times (June to October) to protect adult females, nests, and hatchlings (Danby et al., 2016; MTO, 2017).
- In areas where proposed crossing infrastructure and wildlife movement pathways interact with agricultural land, encourage landowner partnerships with ALUS to promote the maintenance and creation of habitat features on these properties. Agricultural landowners should also be urged to participate in funding programs that incentivize farmers to conduct stewardship activities on their land. These includes programs such as the Species at Risk Farm Incentive (SARFIP) and the Species at Risk Partnership on Agricultural Lands (SARPAL). By participating in these programs, agricultural landowners can contribute to maintaining and restoring connectivity in the priority wildlife movement pathways.

- Human interaction with crossing structures can deter wildlife. Prevent humans from using underpasses, overpasses, and adjacent areas through public awareness, signage, and by prohibiting motor and all-terrain vehicle use in these areas (Clevenger & Huijser, 2011).
- In addition to requiring approval from road authorities, the proposed infrastructure improvements may require permission from environmental agencies such as Fisheries and Oceans Canada and Conservation Authorities. Relevant environmental agencies should be consulted and obligations of permits, if required, should be followed.

5 Conclusion

This report makes clear, scientifically based recommendations that are founded on a compilation of extensive research and reports completed over the past 18 years. The proposed mitigation measures are specific to stretches of Highway 401, the Thousand Islands Parkway, and County Road 2 where these roadways intersect key wildlife movement pathways along the Ontario portion of the Frontenac Arch. We provide a strategy that considers the collective impacts of all three roads, the distribution and configuration of natural habitat along the Frontenac Arch, and appropriate techniques to restore landscape connectivity in this continentally important region. Undertaking the full suite of recommendations would result in massive benefits to Ontario's ecosystems, biodiversity, and climate change resiliency by substantially reducing road mortality and helping to restore landscape connectivity. Implementation of the recommended infrastructure improvements would also reduce safety risks to drivers related to wildlife-vehicle collisions, along with associated economic costs to society.

Mitigating the ecological impacts of roads is becoming common practice. This report provides numerous examples of successful mitigation actions across Canada, varying in scope from temporary road closures to building multiple overpasses. Investing in infrastructure that supports ecosystem resilience enables both natural and human communities to thrive as we adapt and mitigate the biodiversity and climate change crises.

A2A and the authors of this report are dedicated to restoring habitat connectivity across the Frontenac Arch. We will collaborate with road management agencies and conservation organizations to examine all options to develop and implement successful infrastructure and mitigation strategies dedicated to safe wildlife passage. We will consider alternative locations and configurations for wildlife crossings, particularly if there are major feasibility constraints. Along with American members of the A2A Collaborative and A2A's American partners, and with the Wildlands Network, we will work to ensure that mitigation strategies on the U.S. side of the Frontenac Arch will align with those on the Canadian side, and with those of the broader Eastern Wildway. The A2A region contains the pinch-point in eastern North America's crucially important biological pathway that is essential to maintaining longer-term and broader scale landscape connectivity on a continental basis from Georgia in the south to the boreal forest in the north. Creating structures at the pinch-point for wildlife to cross over and under major roads on the Canadian side of the St. Lawrence River is an urgent provincial and national issue within Canada, for wildlife protection and human safety, and has international implications.

6 Literature Cited

Alberti, M., Palkovacs, E.P., Roches, S.D., De Meester, L., Brans, K.I., Govaert, L., Grimm, N.B., Harris, N.C., Hendry, A.P., Schell, C.J., Szulkin, M., Munshi-South, J., Urban, M.C., Verrelli, B.C. 2020. The complexity of urban eco-evolutionary dynamics. *BioScience,* 70(9): 722-793.

Ament, R., Callahan, R., McClure, M., Reuling, M., and Tabor, G. 2014. Wildlife Connectivity: Fundamentals for Conservation Action. Center for Large Landscape Conservation, Bozeman, Montana.

Aresco, M.J. 2005. Mitigation measures to reduce highway mortality of turtles and other herpetofauna at a North Florida lake. *Journal of Wildlife Management*. 69: 549–560.

Arnott, S.E., Celis-Salgado, M.P., Valleau, R.E., DeSellas, A.M., Paterson, A.M., Yan, N.D., Smol, J.P., Rusak, J.A. 2020. Road salt impacts freshwater zooplankton at concentrations below current water quality guidelines. *Environmental Science & Technology,* 54: 9398–9407.

Ashley, E.P., & Robinson, J.T. 1996. Road mortality of amphibians, reptiles and other wildlife on the Long Point Causeway, Lake Erie, Ontario. *Canadian Field-Naturalist,* 110: 403–412.

Ashley, E. P., Kosloski, A., Petrie, S.A. 2007. Incidence of intentional vehicle-reptile collisions. *Human Dimensions of Wildlife,* 12: 137-143.

Atlas Obscura. 2023. Banff Wildlife Crossings. Available at: https://www.atlasobscura.com/places/banff-wildlife-crossings

Baker, S. and R. Danby. 2021. Assessment of Highway #401 Wildlife Fencing Hwy #137 to Escott-Rockport Road. Prepared for the Ministry of Transportation of Ontario. 115 pp.

Baker, S., Danby, R., Urquhart, J., and Gunson, K. 2021. Assessment of highway #401 wildlife fencing, Hwy #137 to Escott-Rockport Road. Report prepared for the Ontario Ministry of Transportation. MTO HIIFP Project 2018-14. 115 pages.

Baker, S. 2022. An adaptive design to reduce animal road mortality: Analyzing the effectiveness of a fence-culvert ecopassage design on Highway 401, Ontario. [Master's thesis]. School of Environmental Studies, Queen's University, Kingston, ON.

Barnett, K., & Belote, R.T. 2021. Modeling an aspirational connected network of protected areas across North America. *Ecological Applications*, 31(6), e02387.

Baxter-Gilbert, J.H., Riley, J.L., Lesbarrères, D., Litzgus, J.D. 2015. Mitigating reptile road mortality: Fence failures compromise ecopassage effectiveness. *PLoS ONE,* 10(3): e0120537. https://doi.org/10.1371/journal.pone.0120537

Beebee, T.J.C. 2013. Effects of road mortality and mitigation measures on amphibian populations. *Conservation Biology,* 27(4): 657-668.

Bennett, V.J., & Zurcher, A.A. 2012. When pathways collide: Road-related disturbance in commuting bats. *The Journal of Wildlife Management,* 77(1): 93-101.

Birch, C. P., Oom, S. P., & Beecham, J. A. 2007. Rectangular and hexagonal grids used for observation, experiment and simulation in ecology. *Ecological Modelling*, 206(3-4): 347-359.

Bishop, C.A., Brogan, J.M. 2013. Estimates of Avian Mortality Attributed to Vehicle Collisions in Canada. *Avian Conservation and Ecology,* 8(2): 2. http://dx.doi.org/10.5751/ACE-00604-080202

Blouin-Demers G & Weatherhead PJ. 2021. Dispersal by gray ratsnakes: Effects of sex, age and time*. Population Ecology*, 63:145–151. https://doi.org/10.1002/1438-390X.12072

Bouchard, J., Ford, A.T., Eigenbrod, F.E., Fahrig, L. 2009. Behavioural responses of Northern Leopard Frog (Rana pipiens) to road and traffic: Implications for population persistence. *Ecology and Society*, 14(2). http://www.jstor.org/stable/26268308

Bowman, J., & Cordes, C. 2015. Landscape Connectivity in the Great Lakes Basin. Available at: https://www.researchgate.net/profile/Jeff-Bowman-4/publication/296845907_Landscape_Connectivity_in_the_Great_Lakes_Basin/links/57a384f308aee07544abea59/Landscape-Connectivity-in-the-Great-Lakes-Basin.pdf

Boyle, S.P., Keevil, M.G., Litzgus, J.D., Tyerman, D., Lesbarrères, D. 2021. Road-effect mitigation promotes connectivity and reduces mortality at the population-level. *Biological Conservation*, 261: 109230.

Brunen, B., Daguet, C., Jaegar, J.A.G. 2020. What attributes are relevant for drainage culverts to serve as efficient road crossing structures for mammals? *Journal of Environmental Management*, 268:110423.

BT Engineering. 2021. 787 King Street East Development, Noise Assessment. Available at: https://www.gananoque.ca/sites/gananoque.ca/files/meetings/agendas/Agenda-Council-05-Without%20Paperclips-02Mar2021_0.pdf

Camacho, C. 2012. Behavioural thermoregulation in man-made habitats: Surface choice and mortality risk in Red-necked Nightjars. *Bird Study,* 60: 124-130.

Canadian Herpetological Society. 2019. Important Amphibian and Reptile Areas Nomination Form, Thousand Islands Ecosystem. Available at:

https://canadianherpetology.ca/conservation/doc/IMPARA%20Nomination%20Form_Thousand%20Islands_Nov2020.pdf

Carr, L.W., & Fahrig, L. 2001. Impact of road traffic on two amphibian species of differing vagility. *Conservation Biology,* 15: 1071-1078.

CBC News. 2022. Banff's Success Story. Available at https://www.cbc.ca/news/canada/edmonton/jasper-national-park-banff-national-park-roadkill-alberta-1.6556666#:~:text=In%20response%20to%20the%20high,cent%2C%20according%20to%20Parks%20Canada

Choquette, J. D., and Valliant, L. 2016. Road Mortality of reptiles and other wildlife at the Ojibway Prairie Complex and Greater Park Ecosystem in southern Ontario. Canadian Field-Naturalist 130(1):64-75.

City of Surrey. 2021. Biodiversity Design Guidelines. Module 3: Road Ecology. Available at: https://www.surrey.ca/renovating-building-development/land-planning-development/environmental-protection/biodiversity-0

Clark, R.W., Brown, W.S., Stechert, R., Zamudio, K.R. 2010. Roads, interrupted dispersal, and genetic diversity in Timber Rattlesnakes. *Conservation Biology,* 24(4): 1059-1069.

Clevenger, A.P., Chruszcz, B., Gunson, K.E. 2001. Highway mitigation fencing reduces wildlife vehicle collisions. *Wildlife Society Bulletin,* 29: 646-653.

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

Clevenger, A.P. and Huijser, M.P. 2011. Wildlife Crossing Structure Handbook: Design and Evaluation in North America. Publication Number FHWA-CFL/TD-11-003, US Department of Transportation, Lakewood, CO.

Clevenger, A.P. 2012. Mitigating continental scale bottlenecks: How small-scale highway mitigation has large-scale impacts. *Ecological Restoration*, 30(4): 300-307.

Colley, M., Lougheed, S.C., Otterbein, K., Litzgus, J.D. (2017). Mitigation reduces road mortality of a threatened rattlesnake. *Wildlife Research*, 44(1), 48-59.

Collins, S.J., & Russell, R.W. 2009. Toxicity of road salt to Nova Scotia amphibians. *Environmental Pollution,* 157(1): 320-324.

