Effects of road-induced habitat fragmentation on reptile and amphibian species at risk in North America: impacts and mitigation efforts

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Abstract

Species at Risk in Canada are protected through the national *Species at Risk Act* (SARA), by provincial legislation such as Ontario's *Endangered Species Act*, and by municipal efforts to preserve critical habitats. However, human activities, particularly the expansion of linear infrastructure, have highly negative impacts on the habitats and movement of animals. Reptiles and amphibians in particular are affected by habitat fragmentation as it interferes with the basic functions necessary for survival, including movement for reproduction, provision of suitable habitat, and availability of food. It has been recognised that the wellbeing and survival of reptiles, amphibians, and other species at risk is suffering as a result of this human interference. To help mitigate the negative impacts associated with road-induced habitat fragmentation, there are a variety of road crossing structures completed, underway, and planned in Canada, with some examples from the United States. This paper will explore some of the types, designs, and effectiveness of road crossing structures being used to help reduce the impacts of roads and resulting habitat fragmentation on reptile and amphibian species at risk in North America.

Introduction

A number of species in North America, particularly reptiles and amphibians, are widely affected by the fragmentation of habitat caused by human actions, particularly the construction of roads (Woltz, Gibbs, & Ducey, 2008). Habitat fragmentation can be caused by the rezoning of wetlands, forests, and fields into building areas, or a transformation in the way tracts of land are used. The construction of roads is a major limiting factor in the viability of reptile and amphibian populations, as road networks can separate groups of animals into subpopulations which severely limits their genetic and demographic makeup, while organism road crossings can result in high levels of mortality (Garcia-Gonzalez, Campo, Pola, & Garcia-Vazquez, 2011; Mata, Hervás, Herranz, Suárez, & Malo, 2004). The fragmentation of habitats also decreases dispersal, reduces the diversity of genes, and increases mortality (Cushman, 2006). Reducing the genetic variation within subpopulations can cause negative effects on the fitness of organisms, while natural selection will begin to favour those that migrate to other habitats (Shepard, Kuhns, Dreslik, & Phillips, 2008). Reptiles and amphibians cross roadways in order to reach suitable habitat for breeding, feeding, nesting, and overwintering; they also seek roads during the night to maintain body temperature as road surfaces remain warm while the air cools off (Langen, Machniak, Crowe, Mangan, Marker, Liddle, & Roden, 2007). Predicting the potential for extinction of reptile and amphibian species resulting from habitat fragmentation is a preeminent issue faced by conservation biologists in North America (With & King, 1997).

This paper will identify and examine some of the road crossing structures that have been implemented to aid the movement of reptile and amphibian species at risk affected by human-caused habitat fragmentation pertaining to the installation of roads. Reptiles and amphibians are particularly vulnerable to road-induced habitat fragmentation due to: their limited ability to relocate to other habitats when theirs are interfered with or destroyed, their habitat sensitivities, and their frequent migrations at designated points in their life cycles (Cushman, 2006). See the appendix for Cushman's explanation of amphibian vulnerability. This paper will delve into the effects that roads have regarding habitat fragmentation in North America, explore some of the implemented and planned assistance measures, and evaluate the impacts of habitat fragmentation on the survival and futures of affected herptile species at risk.

There is an increasing interest in the impacts of habitat fragmentation on the survival of species, and a growing need to identify, study, and ameliorate the effects of roads on reptiles and amphibians (Beebee, 2012). Understanding what types of mitigation measures have been undertaken thus far, and their successes or lack thereof, is an important starting point in the future conservation of reptile and amphibian species at risk (Jochimsen, Peterson, Andrews, & Gibbons, 2004).

This paper is laid out in the following manner: Section (1) will explore the effects of roads on herptiles including both direct and indirect effects, Section (2) will cover the types of road mitigation measures which have been undertaken in North America, including exclusion fencing, tunnels, overpasses, and their design considerations and operational issues, Section (3) will delve into the effectiveness of the physical projects undertaken as mitigation measures, Section (4) will cover other types of mitigation or herpetofauna protection, Section (5) will explore some of the challenges faced in the study of road-induced habitat fragmentation and its impacts on herptiles, and Section (6) will provide the conclusions reached from the examination of this information.

Section I: Effects of roads on herptiles

The impacts of roads on the well-being, survival, and ultimate population viability of reptiles and amphibians come in two forms: direct effects and indirect effects. Direct effects are the ways in which roads cause mortality or inhibit species movement, such as interactions with vehicles and by creating a barrier to dispersal. Indirect effects are the resounding impacts which do not immediately threaten species survival; these include habitat fragmentation, inhibiting habitat connectivity, and causing gender skewing and genetic isolation. Post-construction mitigation efforts limit the level of effects that can be controlled, as it is very difficult to mitigate the indirect effects, while retrofitting roads with crossing structures is very costly (Andrews *et al.*, 2008).

Fahrig and Rytwinski (2009) identified four situations in which roads create negative impacts on organisms:

(1) species are attracted to roads but are unable to avoid individual cars,

(2) species have high levels of movement, low reproductive rates, and low densities regardless of their reaction to roads,

(3) small animals avoid roadside habitat, and

(4) small animals not impacted by road-affected predators, who have no road/traffic avoidance, are unable to avoid oncoming traffic.

This section will explore both direct and indirect effects on reptile and amphibian species in North America as related to road-induced habitat fragmentation.

i. Direct Effects

a. <u>Mortality</u>

Understanding the impacts of habitat fragmentation and destruction on species is too broad of a task to complete comprehensively, as individual species have distinct vulnerabilities, needs, capabilities, and preferences (Cushman, 2006). However, a 2009 study by Langen *et al.* indicates that road mortality hot spots of reptiles and amphibians often overlap. The study also determined that these hot spots are located within a hundred metres of wetlands, while mortality rates are higher when two wetlands are connected by a causeway (in this case a road), rather than a single wetland situated on one side of the road. Findlay and Bourdages also conclude that reptile densities are lower in areas with suitable habitat located on both sides of the road, as reptiles are thus more likely to traverse the surface of the road and interact with vehicles (2000). Study segments with high levels of road mortality are often adjacent to other segments with high road mortality, demonstrating further evidence of hot spots (MacKinnon, Moore, & Brooks, 2005). It should be noted that no two wetlands are the same, thus they have different ecological requirements, provide habitat to a variety of species, and require immigration and emigration of individuals to fulfill their needs and maintain equilibrium (Roe & Georges, 2006).

Studies of road mortality on reptile and amphibian populations are frequently of too short a duration to make concrete conclusions regarding temporary versus long-term effects of roads on herptiles (van der Grift *et al.*, 2012). Literature suggests that roads located within one to two kilometres of wetlands and ponds have higher mortality rates for reptiles and amphibians than roads located elsewhere, with one study tallying more than 625 snakes and 1700 anurans killed per kilometre per year (Forman & Alexander, 1998); this indicates a positive correlation between road density and decreased species richness. A modelling assessment has determined that species fare better when roads are proximal to each other rather than equally distributed (Andrews, Gibbons, & Jochimsen, 2008). While road density is increasing relatively slowly, the number of vehicle kilometres travelled is increasing much more quickly (Forman & Alexander, 1998) which can result in higher levels of road mortality in herptile crossing locations. It has been suggested that increasing traffic and road density rather than constructing new roads would geographically contain the negative ecological impacts of roads on herptiles (Fahrig, Pedlar, Pope, Taylor, & Wegnar, 1994).

Unfortunately, traffic volumes tend to increase during the summer months as people take advantage of the nice weather for vacations, which is the same time of year that reptile and amphibian movements tend to peak for migrations, exacerbating the already high rates of mortality (Ashley, Kosloski, & Petrie, 2007). Additionally, philopatry has been noted in some reptiles and amphibians, causing the animals to continue to head to the same locations year after year, despite a changing landscape (Andrews, Gibbons, & Jochimsen, 2008). This can increase their exposure to the risk of road mortality, as it is anticipated that they will take the shortest route from one habitat to another (Joly, Morand, & Cohas, 2003). Road mortality peaks for turtles during the nesting season, with 30.5% of snapping turtles seen on/near the road found dead during surveys in central Ontario (Andrews *et al*., 2008).

The movements of amphibians are typically inconspicuous and slow, making them particularly susceptible to road mortality (Trombulak & Frissell, 1999). There is an inverse relationship between the abundance of anurans in Ontario and the level of traffic on roads (Trombulak & Frissell, 1999). Wet roadways tend to be attractive to amphibians, while wet roadways with high traffic volumes present the greatest risk to their survival as individuals and populations (Andrews *et al*., 2008). Intense weather events can stimulate mass migration of snakes, resulting in extremely high mortality rates in a small frame of time; these exceptions are extremely difficult to predict, making mitigation possibilities relatively impossible (Andrews *et al.*, 2008).

Mortality rates of herpetofauna on roadways can be an indicator of healthy, vibrant population levels, but also of the direct impacts of roads on population levels. Reptiles and amphibians typically cross road surfaces for the purposes of reproduction, finding a food source, and choosing new habitat as the seasons change (Langen *et al*., 2007). Other factors that contribute to road mortality include: type and structure of roadside vegetation, road design, biodiversity of the ecosystem/species composition, and animal behaviour (Langen *et al*., 2009). Cushman (2006) states, “Each species experiences and responds to ecological conditions in its environment uniquely,” which indicates that the type and size of road effects is species-specific.

A large Snapping Turtle sits in the middle of the highway during its crossing from one wetland to another, as the surface of the road acts as a causeway to connect the two separated habitats, near Kinmount, Ontario, Canada (Griffin, 2014).

To fully understand the impacts of the barrier effect created by roads on a specific species, studies must be ongoing for at least a generation – this means ten years for testing genetic isolation in northern watersnakes as they have a two- to three-year generations and live seven- to nine years, but up to fifty years for snapping turtles which have a fifteen- to twenty-five-year generation and a sixty- to one hundred-year lifespan (Baxter-Gilbert, Lesbarrères, & Litzgus, 2013). It is especially important to view effects of road mortality from a species-specific lens as the variation between species is so great.

However, shorter-term studies on herpetofauna can still provide useful information regarding mortality rates. A study conducted by Ashley, Kosloski, and Petrie (2007) indicates that 2.7 per cent of motorists actually go out of their way to hit reptiles and amphibians on road surfaces. Most studies of road mortality do not take into consideration the actions of drivers to avoid or aim towards herpetofauna species, thus the effects of road mortality may be underestimating the actual number of organisms hit on roads (Ashley *et al.*, 2007).

Many anurans have such delicate body structures that the change in pressure caused by a passing vehicle may be enough to cause the internal organs to expel from their bodies, causing death to organisms which have not been directly struck by a vehicle (Andrews, Gibbons, & Jochimsen, 2008). This becomes particularly problematic with species observed to stop moving when approached by a vehicle (Andrews, Gibbons, & Jochimsen, 2008).

b. Species movement and dispersal

Species dispersal rate and distance is particularly important to the level of impact that habitat fragmentation may cause, as a species which has higher levels of dispersal will encounter greater numbers of roads and other types of fragmentation, thereby becoming more susceptible to road mortality (Cushman, 2006). Additionally, juvenile survival can be greatly influenced by the amount of habitat fragmentation, as juveniles typically move further than adults in search of suitable habitat to fulfill their various lifecycle needs; the levels of dispersal amongst species at risk have often been observed as too low for population viability (Cushman, 2006).

Terrestrial amphibians make up more than seventy-nine per cent of amphibian road mortality as they migrate to breeding ponds (Beebee, 2012). The connectivity of habitats is critical for maintaining the immigration and emigration of individuals within a population, facilitating the migration necessary for reproduction (Cushman, 2006; Beebee, 2012). Migration is also critical for meeting the ecological needs of wetlands (Roe & Georges, 2006). Road mortality studies, conducted on foot and from vehicles, indicate that amphibians frequently constitute two-thirds or more of all vertebrate deaths; of this, 65% were anurans and 35% urodeles (Beebee, 2012). A 1987 study by Lalo approximated that one million vertebrates were killed on the road each day in the United States (Glista, DeVault, & DeWoody, 2008). However, not all organisms struck by vehicles are killed – some are injured and survive, while others are injured and thus become prey to other animals.

A Blanding’s Turtle is seen to be missing the front left leg and foot, possibly as a result of an interaction with an automobile, located in Gelert, Ontario, Canada (Griffin, 2014).

The number of individual reptile and amphibian organisms within a population vary greatly on an annual basis, influenced not only by road mortality rates, but also by the levels of reproduction, the number of juveniles who make it to adulthood, the availability of resources, immigration and emigration, and mortality from other causes (Collins & Halliday, 2005). Seasonal variation in the location of organisms requires studies of a longer duration in order to ensure accuracy; it has been suggested that amphibian populations will feel the impacts of roads within eight years of construction, though the entirety of effects may take decades to manifest (Findlay & Bourdages, 2000). A comprehensive understanding of road impacts on herptiles may take dozens of years to determine, as many of the effects are delayed, and take time to manifest (Andrews *et al.*, 2008).

Road mortality of amphibians is much higher during the breeding season as individuals migrate to breeding ponds (Beebee, 2012). Additionally, construction should take into consideration the location of work as it may be within the habitat of overwintering, nesting, or breeding species – this could be done through environmental assessments and monitoring before, during, and after road construction (Jochimsen *et al*., 2004). An example of an ecological monitoring failure is represented by the burial of newly metamorphosed toads in Yellowstone National Park as the shoulders of the highway were smoothed out (Jochimsen *et al*., 2004).

Both forest cover and road density affect the number and variety of amphibian species seen in Ontario breeding ponds, with long-range consequences being felt a thousand metres from roads; this may lead to low estimates of the impacts of habitat destruction on species richness (Beebee, 2012). Forest cover nearby breeding ponds is positively correlated with species richness in amphibians, with accessible forest accounting for fifty per cent of the anuran species richness once local variables (distance to roads, total forest) had been considered (Eigenbrod, Hecnar, & Fahrig, 2007).