Corlatti, L., Hackländer, K., Fredy, F.R. 2009. Ability of wildlife overpasses to provide connectivity and prevent genetic isolation. *Conservation Biology,* 25(3): 548-556.

Cunnington, G.M., Garrah, E., Eberhardt, E., and Fahrig, L. 2014. Culverts alone do not reduce road mortality in anurans. *EcoScience,* 21: 69-78.

Danby R, Karch M, Shearer C, Schueler F, Smith C. 2016. Highway 401 (Gananoque to Brockville) Species at Risk road ecology project 2014-2016. Prepared for the Ontario Ministry of Natural Resources and Forestry Species at Risk Stewardship Fund (Project #1-14-A2A). Algonquin to Adirondacks Collaborative, Lansdowne, ON, and Ontario Road Ecology Group, Toronto, ON.

Danby, R. and J. Urquhart. 2019. Thousand Islands Wildlife Road Mortality and Landscape Connectivity Project Report. Prepared for Thousand Islands National Park. 25 pp.

Desjardins Insurance. 2021. Wildlife-vehicle collisions: what you need to know. Available at: https://www.desjardinsgeneralinsurance.com/blog/-/wildlife-vehicle-collisions-what-you-need-to-know

Devlin, J. 2004. Home range and habitat identification of the Common Map Turtle (*Graptemys geographica*) and Stinkpot Turtle (*Sternotherus odoratus*) in the Thousand Islands Ecosystem – Preliminary Results. Thousand Islands National Park, Mallorytown, ON.

Donaldson, B.M., & Kweon, Y.J. 2019. Effectiveness of seasonal deer advisories on changeable message signs as a deer crash mitigation tool. *Transportation Research Record,* 2673(12).

Donaldson, B.M., & Elliott, K.E. 2021. Enhancing existing isolated underpasses with fencing reduces wildlife crashes and connects habitat. *Human–Wildlife Interactions*, 15(1): 20.

Dyer, S.J., O'Neill, J.P., Wasel, S.M., Boutin, S. 2001. Avoidance of industrial development by Woodland Caribou. *The Journal of Wildlife Management,* 65(3): 531-542.

Eberhardt, E. 2009. Current and potential wildlife fatality hotspots along the Thousand Islands Parkway in Eastern Ontario, Canada [Unpublished Master's thesis]. Carleton University, Ottawa, ON.

Eberhardt, E., Mitchell, S., Fahrig, L. 2013. Road kill hotspots do not effectively indicate mitigation locations when past road kill has depressed populations. *The Journal of Wildlife Management*, 77(7): 1353-1359.

Eco-Kare International (EKI). 2020. Effectiveness of wildlife mitigation measures for large- to midsized animals on Highway 69 and Highway 11 in MTO Northeastern Region, Ontario. Submitted to the Ontario Ministry of Transportation, North Bay, Ontario, Canada, 73 pp.

Environment and Climate Change Canada (ECCC). 2016. Canada's Biodiversity Outcomes Framework and 2020 Goals and Targets. Ministry of Environment and Climate Change Canada, Gatineau, QC. Available at: https://publications.gc.ca/collections/collection_2016/eccc/CW66-525-2016-eng.pdf

Environment and Climate Change Canada (ECCC). 2022. Range Map extends – Species at Risk – Canada. Available at:

https://open.canada.ca/data/en/dataset/d00f8e8c-40c4-435a-b790-980339ce3121

Forman, R.T.T., and Alexander, L.E. 1998. Roads and their major ecological effects. *Annual Review of Ecology and Systematics,* 29: 207–231.

Forman, R.T.T. and Hersperger, A.M. 1996. Road Ecology and Road Density in Different Landscapes, with International Planning and Mitigation Solutions. Harvard University. Proceedings of the Transportation-related Wildlife Mortality Seminar, State of Florida Department of Transportation, June 1996.

Forman, R.T., Sperling, D., Bissonette, J., Clevenger, A.P., Cutshall, C., Dale, V., Fahrig, L., France, R., Goldman, C., Heanue, K., Jones, J., Swanson, F., Turrentine, T., and Winter, T. 2003. Road Ecology: Science and Solutions. Island Press, 481 pp.

Francl, K.E., Hayhoe, K., Saunders, and M., Maurer. 2010. Ecosystem adaptation to climate change: Small mammal migration pathways in the Great Lakes states. *Journal of Great Lakes Research,* 36: 86-93.

Fraser, D., & Thomas, E.R. 1982. Moose-vehicle accidents in Ontario: Relation to highway salt. *Wildlife Society Bulletin*, 10(3): 261-265.

Frontenac Arch Biosphere. 2022. Natural History. Available at: https://www.frontenacarchbiosphere.ca/science/natural-history

Fuentes-Montemayor, E., Cuarón, A.D., Vázquez-Domíngue, E., Benítez-Malvido, J., Valenzuela-Galván, D., Andresen, E. 2009. Living on the edge: Roads and edge effects on small mammal populations. *Journal of Animal Ecology,* 78: 857-865.

Garrah, E. 2012. Wildlife road mortality on the 1000 Islands Parkway in south eastern Ontario: Peak times, hot spots, and mitigation using drainage culverts. Queen’s University, Kingston, Ontario, Canada. Available at: https://qspace.library.queensu.ca/bitstream/handle/1974/7232/Garrah_Evelyn_finalsubmission201205_MES.pdf?sequence=1&isAllowed=y

Garrah, E., Danby, R.K., Eberhardt, E., Cunnington, G.M., Mitchell, S. 2015. Hot spots and hot times: wildlife road mortality in a regional conservation pathway. *Environmental Management*, 56(4): 874-889.

Gartner Lee, and EcoPlans. 2009. 407 East individual Environmental Assessment and preliminary design study: Natural environmental (terrestrial) impact assessment of the recommended design. Available at: https://www.yumpu.com/en/document/view/27106706/407-east-environmental-assessment-2009-toronto-zoo

Goosem, M. 2001. Effects of tropical rainforest roads on small mammals: inhibition of crossing movements. *Wildlife Reserarch*, 28(4) 351-364.

Government of Newbrunswick, Canada. 2010. Government surpasses 300-km wildlife fencing commitment. Available at:

https://www2.gnb.ca/content/gnb/en/news/news_release.2010.04.0638.html

Hager, S.B. 2009. Human-related threats to urban raptors. *Journal of Raptor Research,* 43(3): 210-226.

Haskell, J., Ritchie, M. & Olff, H. 2002. Fractal geometry predicts varying body size scaling relationships for mammal and bird home ranges. *Nature* 418, 527–530. https://doi.org/10.1038/nature00840

Henson, B.L., & Tellier, D. 2014. Algonquin to Adirondack Analysis Methodology. Ontario Natural Heritage Information Centre, Ontario Ministry of Natural Resources. Available at: http://www.a2acollaborative.org/uploads/7/6/8/5/7685208/a2a_analysis_methodology_2014_final.pdf

Hill, J.E., DeVault, T.L., Belant, J.L. 2019. Cause-specific mortality of the world's terrestrial vertebrates. *USDA National Wildlife Research Center – Staff Publications.* 2249.

Holderegger, R., & Di Guilio, M. 2010. The genetic effects of roads: A review of empirical evidence. *Basic and Applied Ecology,* 11: 522-531.

Huijser, M. P., & McGowen, P. T. 2010. Reducing wildlife-vehicle collisions (pp. 51-74) in "Safe Passages". Island Press: Washington, DC, USA.

Huijser, M.P., Kociolek, A.V., Allen, T.D.H., McGowen, P., Cramer, P.C., & Venner, M. 2015. Construction guidelines for wildlife fencing and associated escape and lateral access control measures. Document prepared for the American Association of State Highway and Transportation Officials. Available online at: https://onlinepubs.trb.org/onlinepubs/nchrp/docs/NCHRP25-25(84)_FR.pdf

Huijser, M.P., Fairbank, E.R., Camel-Means, W., Graham, J., Watson, V., Basting, P., & Becker, D. 2016. Effectiveness of short sections of wildlife fencing and crossing structures along highways in reducing wildlife-vehicle collisions and providing safe crossing opportunities for large mammals. *Biological Conservation,* 197: 61-68.

Important Bird Areas Canada. 2022. Frontenac Forests Buck Lake, Ontario. Available at: https://www.ibacanada.org/site.jsp?siteID=ON158

IN Engineering. 2020. Highway 401 Through Brockville to be expanded. Available at: https://inengineering.ca/highway-401-through-brockville-to-be-expanded/

Jackson, S. 1996. Underpass Systems for Herptiles. Transportation-related Wildlife Mortality Seminar, State of Florida Department of Transportation, June 1996.

Jackson, N.D., & Fahrig, L. 2011. Relative effects of road mortality and decreased connectivity on population genetic diversity. *Biological Conservation,* 144: 3143-3148.

James, A.R.C., & Stuart-Smith, A.K. 2000. Distribution of caribou and wolves in relation to linear pathways. *The Journal of Wildlife Management,* 64(1): 154-159.

Jetz, W., Carbone, C., Fulford, J., Brown, J. 2004. The scaling of animal special use. *Science*, 306 (5694):266-268. Doi 10.1126/science.1102138.

Jones, J.D. 2018. The locations and drivers of herpetofaunal road mortality on two highways within the Frontenac Arch, Ontario [Master's thesis]. School of Environmental Studies, Queen's University, Kingston, ON.

Karraker, N.E., Gibbs, J.P., Vonesh, J.R. 2008. Impacts of road deicing salt on the demography of vernal pool-breeding amphibians. *Ecological Applications,* 18(3): 724-734.

Keddy, C. 1995. The Conservation Potential of the Frontenac Axis: Linking Algonquin Park to the Adirondacks. The Canadian Parks and Wilderness Society, Ottawa Valley Chapter. Ottawa, Ontario. 59 pages.

Keller, I., Excoffier, L., Largiader, C.R. 2005. Estimation of effective population size and detection of a recent population decline coinciding with habitat fragmentation in a ground beetle. *Journal of Evolutionary Biology,* 18: 90-100.

Kintsch, J. and Cramer, P.C. 2011. Permeability of existing structures for terrestrial wildlife: A passage assessment system. Research Report No. WA-RD 777.1. Washington State Department of Transportation, Olympia, WA.

Koen, E.L., Bowman, J., Sadowski, C., Walpole, A.A. 2014. Landscape connectivity for wildlife: Development and validation of multispecies linkage maps. *Methods in Ecology and Evolution,* 5: 626-633.

Laurance S.G.W. 2006. Rainforest roads and the future of forest dependent wildlife: A case study of understory birds. In: Laurance WF & CA Peres (eds.) Emerging Threats to Tropical Forests. University of Chicago Press, Chicago, USA. pp. 253–267

Leeds Grenville. 2018. Traffic Counts on County Roads (Web Map). Available at: https://uclg.maps.arcgis.com/apps/MapSeries/index.html?appid=1b72f53260 9b402eb2f36fdece43e158

Lemieux, C.J., Jacob, A.L., Gray, P.A. 2021. Implementing Connectivity Conservation in Canada. Canadian Council on Ecological Areas (CCEA) Occasional Paper No. 22. Canadian Council on Ecological Areas, Wilfrid Laurier University, Waterloo, Ontario, Canada. vi + 216 pp.