Reptile and amphibian species richness is notably lower in locations with higher road densities near wetlands (Forman & Alexander, 1998). The areas with the highest rates of road mortality are roads within one to two kilometres of wetlands and ponds, in locations which transect the various habitats required during lifecycle changes (Andrews *et al*., 2008). Eigenbrod, Hecnar, and Fahrig suggest that road density may be the best measure of road effects (2008). Given that most human settlements are located near water, and that road density proximal to water bodies is thus higher than other areas, reptile road mortality increased with density of buildings (MacKinnon, Moore, & Brooks, 2005).

Roads decrease the size of habitat patches within the environment, thus increasing the level of edge habitat; this results in smaller animal populations and future viability (Charry & Jones, 2009). Although the exact benefits remain unknown, it has been established that larger habitat patches will have more species than smaller parcels, and connected patches will have greater species richness than isolated parcels (Prugh, Hodges, Sinclair, & Brashares, 2008). The implications of patch size versus patch isolation has not yet been concluded (Prugh *et al*., 2008).

ii. Indirect effects

a. <u>Habitat fragmentation</u>

Habitat fragmentation is one of the greatest threats to biodiversity around the globe (Laurance, Nascimento, Laurance, Andrade, Ewers, Harms, Luizao, & Ribeiro, 2007). The ability of animals to move from one section of land to another can be critical to their survival, well-being, and the future viability of the species (Janin, Léna, & Joly, 2012). It is important to look not only at how habitat fragmentation reduces the amount of habitat available to species at risk, but how it modifies species movement and their propensity for (or willingness to engage in) movement (Janin, Léna, & Joly, 2012). Road-induced habitat fragmentation is only one of several types of fragmentation found in North America, but will be the main focus of habitat fragmentation in this document.

As roads cover up and destroy habitat within North America, they also create the 'edge effect' which lowers the quality of habitat adjacent to roads (Cosentino *et al.*, 2014); this is also called the 'road-effect zone' (Forman & Alexander, 1998). Species richness is affected by the presence of, and proximity to, roads. Amphibian diversity has been found to be affected for distances of up to 2000 metres from roadways (Beebee, 2012), while more conservative estimates consider the 'road-effect zone to be 100 metres to 800 metres beyond the edge of the road (Andrews, Gibbons, & Jochimsen, 2008). It is estimated that the ecology of fifteen to twenty per cent of the land in the United States is affected by roads (Forman & Alexander, 1998; Gibbs & Shriver, 2005).

Studies indicate that amphibians often have a lower movement rate than invertebrates, mammals, and even reptiles (Cushman, 2006). The vast number of roads pose a particular problem for reptiles and amphibians; Canada is home to more than 1.04 million kilometres of roads as of 2012 (Lesbarrères *et al*., 2014). Roads can continue to affect animals even if they are abandoned, thus all constructed roads contribute to the fragmentation of habitat (Lesbarrères *et al*., 2014).

Studies and results regarding indirect effects of roads and habitat fragmentation on herptiles are more obscure than direct effects (Andrews *et al.*, 2008). Therefore, understanding the types, magnitude, and direction of indirect effects on reptiles and amphibians is hard to quantify, making them hard to mitigate.

b. Genetic diversity and gender skewing

Habitat fragmentation caused by roads directly impacts the intraspecific genetic diversity of herpetofauna. The division of critical habitat separates a population into two or more pieces which can result in the alteration of organismal dispersal, demographic changes, and a reduction in the size of the gene pool (Langen *et al.*, 2007). Fragmentation impacts not only the biological diversity of each sector of land, but the intraspecific diversity of species within them (Habel & Zachos, 2012). Genetic diversity is critical to the health and survival rates of both individuals and entire species, demonstrating a positive correlation with population viability (van der Grift *et al.*, 2012). As habitats are separated into unconnected sections of land or water, genetic diversity plummets (Beben, 2012). The greater the intraspecific diversity within a species, the more likely the species is to be resilient; resiliency is regarded as the ability to rebound from shocks and change (Christopherson & Byrne, 2009).

Studies indicate that all effects of habitat fragmentation on reptiles and amphibians must be considered in tandem due to the interconnectivity of the potential damage; ecological, behavioural, and genetic information should be gathered regarding barrier effects on species to fully understand the impacts (Shepard *et al.*, 2008).

There is evidence that the sex of individual reptiles influences their dispersal and sociability, meaning the amount of space required by each sex may vary between species, and the sexes may therefore be unequally affected (Stow, Sunnucks, Briscoe, & Gardner, 2001). Road mortality can result in gender skewing within populations, particularly for turtles as females migrate from wetlands to roadsides to lay eggs; this is particularly common for snapping turtles and painted turtles (Langen *et al*., 2009; Steen & Gibbs, 2004). Gender skewing can have dire impacts on the ultimate survival of a species, as one male can mate with more than one female in a population, thus having fewer males would be less detrimental than having fewer females. While more female than male turtles are affected by road mortality, studies indicate the opposite for snakes and lizards as males travel greater distances to seek out mates (Jochimsen *et al*., 2004).

Peaks of road mortality in anurans and turtles occurred in direct relation to migration patterns. Turtle mortality spikes in June when they migrate for nesting, and again in the fall when they return to deep water marshes for hibernation (Langen *et al*, 2007). Juvenile mortality is extremely high for turtles due to the locations of nests – hatchlings frequently climb out of their nests directly onto road surfaces. Turtle mortality is also highly associated with seasonal migrations, and movement between wetlands (Andrews *et al.*, 2008). Thus, studies of population dynamics must be conducted throughout these peak times in order to get a full understanding of the barrier effects on reptile and amphibian species.

Reptiles, and particularly turtles, are slow to mature, have low rates of reproduction, have long lifespans, and take many years to reach sexual maturity. These traits cause reptiles to be at particular risk of genetic isolation and limitations (Andrews *et al.*, 2008).

A Blanding's Turtle (top) nests on the side of the road in Gelert, Ontario, Canada (Griffin, 2014). A Snapping Turtle (bottom) nests on the side of the road near Denbigh, Ontario, Canada (Griffin, 2014).

c. Other effects

Immigration and emigration are integral aspects in the maintenance of healthy populations. Limiting the levels of movement between habitats, or having low levels of habitat connectivity, interferes with the genetic diversity of populations, and can reduce the viability of the population. Isolation of populations can drastically increase the risk of extinction (Rodriguez, Crema, & Delibes, 1996). The risk of population extinction can be lowered as a result of immigration in what is known as the 'rescue effect' (Nakazowa, 2015). However, lowered connectivity between habitats can mean that local extinctions result in decreased species richness as there is less recolonization (Findlay & Houlahan, 1997).

Traffic noise causes herptile disturbance far from the actual surface of the road, resulting in larger effect zones. Traffic noise is positively correlated with the number of vehicles and average speeds on a given road in a day, where an average of 120km/h can result in noise effects up to 305 metres for a 10,000 vehicle density and 810 metres for 50,000 vehicle density in woodland areas, while prairie/grassland habitats suffer noise disturbances 365 metres for 10,000 vehicle density and 910 vehicle density (Forman & Alexander, 1998). Types of issues arising from traffic noise include: hearing loss, raised stress hormones, changed behavioural patterns, interference with auditory communication, and impacts on other organisms particularly prey (Forman & Alexander, 1998; Andrews, Gibbons, & Jochimsen, 2008). For species that are mainly impacted by road disturbance rather than road mortality, decreased road and vehicle density are the primary methods of reducing negative impacts (Fahrig & Rytwinski, 2009).

Unintentional expulsion of chemicals on roadways, such as gasoline or oil, aluminum, lead, cadmium, copper, manganese, titanium, nickel, zinc, and boron, can be toxic to herptile, particularly amphibians due to their permeable skin (Trombulak & Frissell, 2000). However, intentional application of deicing agents such as sodium chloride and calcium magnesium acetate, dust-inhibitors like calcium chloride, and salt for deicing are also toxic to organisms in roadside habitats (Forman & Alexander, 1998). Lowered reproductive efforts have been recorded for *A. maculatum* and *R. sylvatica* and Green Frogs after they were exposed to deicing agents (Andrews, Gibbons, & Jochimsen, 2008). These agents also affect water and soil characteristics which have resounding impacts on other ecological aspects of roadside habitats.

Roads also contribute greatly to the spread of non-indigenous species throughout North America. The transportation and resulting colonisation of exotic species in various habitat alters the composition of the land, its resources, and its supporting characteristics, often crowding out the native species contributing to the ecology of the area (Trombulak & Frissell, 2000). As invasive species begin to dominate areas, they alter the composition of the land, often resulting in insufficient suitable habitat and prey for native species (Andrews, Gibbons, & Jochimsen, 2008).

Section II: Road mitigation measures

Management strategies have come up with a variety of projects in an effort to repair some of the damages resulting from human infrastructure, and to attempt to ensure the futures of many species, particularly herptiles that are already at risk. A combination of measures, including increased awareness through public information sessions, installed/improved signage denoting the existence of and concerns for threatened species/species habitat, and the installation of barriers and bridges to funnel animals through a particular pathway of movement, have been determined useful measures to assist animals in spanning the boundaries created by human interruptions in habitat (Beben, 2012). Mitigation measures focused on areas with high road mortality are expected to be the most effective (MacKinnon, Moore, & Brooks, 2005).

Several US states have built underpasses and overpasses to help facilitate the movement of animals, reduce road mortalities, and alleviate concerns over the movement of wildlife (Forman & Alexander, 1998). Studies on the efficacy of crossing structures, though limited in number and scope, indicate that the structural qualities of projects have a greater influence on their usability than the level of traffic, human presence, and local vegetative cover (Mata *et al*., 2005). It is much more expensive to retrofit roads with species-specific eco-passages or crossing structures than to plan for and construct passages in the initial building of a road. Around 2010, ten million dollars (7.5% of the road project budget) was spent on retrofitting Highway 93 in the Flathead Indian Reservation in Montana, USA, incorporating forty-one crossing structures (van der Grift, van der Ree, Fahrig, Findlay, Houlahan, Jaeger, Klar, Madrinan, & Olson, 2012).

Beebee (2012) questions the long-term implications of road barriers on the genetic diversity within populations, as changes may take generations to manifest. Roads can also act as barriers to organism movement through avoidance behaviour amongst individuals (Shepard *et al.*, 2008). Many ecologists believe that the interference with animal movement and the resulting consequences are a greater threat to reptile and amphibian persistence than the motorist collisions with organisms and resulting road mortality (Beben, 2012). Variation in movement occurs not just between species, but within species as well. Massassauga rattlesnakes in Ontario, for instance, have been observed to utilise or avoid road surfaces depending on their overall length and size, indicating that smaller organisms are more likely to avoid the openness of road surfaces than larger snakes (Jochimsen *et al*., 2004). This can be particularly damaging because the larger organisms, which are more prone to bask on open surfaces such as roads, are sexually mature and thus contributing to the population numbers.

In a 2001 study by Fahrig, monitoring suggests that the most effective ways to conserve herpetofauna species suffering due to habitat fragmentation is to:

1. preserve and restore habitat,
2. predict extinction thresholds through monitoring organismal movement rates, and
3. consider the quality of habitat not just within the untouched habitat but also that adjacent to road structures.

Extinction thresholds are determined using a combination of a species' traits and the characteristics of the environment, such as the number of organisms and species within each individual parcel of habitat (Hanski, 2011). With & King (1999, p. 315) identify extinction thresholds as "…the minimum proportion of suitable habitat necessary for population persistence – for territorial species with different life-history characteristics and dispersal abilities." By identifying the extinction threshold and taking these steps, the potential for reptile and amphibian extinction is greatly reduced. Given the difficulty of determining the extinction thresholds for herptiles, there is a significant possibility that thresholds may be exceeded before they are identified (With & King, 1999).

Understanding the direct and indirect impacts that roads have on reptile and amphibian species is critical to preserving the integrity of their populations. Given that animal crossing structures vary in their purpose, design, location, cost of construction, and amount of maintenance, the types of physical structures implemented should be considered carefully for their effectiveness. Jackson and Griffin (2000) encourage limited construction of the most expensive options (overpasses) and more common use of the cheaper options available (tunnels, culverts). They also suggest limiting the expensive alternatives for use in areas of significant wildlife corridors and special habitats. The strategic construction of reptile and amphibian road crossing structures should incorporate a 'best bang for the buck' consideration to ensure that the greatest number of organisms in the most significant locations benefit from these mitigation measures. Habitat connectivity is crucial for the survival of amphibians due to their habitat sensitivities and various lifecycle stages (Garcia-Gonzalez *et al.*, 2011).

A synthesis of available studies on road impacts on herptiles includes Forman *et al*.'s six criteria for how to measure the effectiveness of wildlife crossing structures, which should be considered in both the implementation of mitigation measures and in the post-construction monitoring (van der Ree *et al.*, 2007):

1. reduce rates of road-kill,
2. maintain habitat connectivity,
3. maintain genetic interchange,
4. ensure biological requirements are met,
5. allow for dispersal and re-colonisation, and
6. maintain meta-population processes and ecosystem services.

Mitigating the effects of roads on reptiles and amphibians is not a task that can be undertaken by one group alone. Andrews, Gibbons, and Jochimsen call for the combined efforts of government agencies, engineers, local citizen communities, non-profits, and scientists (2008).