Lepczyk, C.A., Aronson, M.F.J., Evans, K.L., Goddard, M.A., Lerman, S.B., MacIvor, J.S. 2017. Biodiversity in the city: Fundamental questions for understanding the ecology of urban green spaces for biodiversity conservation. *Bioscience,* 67(9): 799-807.

Long Point Causeway Improvement Project. 2015. What is the Long Point Improvement Project?. Available at: https://longpointcauseway.com/what-is-the-long-point-causeway-improvement-project/

MacKinnon, C. A., Moore, L. A. & Brooks, R. J. 2005. Why Did the Reptile Cross the Road? Landscape Factors Associated with Road Mortality of Snakes and Turtles in the South Eastern Georgian Bay area. Available at:

Marrotte, R.R., Bowman, J., Wilson, P.J. 2019. Climate connectivity of the bobcat in the Great Lakes region. *Ecology and Evolution,* 10: 2131-2144.

Mayer, T., Rochfort, Q., Marsalek, J., Parrott, J., Servos, M., Baker, M., McInnis, R., Jurkovic, R., Scott, I. 2011. Environmental characterization of surface runoff from three highway sites in Southern Ontario, Canada. *Water Quality Research Journal of Canada,* 46(2): 110-120.

Mazerolle, M.J., Matthieu, H., Mireille, G. 2005. Behavior of amphibians on the road in response to car traffic. *Herpetologica*, *61(4): 380-388*

Merriam, G., Kozakiewicz, M., Tsuchiya, E., Hawley, K. 1989. Barriers as boundaries for metapopulations and demes of Peromyscus leucopus in farm landscapes. *Landscape Ecology,* 2: 227-235.

McLaren, A. A. D. & Patterson, B. R. 2021. There's no place like home — site fidelity by female moose (*Alces alces*) in central Ontario, Canada. *Canadian Journal of Zoology*. 99(7): 557-563. https://doi.org/10.1139/cjz-2021-0010.

Moorehouse, B. 2023. Wildlife collisions costly. Ontario Out of Doors, vol. 55, Issue 1, Jan-Feb 2023.

Miller, D., and Bell, G. 2021. The Algonquin to Adirondacks (A2A) Pathway. Pages 137-148 in CJ Lemieux, AL Jacob, and PA Gray (eds), Implementing Connectivity Conservation in Canada. Canadian Council on Ecological Areas (CCEA) Occasional Paper No. 22. Canadian Council on Ecological Areas, Wilfrid Laurier University, Waterloo, Ontario, Canada.

Ministry of Environment, Conservation and Parks (MECP). 2022. Source Protection Information Atlas. Available at: https://www.lioapplications.lrc.gov.on.ca/SourceWaterProtection/index.html?viewer=SourceWaterProtection.SWPViewer&locale=en-CA

Ministry of Transportation (MTO). 2016. Provincial Highways Traffic Volumes. Highway Standards Branch, Traffic Office. 55 pages. Available at: https://www.library.mto.gov.on.ca/SydneyPLUS/TechPubs/Theme.aspx?r=702797&f=files%2FProvincial+Highways+Traffic+Volumes+2016+AADT+Only.pdf&m=resource

Ministry of Transportation (MTO). 2017. MTO Best Management Practices for Species at Risk Protection During Maintenance Activities. Available at: http://roadsandwildlife.org/data/files/Documents/6b37e529-2ef7-4baa-9e1f-dd48dd10dd20%20%20.pdf

Ministry of Transportation (MTO). 2021. Highway 401 Improvements from 1 km East of Highway 16 to 3.3 West of Maitland Road. Available at: https://www.highway401prescottmaitland.ca/wp-content/uploads/2021/11/Hwy401MaitlandtoHwy16_PIC1_Presentation-Board-Transcript_Final.pdf

Murphy, R.E., Martin, A.E., Fahrig, L. 2022. Reduced predation on roadside nests can compensate for road mortality in road-adjacent turtle populations. *Ecosphere,* 13(2): e3946

The Nature Conservancy of Canada. 2022. Resilient Land Mapping Tool. Available at: https://maps.tnc.org/resilientland/

Ontario Biodiversity Council. 2021. State of Ontario's Biodiversity: 2020 Summary. Ontario Biodiversity Council, Toronto, ON. 17 pages. Available at: http://sobr.ca/_biosite/wp-content/uploads/state-of-biodiversity-report-2020-Final-2.pdf

Ontario Ministry of Natural Resources and Forestry. 2012. Gray Ratsnake (Frontenac Axis Population) Habitat Protection Summary. Available at: https://www.ontario.ca/page/gray-ratsnake-frontenac-axis-population-habitat-protection-summary

Ontario Ministry of Natural Resources and Forestry. 2016. Best Management Practices for Mitigating the Effects of Roads on Amphibians and Reptiles Species at Risk in Ontario. Queen's Printer of Ontario. 112 pp.

Ontario Ministry of Natural Resources and Forestry. 2023. Make a Map: Natural Heritage Areas – Ontario GeoHub. Available at: https://www.google.com/search?q=mnrf+nhic+make+a+map&rlz=1C1GCEA_enCA1015CA1016&oq=mnrf+nhic+make+a+map&aqs=chrome..69i57.1737j0j9&sourceid=chrome&ie=UTF-8

Organisation for Economic Co-operation and Development (OECD). 2019. Biodiversity: Finance and the Economic and Business Case for Action, report prepared for the G7 Environment Ministers' Meeting, 5-6 May 2019.

Parris, K.M., & Schneider, A. 2009. Impacts of traffic noise and traffic volume on birsd of roadside habitats. *Ecology and Society,* 14(1): 29.

Pither, R., O'Brien, P., Brennan, A., Hirsh-Pearson, K. and Bowman, J. 2021. Areas Important for Ecological Connectivity Throughout Canada. *bioRxiv*, https://doi.org/10.1101/2021.12.14.472649

Pomezanski, D. 2015. Monitoring Small Animal Usage Patterns of Suburban Wildlife Tunnels: Behaviour, Design, and Recommendations. [Master's thesis]. Department of Geography, University of Guelph, Guelph, ON.

Proulx, C.L., Fortin, G., Blouin-Demers, G. 2014. Blanding's Turtles (Emydoidea blandingii) avoid crossing unpaved and paved roads. *Journal of Herpetology,* 48(2): 267-271.

Quinby, P., Trombulak, S., Lee, T., Lane, J., Henry, M., Long, R., and MacKay, P. 1999. Opportunities for wildlife habitat connectivity between Algonquin Park, Ontario and the Adirondack Park, New York. The Greater Laurentian Wildlands Project, South Burlington, Vermont. 27 pages.

Rajlic, B., Majstorovic, S., Lambert, A., Mott MacDonald, H. 2016. Highway in a Park: The Rt. Hon Herb Gray Parkway. Canadian Consulting Engineer, March-April: 14. Available at: https://www.canadianconsultingengineer.com/features/highway-park-rt-hon-herb-gray-parkway/

Read, K.D., & Thompson, B. 2021. Retrofit ecopassages effectively reduce freshwater turtle road mortality in the Lake Somcoe Watershed. *Conservation Science and Practice,* 3: e491.

Reijnen, R., Foppen, R., Veenbaas, G. 1997. Disturbance by traffic of breeding birds: evaluation of the effect and considerations in planning and managing road pathways. *Biodiversity and Conservation,* 6: 567-581.

Rheindt, F.E. 2003. The impact of roads on birds: Does song frequency play a role in determining susceptibility to noise pollution. *Journal of Ornithology,* 144: 295-306.

Roch, L. 2015. Algonquin to the Adirondacks (A2A): Using circuit theory to measure landscape connectivity. [Master's thesis]. Department of Geography, Planning and Environment, Concordia University, Montreal, QB.

Ross, D. 2004. Analyzing the Resistance Values of the 401 Highway to Wildlife Movements in the Thousand Islands Section of the Algonquin to Adirondack Pathway and Thousand Islands Frontenac Arch Biosphere Reserve. Algonquin to Adirondack Conservation Association, Lansdowne, ON. 65 pages.

Rytwinski, T., Soanes, K., Jaeger, J.A.G., Fahrig, L., Findlay, C.S., Houlahan, J., van der Ree, R., van der Drift, E.A. How effective is road mitigation at reducing road-kill? A meta-analysis. *PLoS ONE,* 11(11): e0166941.

Sanderson, E.W., Jaiteh, M., Levy, M.A., Redford, K.H., Wannebo, A.V., and Woolmer G. 2002. The human footprint and the last of the wild. *BioScience,* 52: 891-904.

Sawaya, M.A., Clevenger, A.P., Kalinowski, S.T. 2013. Demographic connectivity for ursid populations at wildlife crossing structures in Banff National Park. *Conservation Biology, 27(4): 721-730.*

Sawaya, M.A., Kalinowski, S.T. Clevenger, A.P. 2014. Genetic connectivity for two bear species at wildlife crossing structures in Banff National Park. *Proceedings of the Royal Society B: Biological Sciences,* 281: 20131705.

Seiler, A. 2003. The toll of the automobile – Wildlife and roads in Sweden. [Doctoral thesis]. Swedish University of Agricultural Sciences, Uppsala, Sweden.

Smith, D.J., van der Ree, R., and Rosell, C. 2015. Wildlife crossing structures: an effective strategy to restore or maintain wildlife connectivity across roads. pp. 172-183 in Handbook of Road Ecology, John Wiley & Sons, Oxford, UK.

Stephenson, B. 2001. The Algonqiun-to_Adirondack conservation initiative: a key macro-landscape linkage in eastern North American. *Crossing Boundaries in Park Management: Proceedings of the 11th Conference on Research and Resource Management in Parks and on Public Lands*, 303-310.

Stewart, F.E.C., Darlington, S., Volpe, J.P., McAdie, M., Fisher, J.T. 2019. Pathways best facilitate functional connectivity across a protected area network. *Scientific Reports*, 9:10852(2019). https://doi.org/10.1038/s41598-019-47067-x

Stewart, L., Russell, B., Zelig, E., Patel, G., Stack Whitney, K. 2020. Wildlife Crossing Design Influences Effectiveness for Small and Large Mammals in Banff National Park. *Case Studies in the Environment*, 4 (1): 1231752.

Sucharzewski, S. 2022. White-tailed deer adult doe "T107" locations on Hill Island, Thousand Islands National Park, Ontario, Canada from February 2022 to September 2022. [Unpublished data in support of Master's Thesis]. Trent University, Peterborough, ON.

Sullivan, T.L., Williams, A.F., Messmer, T.A., Hellinga, L.A., Kyrychenko, S.Y. 2004. Effectiveness of temporary warning signs in reducing deer-vehicle collisions during mule deer migrations. *Wildlife Society Bulletin (1973-2006),* 32(3): 907-915.