The following subsections will explore the use of physical projects: exclusion fencing, tunnels and culverts, and overpasses. Studies have found that reptiles and amphibians are more prone to use tunnels, culverts, and underpasses than overpasses and flyovers (Rodriguez, Crema,

& Delibes, 1996); thus, road construction and resulting habitat fragmentation is cheaper to mitigate for reptiles and amphibians than for larger animals. Improving the connectivity of habitats while reducing road mortality of reptiles and amphibians is often considered imperative to maintaining populations and reducing potential extinctions both locally and regionally (Shepard *et al*., 2008).

i. Exclusion Fencing

Exclusion fencing is one such mitigation measure that has been implemented to keep herpetofauna, particularly reptiles, off of road surfaces (Baxter-Gilbert, Lesbarrères, & Litzgus, 2013). Exclusion fencing is intended to prevent animals from entering certain areas in which they may be struck by motorists, thereby reducing the chances of injury or mortality. While exclusion fencing aims to keep individuals off road surfaces in order to reduce road mortalities, it can also have some negative effects.

a. Design

The height of exclusion fencing is highly variable, depending on the type of animals that are intended to be excluded; should multiple species be targeted, the highest recommended height should be used. A study by Woltz, Gibbs, & Ducey (2008) indicate barriers should be between heights of 0.6m and 0.9m to prevent the greatest number of reptile and amphibian species from accessing road surfaces. Similarly, other studies state that exclusion fences should be at least 0.6m in height (Beben, 2012), and extent 100m on either side of a tunnel or culvert (Beebee, 2012). This result has also been reached by other studies and sources.

Table 3, below, is adapted from a publication by the Ontario Ministry of Natural Resources and demonstrates the height requirements for effective exclusion fencing for various species (2013). Figure 1, also below, depicts a model of exclusion fencing used to inhibit the movement of herpetofauna onto roadways.

Species	**Recommended depth of fence buried (cm)**	**Recommended height of fence (cm)**
Turtles – general	10 – 20	60
Eastern Musk Turtle, Wood Turtle	10 – 20	50
Massasauga, Eastern Hog-Nosed Snake, Butler's Gartersnake, Queensnake	10 – 20	60
Gray Ratsnake & Eastern Foxsnake	10 – 20	200
Fowler's Toad	10 – 20	50
Snakes – general	10 – 20	100
Common Five-Lined Skink	10 – 20	Unknown
Salamanders	10 – 20	30

Table 3: The recommended height of exclusion fencing and depth of fence buried required for various reptile and amphibian species at risk. Adapted from the Ontario Ministry of Natural Resources (2013).

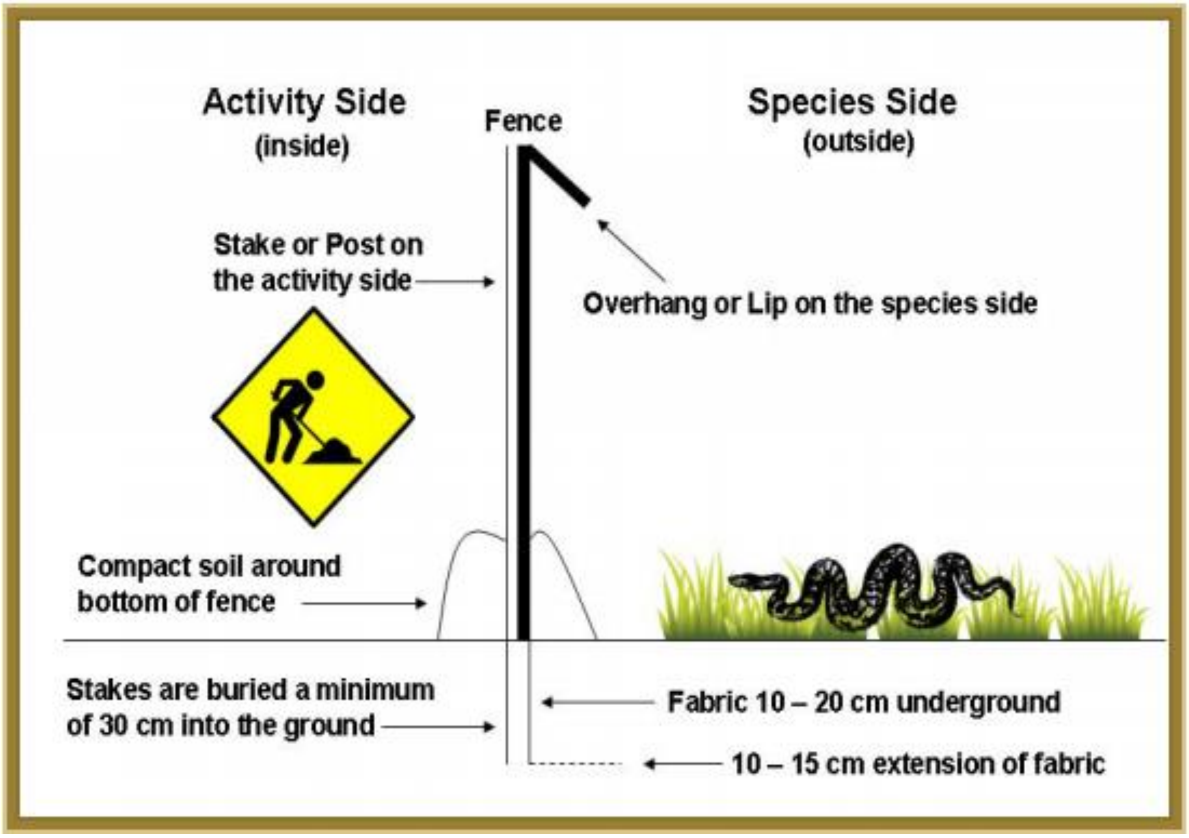

Figure 1: basic exclusion fencing (side view) used to prevent animals from traversing road surfaces. An overhang is used to prevent animals from climbing or jumping over the top of the fence (OMNR, 2013).

A common use of exclusion fencing is to place the fences parallel to road to prevent animals from traversing the surfaces, thus reducing the risk of road mortality (Ontario Ministry of Natural Resources, 2013a). Fencing is commonly paired with a tunnel that then funnels animals underneath the road, thus allowing them to get to their desired destination in a safe manner (Mata *et al*., 2005). Tunnels will be further examined in the following subsection.

To ensure that target species are not able to surmount the exclusion fencing, it is best to use a slippery material and construct a lip at the top of the structure to prevent climbing (Woltz, Gibbs, & Ducey, 2008). Exclusion fencing designed to inhibit the movement of snakes should ensure that fencing stakes are on the upland side of the fence, as snakes have a proven ability to use the stakes to climb over the top of fencing (Government of Wisconsin, 2009).

An additional consideration for exclusion fencing design is the anticipated longevity of the barrier – longer timeframes will require sturdier and more permanent fencing structure than shorter-term constructions (OMNR, 2013). Should exclusion fencing be required only for one season during road repairs, a lighter-duty material (such as silt fencing) could be used. If construction in a sensitive area is expected to persist over several years, exclusion fencing should be designed to withstand the various seasonal conditions, including erosion by rain, heavy snowfall, and winds. The Ontario Ministry of Natural Resources (OMNR) notes that it is not appropriate to use light-duty textile fencing in locations with rocky ground as it will prevent the proper anchoring of the fence (2013); this is of particular concern in Canada due to the structural geology of the land.