Sustaining What We Value Project Team (SWWV). 2011. Sustaining What We Value: A Natural Heritage System for the Frontenac, Lanark, Leeds & Grenville Area of Eastern Ontario. Available at http://www.a2acollaborative.org/mapping.html

Taylor, K.G., & Owens, P.N. 2009. Sediments in urban river basins: a review of sediment-contaminant dynamics in an environmental system conditioned by human activities. *Journal of Solids and Sediments,* 9: 281-303.

Taylor, P.D., Fahrig, L., Henein, K., and Merriam, G. 1996. Connectivity is a vital element of landscape structure. *Oikos,* 68 (3): 571-573.

Traffic Injury Research Foundation. 2012. Wildlife-vehicle collisions in Canada: A review of the literature and compendium of existing data sources. Available at: https://tirf.ca/wp-content/uploads/2017/01/WildlifeVehicle_Collision_Deliverable1_Eng_6.pdf

Transport Canada. 2008. Transportation in Canada 2007: An Overview. Government of Canada, Ottawa. Catalogue no. TP 14816E. Available at: https://publications.gc.ca/collections/collection_2008/tc/T1-10-2007E.pdf, data accessible at: https://www150.statcan.gc.ca/n1/pub/16-002-x/2009001/tbl/transpo/tbl001-eng.htm

Transport Canada. 2020. Statistical Review. Available at: https://tc.canada.ca/en/road-transportation/motor-vehicle-safety/statistical-review#e5.1

United Nations Educational, Scientific and Cultural Organization (UNESCO). 2018. Frontenac Arch Biosphere Reserve, Canada. Available at: https://en.unesco.org/biosphere/eu-na/frontenac-arch

United Nations Educational, Scientific and Cultural Organization (UNESCO). 2023. UNESCO. Available at: https://www.unesco.org/en

Urquhart, J., Jones, J., Danby, R., Aarts, M., Smith, C. 2018. The Frontenac Arch Road Ecology Project – Highway 2 road mortality hotspot identification. Available at: https://www.a2acollaborative.org/uploads/7/6/8/5/7685208/final_hwy_2_report_.pdf

Van der Ree, R., Gagnon, J.W., Smith, D.J. 2015a. Fencing: a valuable tool for reducing wildlife–vehicle collisions and funneling fauna to crossing structures. *Handbook of Road Ecology*, 159-171. Wiley-Blackwell, Oxford.

Van der Ree, R., Smith, D.J., Grilo, C. 2015b. Handbook of Road Ecology. Wiley Blackwell, Oxford.

Vu, J. 2019. The Effect of Access Road Construction on the Hydrology of Wetlands in Rock Barren Landscapes. [Master's thesis]. Department of Earth and Environmental Sciences, McMaster University, Hamilton, ON.

Walker, K.V., Davis, M.B., Sugita, S. 2002. Climate change and shifts in potential tree species range limits in the Great Lakes region. *Journal of Great Lakes Research,* 28(4): 555-567.

Whittington, J., Low, P., Hunt, B. 2019. Temporal road closures improve habitat quality for wildlife. *Scientific reports*, 9(1): 1-10.

Wildlands Network. 2019. Eastern Wildway Map. Available at: https://wildlandsnetwork.org/resources/eastern-wildway-map.

Wilson, E.O. 2003. The Future of Life. Vintage Books, New York.

Woltz, H.W., Gibbs, J.P., and Ducey, P.K. 2008. Road crossing structures for amphibians and reptiles: Informing design through behavioural analysis. *Biological Conservation*, 141(11): 2745–2750.

Zachos, F.E., Althoff, C., Steynitz, Y.V., Eckert, I., and Hartl, G.B. 2007. Genetic analysis of an isolated red deer (Cervus elaphus) population showing signs of inbreeding depression. *European Journal of Wildlife Research,* 53: 61-67.

7 Appendix A – List of wildlife species killed on Highway 401, Thousand Islands Parkway, and County Road 2

Animal species found during roadkill surveys conducted on County Road 2 (CR2), Highway 401 (401), and Thousand Islands Parkway (TIP). Data were collected from County Road 2 in 2016, 2017, and 2020. Data were collected from Highway 401 in 2014-2017 and 2019-2020. Data were collected from Thousand Islands Parkway in 2008-2011.

Common Name	Taxonomic Name	CR2	401	TIP
Snakes				
Dekay's Brown Snake	*Storeria dekayi*	✓	✓	✓
Eastern Gartersnake	*Thamnophis sirtalis*	✓	✓	✓
Eastern Milksnake	*Lampropeltis triangulum*	✓	✓	✓
Eastern Ribbonsnake	*Thamnophis sauritus*	✓	✓	✓
Gray Ratsnake	*Pantherophis obsoletus*	✓	✓	✓
Northern Ring-necked Snake	*Diadophis punctatus*			✓
Northern Watersnake	*Neodia sipedon sipedon*	✓	✓	✓
Red-bellied Snake	*Storeria occipitomaculata*	✓	✓	✓
Smooth Greensnake	*Opheodrys vernalis*	✓	✓	
Unidentified Snake		✓	✓	✓
Turtles				
Blanding's Turtle	*Emydoidea blandingii*	✓	✓	✓
Eastern Musk Turtle	*Sternotherus odoratus*			✓
Midland Painted Turtle	*Chrysemys picta marginata*	✓	✓	✓
Northern Map Turtle	*Graptemys geographica*		✓	✓
Snapping Turtle	*Chelydra serpentia*	✓	✓	✓
Unidentified Turtle		✓	✓	✓
Frogs				
American Bullfrog	*Lithobates catesbeianus*	✓	✓	✓
American Toad	*Anaxyrus americanus*	✓		✓
Gray Treefrog	*Hyla versicolor*	✓		✓

Common Name	Taxonomic Name	CR2	401	TIP
Green Frog	*Lithobates clamitans*	✓	✓	✓
Mink Frog	*Lithobates septentrionalis*			✓
Northern Leopard Frog	*Lithobates pipiens*	✓	✓	✓
Northern Leopard Frog or Pickerel Frog	*Lithobates pipiens or palustris*			✓
Spring Peeper	*Pseudacris crucifer*			✓
Wood Frog	*Lithobates sylvaticus*			✓
Unidentified Frog		✓	✓	✓
Salamanders				
Blue-spotted Salamander	*Ambystoma laterale*			✓
Eastern Newt	*Notophthalmus viridescens*	✓	✓	✓
Spotted Salamander	*Ambystoma maculatum*		✓	✓
Unidentified Salamander		✓	✓	✓
Bats				
Big Brown Bat	*Eptesicus fuscus*	✓		
Eastern Red Bat	*Lasiurus borealis*		✓	
Little Brown Bat	*Myotis lucifugus*		✓	
Unidentified Bat			✓	✓
Carnivores				
American Black Bear	*Ursus americanus*		✓	
American Marten	*Martes americana*		✓	
American Mink	*Neovison vison*	✓	✓	✓
Coyote	*Canis latrans*	✓	✓	
Domestic Cat	*Felis catus*	✓	✓	
Domestic Dog	*Canis lupus familiaris*		✓	
Fisher	*Martes pennanti*		✓	
Long-tailed Weasel	*Mustela frenata*			✓
North American River Otter	*Lutra canadensis*		✓	
Raccoon	*Procyon lotor*	✓	✓	✓
Red Fox	*Vulpes vulpes*	✓	✓	✓
Short-tailed Weasel	*Mustela erminea*	✓	✓	
Striped Skunk	*Mephitis mephitis*	✓	✓	✓
Unidentified Weasel			✓	
Lagamorphs				
Snowshoe Hare	*Lepus americanus*		✓	
Eastern Cottontail	*Sylvilagus floridanus*	✓	✓	✓

Common Name	Taxonomic Name	CR2	401	TIP
Unidentified Lagomorph			✓	✓
Rodents				
American Beaver	*Castor canadensis*		✓	✓
Muskrat	*Ondatra zibethicus*		✓	✓
North American Porcupine	*Erethizon dorsatum*	✓	✓	✓
Northern Red-backed Vole	*Myodes rutilus*	✓		
Field Mouse	*Mus musculus*	✓	✓	
American Red Squirrel	*Tamiasciurus hudsonicus*	✓	✓	✓
Brown Rat	*Rattus norvegicus*	✓	✓	
Deer Mouse	*Peromyscus maniculatus*	✓	✓	✓
Eastern Chipmunk	*Tamias striatus*	✓	✓	✓
Eastern Gray Squirrel	*Sciurus carolinensis*	✓	✓	✓
Groundhog	*Marmota monax*	✓	✓	
Flying Squirrel	*Glaucomys sp.*		✓	
Unidentified Rodent		✓	✓	✓
Shrews and Moles				
Masked Shrew	*Sorex cinereus*			✓
Northern Short-tailed Shrew	*Blarina brevicauda*	✓	✓	
Star-nosed Mole	*Condylura cristata*	✓		✓
Hairy-tailed Mole	*Parascalops breweri*	✓	✓	✓
Unidentified Mole		✓		
Cervids				
White-tailed Deer	*Odocoileus virginianus*		✓	✓
Unidentified Mammal		✓	✓	✓
Accipitriformes				
Cooper's Hawk	*Accipiter cooperii*	✓		
Unidentified		✓	✓	
Anatidae				
Canada Goose	*Branta canadensis*		✓	✓
Anseriformes				
Mallard	*Anas platyrhynchos*		✓	✓
Unidentified			✓	
Cathartiformes				
Turkey Vulture	*Cathartes aura*	✓	✓	✓
Charadriiformes				
Herring Gull	*Larus argentatus*			✓

Common Name	Taxonomic Name	CR2	401	TIP
Ring-billed Gull	*Larus delawarensis*	✓	✓	✓
Unidentified			✓	✓
Columbiformes				
Mourning Dove	*Zenaida macroura*		✓	
Falconiformes				
Merlin	*Falco columbarius*	✓		
Galliformes				
Domestic Chicken	*Gallus gallus domesticus*	✓		
Gray Partridge	*Perdix perdix*		✓	
Ruffed Grouse	*Bonasa umbellus*	✓	✓	
Wild Turkey	*Meleagris gallopavo*	✓	✓	✓
Passeriformes				
American Crow	*Corvus brachyrhynchos*	✓	✓	✓
American Goldfinch	*Spinus tristis*	✓	✓	✓
American Redstart	*Setophaga ruticilla*	✓		
American Robin	*Turdus migratorius*	✓	✓	✓
Baltimore Oriole	*Icterus galbula*		✓	✓
Barn Swallow	*Hirundo rustica*	✓		✓
Black-capped Chickadee	*Poecile atricapillus*	✓	✓	✓
Blue Jay	*Cyanocitta cristata*	✓	✓	✓
Bohemian Waxwing	*Bombycilla garrulus*		✓	
Canada Warbler	*Cardellina canadensis*		✓	
Cedar Waxwing	*Bombycilla cedrorum*	✓	✓	✓
Chestnut-sided Warbler	*Setophaga pensylvanica*	✓	✓	
Chipping Sparrow	*Spizella passerina*	✓	✓	
Common Grackle	*Quiscalus quiscula*	✓	✓	✓
Common Raven	*Corvus corax*	✓	✓	
Common Yellowthroat	*Geothlypis trichas*	✓	✓	✓
Eastern Kingbird	*Tyrannus tyrannus*			✓
Eastern Towhee	*Pipilo erythrophthalmus*	✓	✓	
European Starling	*Sturnus vulgaris*	✓	✓	✓
Gray Catbird	*Dumetella carolinensis*	✓	✓	✓
House Sparrow	*Passer domesticus*	✓	✓	
House Wren	*Troglodytes aedon*	✓		✓