While considering the location of fencing when choosing a material is imperative, the target species must also be known. Although turtles are less likely to capitalise on gaps and tears in the fencing and are thus more successfully excluded by textile fences, reptiles are prone to utilise any gap possible to evade the barrier and thus will have access to the surface of the road and be at risk of mortality (OMNR, 2013).

In order to minimize the number of organisms avoiding the fence and crossing the road at the end of the barrier, turn-arounds should be built into the fencing design (Government of Wisconsin, 2009). A turn-around is a loop created at the end of the fence intended to redirect the organism back the way they came, and to keep them away from the surface of the road. This tactic should be paired with an eco-passage, tunnel, or culvert to ensure the connectivity of habitats for target species (OMNR, 2013).

b. Operational issues

Exclusion fencing without proper connectivity to other habitats has the potential to result in even greater genetic limitations than roads due to their very purpose: excluding the movement of reptiles and amphibians through additional artificial barriers (Beben, 2012; Marsh & Trenham, 2001). Installing exclusion fencing and alternative means of road crossing is only effective should reptiles and amphibians choose to use them (Woltz, Gibbs, & Ducey, 2008). Ecologists have noted that halting the movement of organisms over roadways may have long-term impacts on the genetic diversity of populations, though the impacts may not appear for generations (Beebee, 2012). Monitoring studies conducted on road crossing structure usage also indicate that the results found in the first years after road construction are considered preliminary as organisms are still adapting to the presence of a barrier (Mata *et al*., 2005).

It should be noted that exclusion fencing requires extensive upkeep to ensure no holes or gaps have formed in the barrier. In a 2012-2013 Before-After-Control-Impact (BACI) study conducted on the eastern shores of Georgian Bay, reptile abundance was measured in a non-mitigated section of highway and in a mitigated new section of Highway 69. This two-year study found that "the present design of reptile fencing was not effective (Baxter-Gilbert, Lesbarrèresm & Litzgus, 2013, p. 2). However, the study also explains that at the end of the study they discovered that "…115 reptile-sized (or larger) gaps had formed along the 3 km stretch of fence (p. 14)." Inadequate monitoring and upkeep of study areas and fencing can thus result in unsubstantiated claims and misinformation – such as declaring exclusion fencing not effective based on a flawed study. The level of snowfall in North America makes exclusion fencing particularly arduous to upkeep, as snow can cause severe fence damages which are expensive to repair. In response to this issue, it has been suggested that temporary fencing be put up each spring and taken down each fall – this will not cause negative effects on herptiles as they are inactive during the months of snowfall anyways (Cunnington *et al.*, 2014).

Once materials have been selected for the construction of exclusion fencing, the level of monitoring for damages and necessary repair should also be established to ensure the functionality of the barrier (OMNR, 2013). The Government of Wisconsin requires fences to be inspected twice per week, on non-consecutive days, and any repairs required must be completed within twenty-four hours (2009). The efficacy of exclusion fencing depends not just on the design and initial success, but also on continued structural integrity. Inspections of fencing should be conducted at set intervals throughout the year, and after any significant weather event (OMNR, 2013).

ii. Tunnels

Tunnels and culverts have been used by reptiles and amphibians as road crossing structures for many decades, though the structures have only been strategically built for this purpose since the 1960s. Such tunnels were first designed in Europe for the purpose of amphibian movement, and are now commonly used as road-crossing structures around the world (Beebee, 2012). Studies indicate that herptiles prefer eco-passages in the form of culverts less than 1.2 metres in diameter, provided they offer natural substrates and high moisture levels (Cunnington, Garrah, Eberhardt, & Fahrig, 2014). Ensuring the connectivity of habitats is particularly important for amphibians as they must migrate from aquatic habitat to terrestrial habitat as they mature through their life stages (Garcia-Gonzalez, 2011). As noted in the previous section, exclusion fencing without habitat connectivity may result in greater population damage over time than road mortality would cause in the absence of a barrier.

a. <u>Design</u>

Pipe culverts are typically already in place for the purpose of allowing water to move beneath road surfaces, and provide crossing structures for reptiles and amphibians as a by-product of their presence (Glista, DeVault, & DeWoody, 2008). Pipe culverts range from approximately 0.3m to 2.0m in diameter, and are constructed of concrete, smooth steel, or corrugated metal – their small diameter makes them ideal for use by reptiles and amphibians, while the fact that they are often already in place for water flow makes them economically feasible (Glista, DeVault, & DeWoody, 2008). These structures are the most commonly used facilitators of animal movement as they are the most affordable due to their multiple functions, and are thus the most numerous in most countries (Rodriguez, Crema, & Delibes, 1996).

Some reptile and amphibian species have exhibited strong preference for the type of substrate used within the tunnels; bare concrete is much less preferable to frogs than sand or soil (Beebee, 2012). Beebee (2012) also notes that a variance in tunnel diameter between 0.3m and 0.8m has no effect on toads, but can result in a fifty per cent increase in the utilisation by leopard and green frogs. Mid-sized tunnels have been found to be used more by painted turtles and snapping turtles than did tunnels of small (0.3m) and large (0.8m) diameters (Woltz, Gibbs, & Ducey, 2008). Tunnels aimed at encouraging use by anurans and turtles should thus be equal to or greater than 0.4m in diameter, with some light infiltration, and a soil or sand substrate along the floor to ensure the continuity of habitat which can encourage organisms to utilise the tunnels (Beebee, 2012; Glista, DeVault, & DeWoody, 2009). However, the issue of light, or the absence of light, remains a contentious and unsolved matter (Woltz, Gibbs, & Ducey, 2008). Other considerations for tunnel design include openness ratios (length x width x height of underpass), human presence, type and quality of habitat near tunnel entrances, and the availability of habitat structures within the tunnel (including logs, rocks, and fauna) (van der Ree *et al.*, 2007).

The location of culverts and tunnels specifically built for reptile and amphibian use should be carefully considered, particularly as these organisms have limited movement abilities and are thus unlikely to reach distant crossing structures (Glista, DeVault, & DeWoody, 2008). Placing crossing structures in areas near to water is imperative to the effectiveness of the mitigation measures (MacKinnon, Moore, & Brooks, 2005).

A box culvert facilitates the movement of animals beneath the surface of the road in Kootenay National Park, British Columbia, Canada (Parks Canada, 2015). This culvert is intended for larger organisms, as the size of the exclusion fencing indicates. Solid fencing is required for reptile and amphibians due to their small size and propensity for finding small gaps in exclusion barriers (Baxter-Gilbert, Lesbarrères, & Litzgus, 2013).

Pairing pipe culverts with drift- or exclusion fencing is an effective method of promoting reptile and amphibian crossings via tunnels (Glista, DeVault, & DeWoody, 2008). Studies indicate that this is the most successful and safe method of promoting reptile and amphibian movement from one side of the road to the other (Woltz, Gibbs, & Ducey, 2008). Tunnels with fences were successfully used in Alberta, Canada to reduce annual road mortality of long-toed salamanders, *Ambystoma macrodactylum*, from ten per cent to two per cent of the population (Beebee, 2012).