Common Name	Taxonomic Name	CR2	401	TIP
Indigo Bunting	*Passerina cyanea*	✓		
Marsh Wren	*Cistothorus palustris*		✓	
Northern Cardinal	*Cardinalis cardinalis*			✓
Northern Waterthrush	*Parkesia noveboracensis*		✓	✓
Ovenbird	*Seiurus aurocapilla*		✓	
Pine Warbler	*Setophaga pinus*		✓	
Purple Finch	*Haemorhous purpureus*		✓	
Red-eyed Vireo	*Vireo olivaceus*	✓	✓	
Red-winged Blackbird	*Agelaius phoeniceus*		✓	✓
Rose-breasted Grosbeak	*Pheucticus ludovicianus*	✓	✓	✓
Scarlet Tananger	*Piranga olivacea*	✓		
Song Sparrow	*Melospiza melodia*	✓	✓	
Swamp Sparrow	*Melospiza georgiana*		✓	✓
Yellow Warbler	*Setophaga petechia*	✓	✓	✓
Unidentified passerines		✓	✓	✓
Pelecaniformes				
American Bittern	*Botaurus lentiginosus*		✓	
Great Blue Heron	*Ardea herodias*		✓	
Least Bittern	*Ixobrychus exilis*		✓	
Piciformes				
Downy Woodpecker	*Dryobates pubescens*		✓	
Northern Flicker	*Colaptes auratus*	✓		✓
Pileated Woodpecker	*Dryocopus pileatus*		✓	
Yellow-bellied Sapsucker	*Sphyrapicus varius*		✓	
Unidentified		✓		
Strigiformes				
Barred Owl	*Strix varia*		✓	
Northern Saw-whet Owl	*Aegolius acadicus*		✓	
Unidentified Birds		✓	✓	✓

8 Appendix B – Summary of previous road ecology studies conducted for Highway 401, Thousand Islands Parkway, and County Road 2

8.1 Highway 401 Permeability Study

Highway 401 has long been regarded as a barrier to wildlife connectivity in eastern Ontario. Indeed, the initial vision for an A2A pathway (Keddy, 1995) recognized the highway as one of the major impediments to ecosystem connectivity in the region, and a follow-up study confirmed this (Quinby et al., 1999). A2A implemented a study in 2004 to examine the potential value of existing culverts and other structures along Highway 401 as passages for mammals and herpetiles and to assess the porosity of different segments of the highway as it relates to wildlife crossing (Ross, 2004). The study focused on a 47 km stretch of Highway 401 on the Frontenac Arch. Each side of the road was walked, and relevant structural features and qualities of the highway were documented and logged with a GPS (Ross, 2004). A scoring system based on variables including placement, size, shape, light, moisture, temperature, noise, substrate, approaches, and fencing was developed to assess the structures and evaluate their potential for use in facilitating safe passage of wildlife.

The study determined that there were 11 structures with potential to provide mammal passage. The structure that ranked highest was the bridge over the Gananoque River. The second highest was a tall box culvert at the back of Landons Bay, which was originally built for livestock. A total of 37 underpasses were assessed to have some potential for herpetile passage, though only 15 were ranked as high value (Figure B1). The results of this assessment drew attention to the barrier imposed by Highway 401 and helped instigate the series of subsequent studies focussing on road ecology in the region.

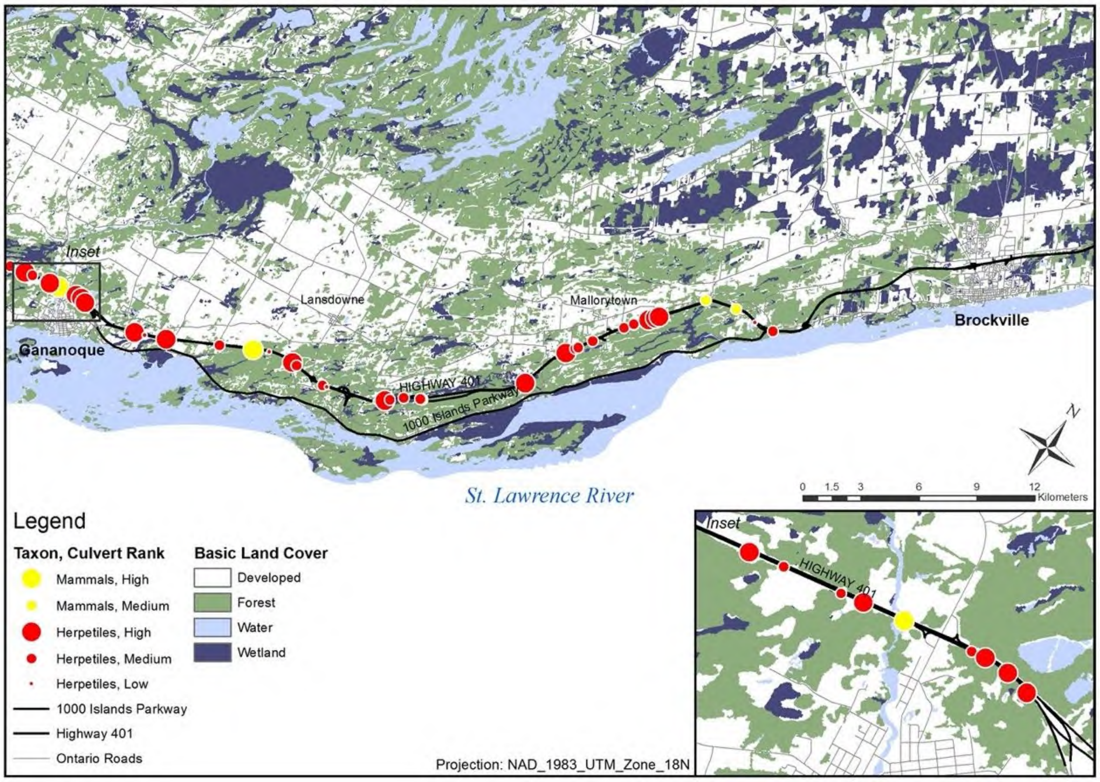


Figure B1: Culverts and underpasses assessed in 2004 as part of the Highway 401 permeability study (Ross, 2004). Larger circles indicate structures ranked as high for their respective taxa (mammals in yellow, herpetiles in red). Figure from Danby et al. (2016).

8.2 Highway 401 Wildlife Road Mortality Assessment

A study led by A2A and funded by the Ontario Ministry of Natural Resources and Forestry (OMNRF) was conducted in 2014 and 2015 to quantify the magnitude of wildlife-vehicle collisions on Highway 401 on the Frontenac Arch, and to identify possible mitigation measures that could be implemented to reduce this mortality (Danby et al., 2016). Field surveys of the entire 47 km stretch were conducted on foot from Gananoque (decimal degrees 44.334, -76.235) to Butternut Bay (44.521, -75.783) from May to December 2014 and June to November 2015. The field team recorded evidence of all wildlife/road interactions, including remains/carcasses, prints, scat, nests, and live specimens. Other relevant information on animals and their locations were also recorded when possible (e.g., dead/alive, state of decay, position on roadway, etc.). Surveys in 2014 focused heavily on specific stretches of Highway 401 within the study area that were considered to be at heightened risk of wildlife mortality based on adjacent habitat quality. In 2015, the team surveyed all stretches equally, walking both sides of the entire 47 km length a total of three times over the course of the monitoring season.

The study identified three major wildlife road mortality hotspots on Highway 401 for species at risk, and four additional areas of concern for vertebrates more generally, for a total of seven areas that should be prioritized for remediation (Figure B2). A 3.9 km segment of the expressway, located between Exit 661 (Highway 137) and Escott-Rockport Road, contained two of these species at risk hotspots and one of the areas of concern (Figure B2). This segment had especially high levels of road mortality for turtles, including the threatened Blanding's turtle. Subsequent wildlife mortality surveys were voluntarily conducted by A2A in 2016 along this portion of the highway and in 2017 along the entire stretch of Highway 401 spanning from just east of Ganonoque to where Highway 401 crosses under County Road 2 at exit 687. These surveys confirmed that Highway 401 between Highway 137 and Escott-Rockport Road was an area of high turtle mortality.

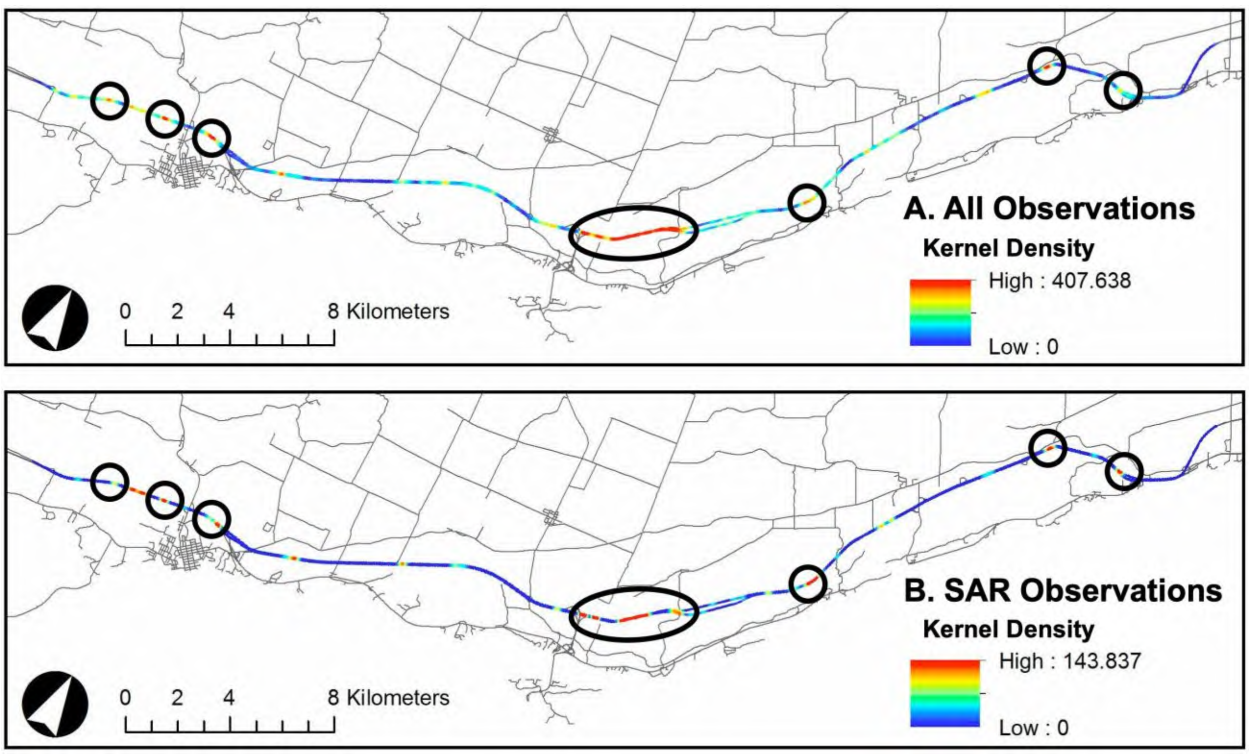


Figure B2: The seven areas of highest concern identified as part of the Highway 401 road mortality study in 2014-2015 (Danby et al., 2016). All vertebrate observations were used to generate the hotspot map presented in A (top), while only species at risk (SAR) observations were used to derive the second map, B (bottom). Figure from Danby et al. (2016).