The first salamander tunnel was constructed in 1987 in Amherst, Massachusetts (Jackson, 1996). Observation of this tunnel revealed that the presence of light within the under-road tunnel increased salamander use dramatically. It has thus been suggested that a grated roof be used rather than a solid top, or construct shorter and wider tunnels to allow for internal light to limit animal hesitation and avoidance (Jackson, 1996); other studies state that no conclusion has yet been reached regarding the availability of light and resulting use or non-use (Woltz, Gibbs, & Ducey, 2008).

A large-scale “eco-passage” was constructed in Paynes Prairie State Preserve in Florida, United States of America was constructed between 1998 and 2002, pairing 3.2 kilometres of exclusion fencing with eight underpass culverts (Barichivich & Dodds, 2002). This project resulted in a forty-one per cent decrease in organism mortality from pre-installation to post-installation studies; this number increased dramatically with the exclusion of hylids, with a ninety per cent drop in road mortality caused by automobiles. This particular project included various types of culverts in order to appeal to the various types of target organisms located in the 3.2km stretch of highway (Barichivich & Dodds, 2002). Highway 27 in the United States created an impenetrable barrier for turtles attempting to cross Lake Jackson in Florida. This prompted the installation of barrier fencing which funnelled the turtles towards a culvert, reducing mortality rate from 11.9 to 0.09 individuals per kilometre per day (Andrews *et al.*, 2008). These projects provide testaments to the potential mitigation, through the implementation of a tunnel and exclusion fencing pairing, of habitat fragmentation caused by roads in North America.

b. Operational Issues

Given that culverts' and tunnels' primary function is the movement of water, there are times when these structures are not suitable for reptiles and amphibians to use as crossing structures. In locations with consistently wet culverts, ledges can be built into the walls to facilitate animal movement (Glista, DeVault, & DeWoody, 2009). Alternatively, there are times when these structures become very dry, limiting their suitability for amphibians which require moist conditions due to the permeability of their skin (Glista, DeVault, & DeWoody, 2009). Thus, tunnels designed for use by amphibians must have some manner of allowing moisture into the substrate to promote amphibian movement (Jackson, 1996). The length of tunnels will vary by road, which may have an effect on reptile and amphibian use; tunnels that are too long may be avoided by organisms (Woltz, Gibbs, & Ducey, 2008). Shorter pipe lengths (less than 40 metres) have demonstrated higher levels of use than longer pipes (longer than 40 metres) (Smit, Brandjes, & Veenbaas, 2007).

iii. Overpass systems

Overpasses, also known as green bridges, are the largest and most resource-intensive of the road crossing options presented in this paper (Beben, 2012). While culverts and tunnels may save reptiles and amphibians as a by-product of their existence, overpass systems are designed specifically to facilitate the movement of animals across barriers such as roads (Beben, 2012).

A Snapping Turtle crosses the road surface in search of suitable habitat during a spring migration near Denbigh, Ontario, Canada (Griffin, 2014). Snapping Turtles can grow to be quite large, making them difficult to avoid on road surfaces, particularly as they ‘balk’ at threats. Snapping Turtles cannot retract into their shells as other turtles can, so they raise themselves up to appear larger and threatening – this can result in their death should vehicles attempt to straddle them.

a. Design

The width of overpasses is variable, though most are found to be over one hundred metres (Beben, 2012). Overpasses are less-confining, preserve natural environmental aspects such as lighting and moisture, and allow for the continuity of environment via preservation of existing vegetation (Glista, DeVault, & DeWoody, 2009). Beben (2012) suggests a minimum overhead clearance of six metres when constructing ‘flyovers’, or roads constructed over natural boundaries such as valleys and rivers; this creates less interference with the natural landscape used by vertebrates in the environment. Green bridges should also maintain as much natural habitat as possible to encourage animals to use them. The use of overpasses has been proven to increase with time after construction, as natural vegetative succession occurs and the environment adapts to a new structure.

b. Operational issues

Given their size and cost, and the fact that reptiles and amphibians are most likely to use tunnels and culverts, overpasses are not a feasible physical project for facilitating animal crossings for herpetofauna. Amphibians in particular are not prone to use overpasses (Beebee, 2012).

A fifty metre wide wildlife overpass system in Banff National Park, Alberta, Canada provides a continuation of the natural environment to facilitate animal movement across a four lane highway (Parks Canada, 2013).

A wildlife overpass incorporates natural vegetation in various degrees of succession, and fencing to ensure animals do not surpass the boundaries of the bridge and end up on roadways. Photo taken in Banff National Park, Alberta, Canada. (Griffin, 2015).

Section III: effectiveness of road mitigation measures

While the presence or lack thereof of reptiles and amphibians in overpass and underpass systems is an important factor in determining whether or not mitigation efforts are working, mere presence does not determine the impact structures are having on individuals and populations (van der Ree, van der Grift, Gulle, Holland, Mata, and Suarez, 2007). The 'effectiveness' of mitigation measures "relates to a specific question or the goal of mitigation" (van der Ree *et al.*, 2007). This is an important distinction which must be made in order to understand the inferences of the data collected within studies of herptiles.

The effectiveness of mitigation measures must take into consideration which of the direct and/or indirect effects that the mitigation effort was intended to solve (van der Ree *et al.*, 2007). Mitigation measures to solve for road mortality may be very effective, but may result in genetic isolation and gender skewing; should the measure be considered for its effectiveness in promoting road permeability and therefore improving genetic diversity it would be deemed very ineffective, though its purpose was intended to reduce mortality which it did effectively.

i. Fences

Fences alone are effective at keeping herptiles off of road surfaces, with barriers of 0.9 metres excluding ninety-nine per cent of anurans (Cunnington *et al.,* 2014). Highway 441 in Florida, which passes through 3.2 kilometres of prairie wetland, was rebuilt with roadkill concerns in mind. The surface of the road was rebuilt raised above the surrounding land, with walls on each side of the road for species exclusion purposes; this resulted in a ninety per cent decrease in road mortality of species (except for birds) (Cunnington *et al.,* 2014). However, they create such a successful barrier to movement that they can pose more problems than answers.

The implementation of fencing and culverts can interfere with the movements and needs of other local species, indicating that mitigation measures should only be conducted when:

1. There is a known population at risk,
2. There is a known crossing point,
3. A rare or endangered species is involved,
4. Traffic volumes are high enough to pose serious threats to species,
5. Target species suffer extensive damage from roads, primarily road mortality,
6. Benefits to target species outweigh the risks to other species,
7. Tunnels are designed, located, and constructed in a manner conscious of other species,
8. A sufficient maintenance plan is in place for upkeep of structures.

(Adapted from Jackson, 2003).

Road fencing and underpasses are expected to be the most effective in situations where the primary threat to reptiles and amphibians stems from road mortality (Fahrig & Rytwinski, 2009).

ii. Underpasses

Culverts alone are not an effective means of limiting road mortality of herptiles in North America, just as herptile presence within a culvert does not indicate the level of effectiveness of culverts as crossing structures (Cunnington *et al.,* 2014). Unless culverts or tunnels are paired with exclusion fencing that directs reptiles and amphibians to the underpass, studies show that anurans are no more likely to use the underpass than to traverse the surface of the road (Cunnington *et al.*, 2014). Knowing this, mitigation projects should ensure that underpasses contain fencing along the road to force herpetofauna to seek another means of getting to the other side.