8.3 Highway 401 Wildlife Fence Installation and Monitoring

Based on the wildlife mortality data collected by A2A, the Ontario Ministry of Transportation (MTO) installed fencing along a 1 km stretch of Highway 401 in 2017 and 2018 that coincided with the most significant hotspot (Figure B2). The fencing was intended to decrease road mortality of wildlife, particularly turtles, by providing a barrier to prevent them from entering the roadway (Figure B3). The fencing was also intended to facilitate safe passage of wildlife (again, particularly turtles) across the highway by funnelling animals toward existing drainage culverts that pass beneath the highway.

Figure B3: A section of fencing installed on Highway 401, intended to prevent entry of turtles onto the roadway and facilitate their use of existing drainage culverts for safe crossing. Photo by R. Danby.

The MTO provided two years of funding to monitor the fence system and evaluate its effectiveness, and a comprehensive report was submitted in 2021 (Baker et al., 2021). The project also served as the basis of a Master's thesis at Queen's University (Baker, 2022).

Road mortality data were collected from the fenced segment as well as adjacent areas in 2019 and 2020 and compared to data collected prior to fence installation using a before-after-control-impact (BACI) framework. Camera trapping, sand trapping, and field observations of wildlife behavior were also used to assess the fence-culvert design. Enhanced kernel density analysis

(KDE+) was used to analyze the wildlife mortality data and indicated that the fence was effective in reducing turtle and small mammal mortality, but the results also suggested that the fencing contributed to increased mortality of snakes. Camera trapping at culvert entrances indicated that most complete crossings under the highway through the culverts were by small mammals (primarily muskrats and raccoons), with very few reptile crossings. Nevertheless, reptiles and amphibians were observed frequently at culvert openings, suggesting that adequately sized and configured ecopassages may aid in connectivity when paired with fencing.

8.4 Thousand Islands Parkway Wildlife Road Mortality Assessment

The Thousand Islands Parkway Wildlife Road Mortality Assessment project began in 2008 as a partnership between Parks Canada and Carleton University. Its purpose was to analyze and explain spatial and temporal variability in wildlife road mortality on the Parkway. Surveys of road mortality along the Parkway's entire length (37 km) were conducted regularly from April to October by bicycle. Queen's University joined the project as a partner in 2010 and surveys were completed in 2011, resulting in four years of data. In total, 209 surveys were completed. Observations of all vertebrates were recorded to the finest taxonomic level possible. When possible, sex and age class of animals was recorded during 2010 and 2011 surveys.

The project identified several areas along the Thousand Islands Parkway where wildlife road mortality was particularly high relative to other areas, including at Thompson's Bay where the road runs adjacent to a large expanse of wetlands (Figure B4). While some of these hotspots were evident in each year of the project, many others were not, indicating that one year of surveys is insufficient for identifying salient hotspots. The project also identified several "hot times" when road mortality was elevated for certain taxa. This included September for snakes, June for turtles, July for frogs, and June and July for birds.

Project results were published in two Master's theses (Eberhardt, 2009; Garrah, 2012) and two peer-reviewed journal articles (Eberhardt et al., 2013; Garrah et al., 2015).

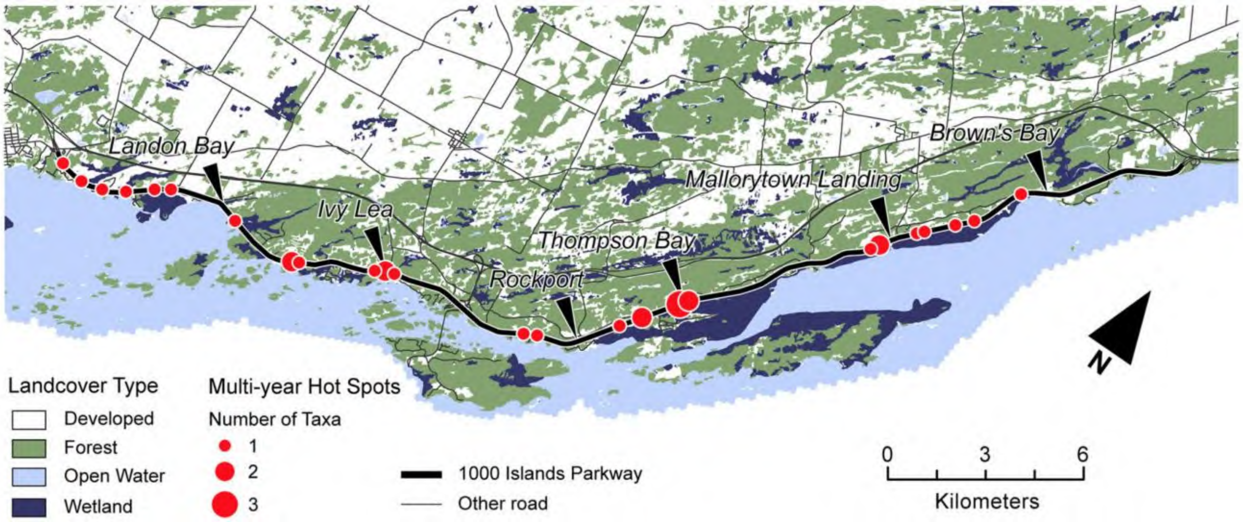


Figure B4: Multi-year hotspots of wildlife mortality on the Thousand Islands Parkway from 2008–2011. Multiyear hotspots for each taxon were defined as road segments where significant spatial clustering occurred in at least two of the four survey years. Circle size is indicative of the number of taxa (out of five) for which the road segment was a hotspot. Figure from Garrah et al. (2015).

8.5 Thousand Islands Parkway Fence Experiment

A field experiment was implemented in connection with the Thousand Islands Parkway Wildlife Road Mortality Assessment to assess the efficacy of culverts and fencing in reducing mortality. Twenty concrete box culverts were chosen for the study. Grates constructed of 6 mm mesh hardware cloth were installed onto both ends of six culverts to exclude animals from the culverts. Fencing was installed at an additional four sites to keep animals off the road. A 180 m length of temporary plastic silt fencing, centered on the culvert opening, was erected on both sides of the road. Ten culverts were left unmanipulated and acted as experimental controls. Roadkill surveys were conducted in the year prior to experimental treatment (2008), and in each of the two years after (2009 and 2010; Cunnington et al., 2014).

Only mortalities of anurans were high enough to permit a robust statistical analysis of the results. The research team predicted that road mortality should increase following installation of the grates if culverts alone mitigated mortality. If fencing was effective for mitigation, then mortality should decrease following their installation (Cunnington et al., 2014). There was no evidence found for the first prediction: culverts alone did not mitigate roadkill effects for anurans. In contrast, there was a large decrease in mortality at fenced sites relative to the control sites, indicating that fencing was effective in mitigating road mortality of anurans (Figure B5).

Figure B5: Grates were installed at six culverts along the Thousand Islands Parkway in 2009 and 2010 as part of a field experiment to evaluate the efficacy of culverts and roadside fencing in reducing vehicle-wildlife collisions. Results showed that culverts were effective for reducing road mortality but only when paired with fencing. Photo by R. Danby.

8.6 County Road 2 Wildlife Road Mortality Assessment

Building on the Thousand Islands Parkway and Highway 401 studies, a study of road mortality on County Road 2 (formerly Highway 2) was conducted in 2016 and 2017. Methods were nearly identical to the those used for the Thousand Islands Parkway Wildlife Road Mortality Assessment except that only half of the surveys were conducted by bicycle; the other half were conducted from a slow-moving car. In total, 133 surveys were conducted extending from Gananoque east to where County Road 2 passes over Highway 401. Time periods of heightened mortality were similar to those identified on the Parkway, and two main hotspots of road mortality were identified. “Hotspot A” occurred in the middle of the road’s extent between Blue Mountain Road and Escott. This is an area where the road passes through a wetland that is part of a large pathway of natural habitat that extends southwards from Charleston Lake to the St. Lawrence River. “Hotspot B” was located near the eastern end of the study area, at a sharp bend in the road where visibility is poor (Figure B6).

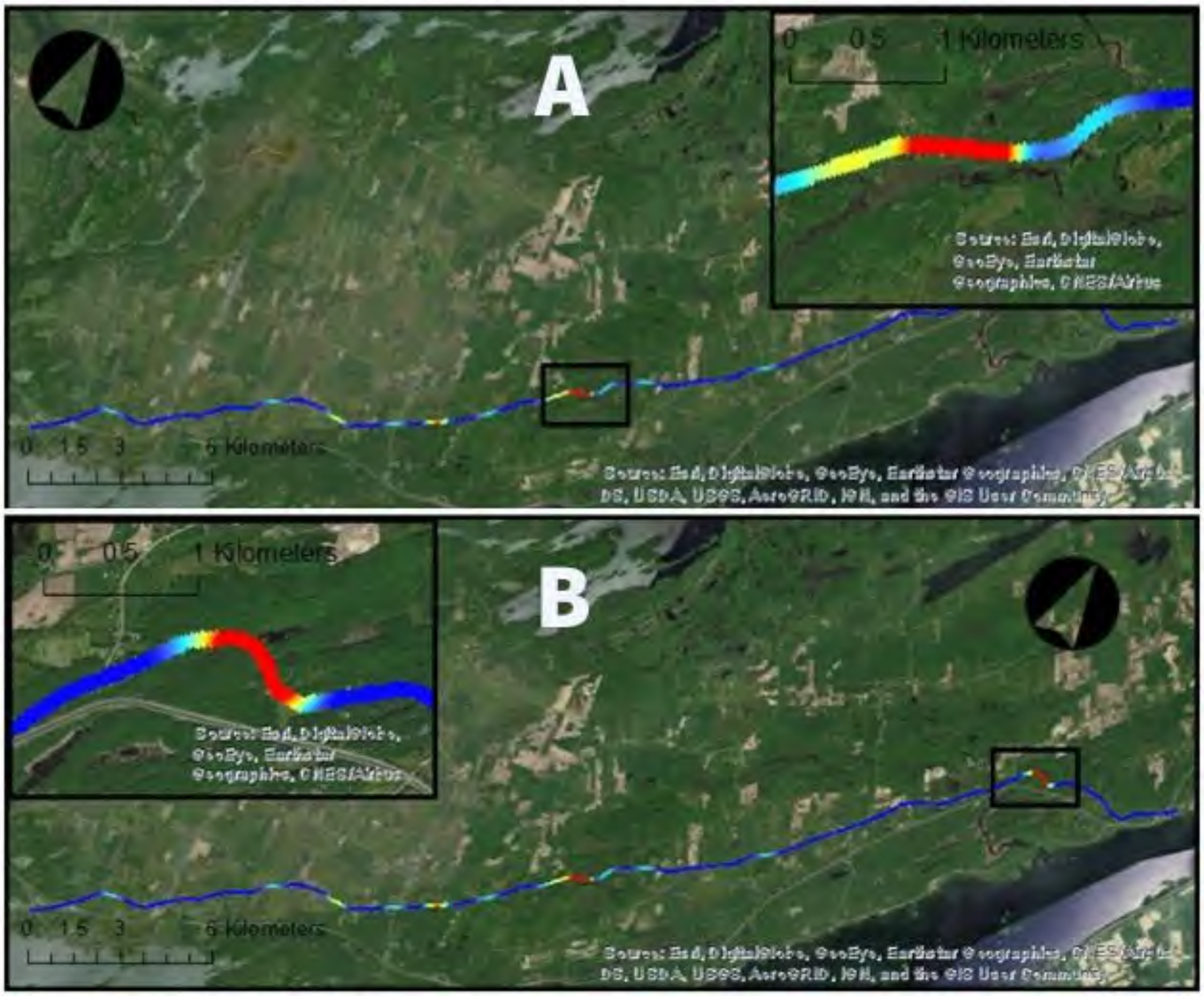


Figure B6: The two main hotspots that emerged from Highway 2 wildlife road mortality modelling (Hotspot A is top image, Hotspot B is bottom image). Figure from Urquhart et al. (2019).

The herpetile data obtained from this study was analyzed to identify the landscape features that are most closely associated with their mortality, and a similar model was developed to analyze the herpetile data collected from the Thousand Islands Parkway several years earlier (Jones, 2018). Models were developed at two different scales to reflect roadside conditions as well as broader landscape-level conditions. The results from both scales revealed that turtle, snake, and frog mortality on both roadways was overwhelmingly related to the proximity and number of wetlands and other water-related features (Jones, 2018).

8.7 Thousand Islands National Park Road Ecology Analysis

Given the number of road ecology studies and ecosystem mapping studies conducted for the region, Thousand Islands National Park commissioned a study that was aimed at bringing these data together to identify priority areas that Parks Canada might target for road mortality mitigation measures (Danby & Urquhart, 2019). Data from many of the aforementioned projects were compiled into an integrated GIS whose extent matched a priority zone of interest identified by Thousand Islands National Park, but was expanded to include the town of Gananoque, the eastern edge of Brockville, and areas 3 km to the north of County Road 2. A multistep geospatial analysis was conducted on these data with the output being a series of six scenario maps identifying potential areas of interest for road ecology mitigation, including habitat conservation. The six scenarios differed based on their weighting of the input data, but they were not ranked in terms of their preference. The analysis conducted for the Thousand Islands National Park project provided the foundation of the work for this present study and the geospatial methodology described in the following section draws heavily from this previous study.

9 Appendix C – Summary of proposed mitigation measures and their locations

Location ID used in Figures	Wildlife Movement Pathway	Roadway	Location Description	Approximate Location (Latitude, Longitude)	Level of Mitigation (Major vs. Minor)	Type of Crossing Infrastructure (Overpass vs. Underpass)	Recommendation No.	Proposed Mitigation
O1	Landons Bay to Lansdowne	Highway 401	Proposed overpass location #1	44.377067, -76.037853	Major	Overpass	Recommendation #1 for Landons Bay to Lansdowne route (report section 4.2.1.1)	Install overpass and fencing
U1	Landons Bay to Lansdowne	Highway 401	Box culvert crossing originally designed for cattle passage; assessed by Ross (2004)	44.372953, -76.050921	Minor	Underpass	Recommendation #2 for Landons Bay to Lansdowne route (report section 4.2.1.2)	Retrofit existing tall box culvert, add fencing
U2	Landons Bay to Lansdowne	Highway 401	Small culvert crossing assessed by Ross (2004)	44.376385, -76.041487	Minor	Underpass	Recommendation #3 for Landons Bay to Lansdowne route (report section 4.2.1.3)	Replace culvert, add fencing
I1-I5	Landons Bay to Lansdowne	Thousand Islands Parkway	Along road mortality hotspots	I1: 44.35325962, -76.07756215 I2: 44.35072316, -76.06766078 I3: 44.35164598, -76.04180721 I4: 44.35980026, -76.02398308 I5: 44.36310367, -76.0150688	Minor	Underpass	Recommendation #4 for Landons Bay to Lansdowne route (report section 4.2.1.4)	Retrofit/replace culverts as necessary, add fencing
U3	Landons Bay to Lansdowne	County Road 2	No existing crossing infrastructure; near intersection of County Road 2 with Railway Street/Grahams Road	44.405408, -75.993036	Minor	Underpass	Recommendation #5 for Landons Bay to Lansdowne route (report section 4.2.1.5)	Install underpass and fencing
U4	Landons Bay to Lansdowne	County Road 2	Culvert crossing at County Road 2 near Kidd Road South	44.385754, -76.0414641	Minor	Underpass	Recommendation #6 for Landons Bay to Lansdowne route (report section 4.2.1.6)	Replace culvert, add fencing
U5	Landons Bay to Lansdowne	County Road 2	Multiple culverts along Reynolds Road south of County Road 2	44.391395, -76.016944	Minor	Underpass	Recommendation #6 for Landons Bay to Lansdowne route (report section 4.2.1.6)	Retrofit/replace culverts along Reynolds Road as necessary, add fencing
O2	Rockport to Waterton	Highway 401	Proposed overpass location #2	44.386749, -75.965242	Major	Overpass	Recommendation #1 for Rockport to Waterton route (report section 4.3.1.1)	Install overpass and fencing
O3	Rockport to Waterton	Highway 401	Proposed overpass location #3	44.400171, -75.940820	Major	Overpass	Recommendation #1 for Rockport to Waterton route (report section 4.3.1.1)	Install overpass and fencing
U6	Rockport to Waterton	Highway 401	Box culvert crossing at Highway 401 between Highway 137 and Escott-Prescott Road	44.39932, -75.94339	Minor	Underpass	Recommendation #2 for Rockport to Waterton route (report section 4.3.1.2)	Retrofit/replace culvert as necessary, add fencing

Location ID used in Figures	Wildlife Movement Pathway	Roadway	Location Description	Approximate Location (Latitude, Longitude)	Level of Mitigation (Major vs. Minor)	Type of Crossing Infrastructure (Overpass vs. Underpass)	Recommendation No.	Proposed Mitigation
U7	Rockport to Waterton	Highway 401	Box culvert crossing at Highway 401 between Highway 137 and Escott-Prescott Road	44.39325, -75.95536	Minor	Underpass	Recommendation #2 for Rockport to Waterton route (report section 4.3.1.2)	Retrofit/replace culvert as necessary, add fencing
NA	Rockport to Waterton	Highway 401	CSP culvert crossings at Highway 401 between Highway 137 and Escott-Prescott Road	Unknown	Minor	Underpass	Recommendation #2 for Rockport to Waterton route (report section 4.3.1.2)	Replace culverts, add fencing
I6-7	Rockport to Waterton	Thousand Islands Parkway	Along road mortality hotspots	I6: 44.37484, -75.95015 to 44.37664, -75.94187 I7: 44.42412, -75.89057 to 44.38444, -75.93197	Minor	Underpass	Recommendation #3 for Rockport to Waterton route (report section 4.3.1.3)	Retrofit/replace culverts as necessary, add fencing
U8	Rockport to Waterton	County Road 2	Box culvert crossing (tributary of LaRue Creek)	44.421285, -75.969732	Minor	Underpass	Recommendation #4 for Rockport to Waterton route (report section 4.3.1.4)	Retrofit culvert, add fencing
U9	Rockport to Waterton	County Road 2	Small culvert crossing (tributary of LaRue Creek)	44.4287213, -75.957134	Minor	Underpass	Recommendation #5 for Rockport to Waterton route (report section 4.3.1.5)	Retrofit/replace culvert as necessary, add fencing
U10	Rockport to Waterton	County Road 2	Bridge crossing (tributary of LaRue Creek)	44.435847, -75.947850	Minor	Underpass	Recommendation #6 for Rockport to Waterton route (report section 4.3.1.6)	Retrofit bridge, add fencing
U11	Jones Creek	Highway 401	Arch-shaped tunnel crossing	44.514041, -75.828994	Major	Underpass	Recommendation #1 for Jones Creek route (report section 4.4.1.1)	Replace arch-shaped tunnel, add fencing
U12	Jones Creek	Thousand Islands Parkway	Jones Creek bridge crossing at Thousand Islands Parkway	44.503312, -75.805960	Minor	Underpass	Recommendation #2 for Jones Creek route (report section 4.4.1.2)	Retrofit bridge, add fencing
I8-10	Jones Creek	Thousand Islands Parkway	Along road mortality hotspots	I8: 44.45090798, -75.86298031 I9: 44.46199978, -75.85020235 I10: 44.488712, -75.822284	Minor	Underpass	Recommendation #4 for Jones Creek route (report section 4.4.1.3)	Retrofit/replace culverts as necessary, add fencing
U13	Jones Creek	County Road 2	Watercourse crossing at County Road 2 east of Yonge Mills Rd	44.521918, -75.8179610	Minor	Underpass	Recommendation #4 for Jones Creek route (report section 4.4.1.4)	Retrofit/replace as necessary, install signage, reduce speed limit, consider fencing

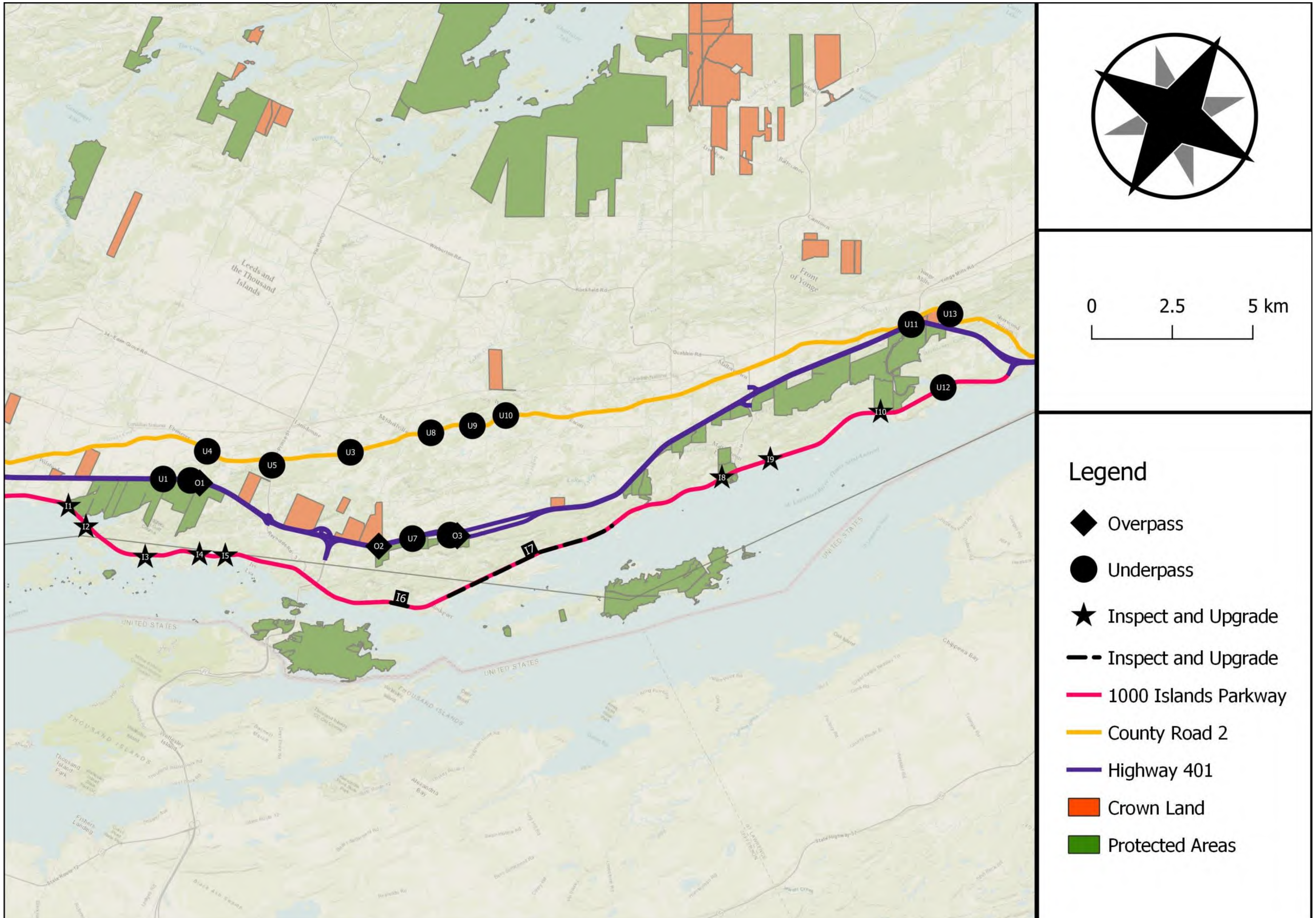


Figure C1: Map showing the three wildlife pathways fragmented by Highway 401, the Thousand Islands Parkway, and County Road 2, and road areas proposed for mitigation.

10 Appendix D – Examples of wildlife overpasses

Figure D1: Wildlife overpass on the Trans-Canada Highway in Banff National Park. Image source: https://9gag.com/gag/aE8L0ZG

Figure D2: California’s Wallis Annenberg Wildlife Crossing. Image source: https://www.newcivilengineer.com/latest/worlds-largest-wildlife-crossing-breaks-ground-in-california-22-04-2022/

Figure D3: Wildlife overpass built on rock cuts. Image source: https://www.worldatlas.com/articles/what-is-a-wildlife-pathway.html

Figure D4: Example wildlife overpass design with fencing. Image source: https://coloradooutdoorsmag.com/2020/12/09/colorado-wildlife-crossing/

Figure D5: Constructed amphibian habitat at edge of wildlife overpass (© T. Clevenger via Clevenger & Huijser, 2011).

11 Appendix E – Examples of wildlife underpasses

Figure E1: Wildlife underpass (arched tunnel) designed to incorporate a natural stream crossing and associated riparian area (© D. Seburn via OMNRF, 2016).

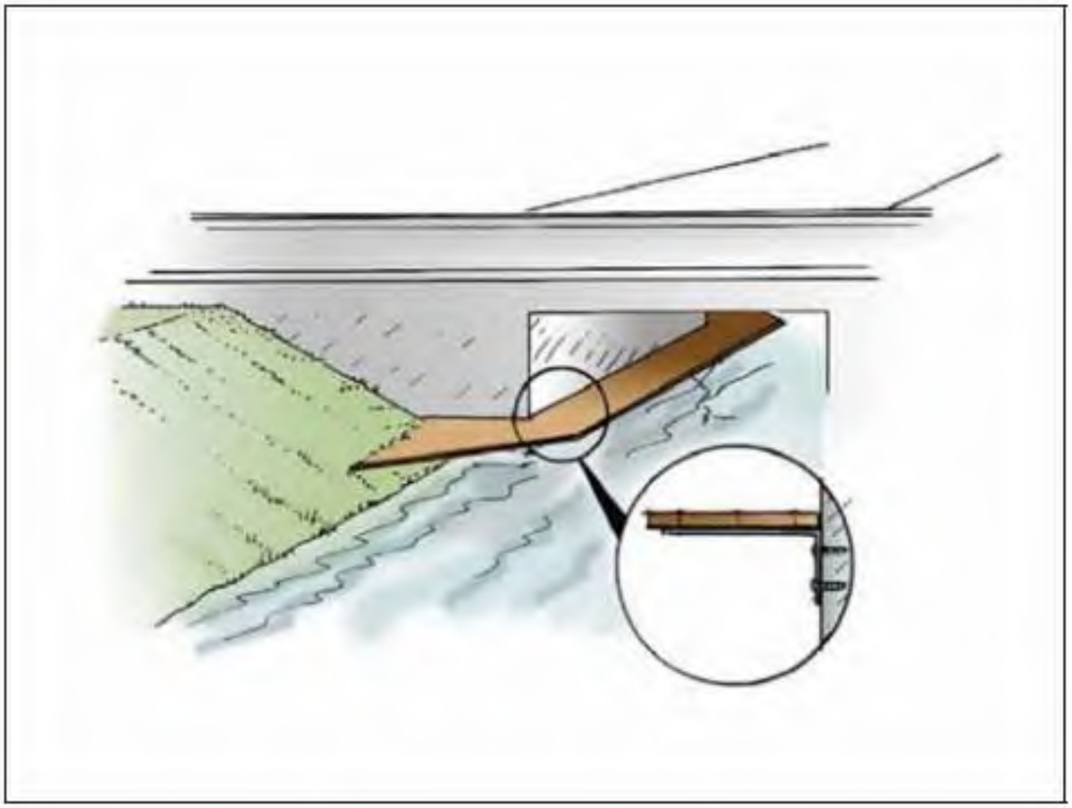


Figure E2: Wildlife underpass (box culvert) with terrestrial shelf (© Kruidering et al., 2005 via Clevenger & Huijser, 2011)

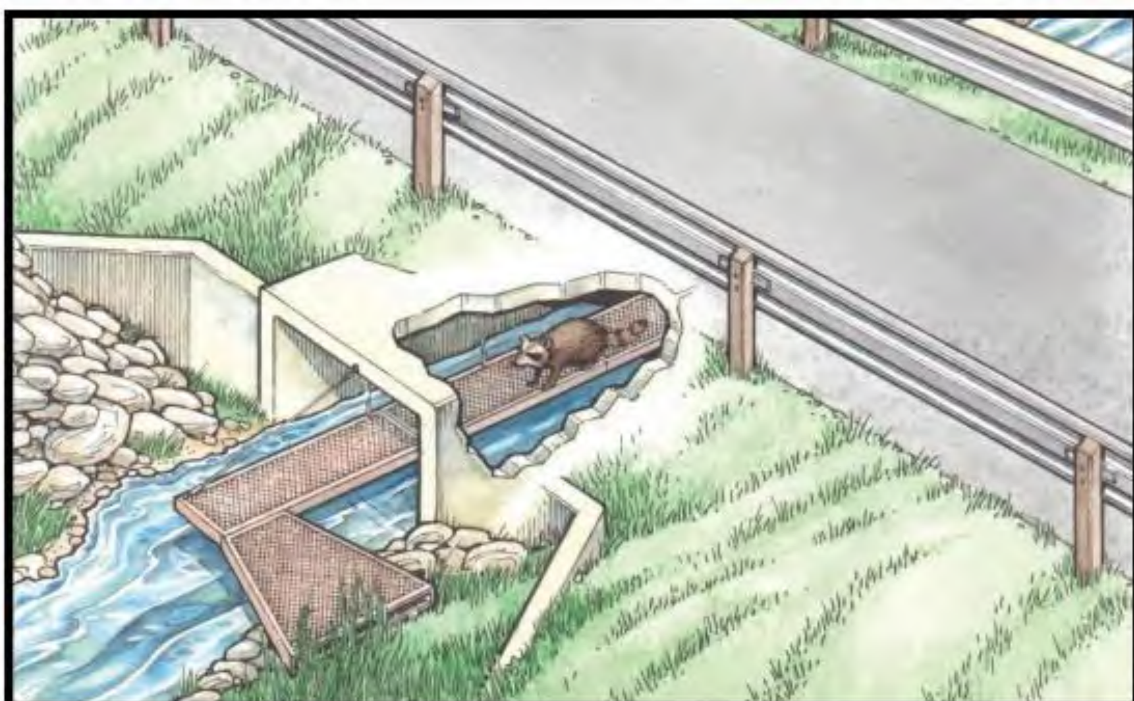


Figure E3: Wildlife underpass (box culvert) with terrestrial shelf (© Roscoe Culvert via Danby et al., 2016)

Figure E4: Wildlife underpass (box culvert) with soil and branches inside tunnel to increase microhabitat structure and complexity (© B. Beasley via OMNRF, 2016).

Figure E5: Massasauga rattlesnake exiting an underpass with natural substrate, vegetation cover, and wildlife fencing. Image source: https://www.ontarioparks.com/parksblog/ecopassages-help-wildlife-cross-roads-safely/

12Appendix F – Examples of wildlife fencing

Figure F1: Roadside turtle fencing in Ottawa, made of hardwire mesh and wooden poles. Image source: https://blog.cwf-fcf.org/index.php/en/victory-for-eastern-ontarios-freshwater-turtles/

Figure F2: Two-metre-tall wildlife exclusion fence (hardwire mesh and metal poles) with overhang tied into concrete wildlife barrier along wetland habitat in Ottawa (© K. Black).

Figure F3: Reptile and amphibian fence with overhang, made of hardwire mesh and wooden stakes (© T. Clevenger via Clevenger & Huijser, 2011).

Figure F4: Large mammal exclusion fence made of metal wire and wooden poles (© T. Clevenger via Clevenger & Huijser, 2011). This photo shows an escape ramp (jump-out) for wildlife that get trapped inside the right-of-way. Note that this gauge of wire is not effective for excluding small animals, and metal posts are recommended over wood.