Underpass design must take into consideration which species are being targeted, as the design and location of structures must be tailored to their preferences and needs (van der Grift *et al.,* 2012). Smit, Brandjes, and Veenbaas suggest that the location of underpasses is of greater importance than the design specifications of the tunnel (2007). However, designing tunnels with herptile preferences in mind should encourage a greater level of usage.

iii. Overpasses

Overpasses are typically not used by reptiles and amphibians, and are not constructed specifically for their use. Beebee notes that amphibians in particular are not incline to use overpass structures (2013). Given their large size and thus greater cost, overpasses are not an effective means of mitigating road-induced habitat fragmentation for herptiles in North America. A combined system of fencing and underpasses is anticipated to be the primary and most effective means of preventing direct mortality and indirect effects of roads on herptiles (Ashley, Kosloski, & Petrie, 2007). While overpasses tend to maintain the most natural habitat characteristics due to their large size, they are still primarily used by large mammals rather than herpetofauna (Glista *et al*., 2009).

Section IV: Other types of mitigation

To protect herpetofauna species from further population declines and ultimately extinction, there have been a variety of physical projects and monitoring programs put in place to limit the levels of reptile and amphibian mortalities seen on roadways (Woltz, Gibbs, & Ducey, 2008). There are two methods of mitigating reptile and amphibian road mortality rates: by either changing the habits of motorists or the habits of animals (Glista, DeVault, & DeWoody, 2008). Although conservationists ask scientists for information regarding the specific amount of habitat and land that must be protected to safeguard reptile and amphibian species, there is too great of a variance in the required habitat characteristics amongst species to give an overarching conservation goal (Fahrig, 2001). This section will explore the methods in which reptiles and amphibians are protected by law, monitoring, and injury assistance programs which help animals affected by interactions with humans.

i. Legislation

As the awareness surrounding the impacts of human interference with landscapes has grown, the need to mitigate the negative results has come to the forefront. Legalised protection of species is mainly conducted through the federal *Species at Risk Act*, provincial legislation such as Ontario's *Endangered Species Act*, and via municipal monitoring and protection. However, not all the provinces have designated species protection legislation, leaving much room for improvement in the coming years. In addition, there are many criticisms of the shortcomings of the Act, including that it: contains loopholes, lacks funding for proper enforcement, applies only to federal lands, and species can be denied listing if there are social, political, or economic implications of protecting it under SARA (David Suzuki Foundation, 2014). While legislation may not itself be a direct form of mitigation, it mandates the consideration of species at risk prior to construction, thereby limiting the post-construction need for mitigation.

ii. Population monitoring

Managing populations of herpetofauna requires the collection of data on the statuses and trends of the various populations, while the effectiveness of management strategies should also be evaluated (Walls, 2014). While population monitoring may not appear at first glance to be a mitigation measure, it is an integral aspect of mitigation in that we must understand how populations are reacting to assistance measures in order to better mitigate concerns in the future. According to van der Grift *et al*., population density trends over time are the most critical measurement regarding the potential for herptile population viability (2012). Understanding how populations react to mitigation measures is essential to drawing conclusions regarding population characteristics post-mitigation, and in determining the effectiveness of such measures (van der Ree *et al*., 2007).

There is often a great difference between the scale of reptile and amphibian studies and the implications on entire species, as most studies are conducted at the local level whereas species-level information must cover much vaster landscapes (Cushman, 2006). Road mortality studies of herpetofauna are typically conducted as a result of localised public concern, and are therefore small-scale and piecemeal (Langen *et al.*, 2009). Most of the monitoring studies are conducted by stewardship groups, naturalist groups, conservation committees, and volunteers

(Olson, 2009). There are a number of design and operational issues that arise when studies attempt to determine the effects of roads on herpetofauna, and in the quantification of the benefits created by mitigation efforts, which will be explored in Section V.

In addition to the monitoring of herpetofauna species, future plans for the construction of roads or the expansion of infrastructure must take into account the known, anticipated, and potential threats that the work may pose to species at risk, their habitat, and ecosystem biodiversity. Langen *et al*. states in a 2009 report that "regional declines of some reptile and amphibian populations are likely unless effective technologies and best practices to reduce road mortality and maintain connectivity are implemented throughout a road network."

The threat that roads pose to reptile and amphibians, especially species at risk, are exacerbated by the knowledge that some motorists will purposefully hit organisms when they are on road surfaces (Baxter-Gilbert, Lesbarrères, & Litzgus, 2013). Gibbons *et al*., (2000, p.662) explicitly state the importance of maintaining accurate and long-term monitoring programs which will evaluate impacts on reptiles:

> …long-term monitoring of reptile populations is essential and must be aided by the establishment of standard methods and techniques. It is equally important that the academic community, land managers, and conservation organizations recognize that rigorous field programs focusing on the distribution, abundance, status, and trends of populations and species are critical and worthwhile. Herpetofaunal inventories should become a standard part of environmental assessment programs, and the publication of field survey efforts that document potential or suspected declines should be encouraged. When long term and widespread monitoring becomes the norm, declines are likely to become less equivocal (in terms of protracted declines versus natural fluctuations) and the causes less mysterious.

In addition to monitoring, Olson (2009) calls for the creation of an inventory to maintain accurate documentation of reptile and amphibian locational data, including up-to-date distribution maps. Proper documentation is required in order to recognise change in species populations and occurrence, and to allow multiple levels of government and public groups to work together on conservation issues faced by reptiles and amphibians (Olson, 2009). In addition to recording changes in herpetofauna persistence, these records could be used to best identify future mitigation efforts through the construction of physical projects such as road crossings – this will be thoroughly explored in the following section.

Table 4, below, indicates which factors have been identified as having negative effects on the survival of amphibian species at different life stages, and the potential amelioration (and limitations) humans can take to limit the damage. Habitat destruction and road traffic are the first two causative factors in the threats against amphibians according to Beebee and Griffiths (2005).

Cause of decline	**Major life states affected**	**Possible amelioration**	**Limits to amelioration**
Habitat destruction	All	Protection of natural sites Creation of amenity habitats (e.g. garden ponds)	Habitat still fragmented Not all species benefit
Road traffic	Adults and juveniles	Under-road tunnels	Expensive; may not be adequately used by many species

Table 4: Possible causes of amphibian decline and prospects of amelioration. Adapted from Beebee & Griffiths, 2005.

Pre-construction studies on the expansion of Highway 69 near Georgian Bay allowed assessors to track turtle movements and establish which areas provided critical habitat for sensitive species within the region (Baxter-Gilbert, Lesbarrères, & Litzgus, 2013). Monitoring populations prior to physical work is a method of limiting human impact on species at risk, and minimizing the need for mitigation in the future; however, monitoring populations too soon after construction can be preliminary, leading to an underestimation of impacts (Findlay & Houlahan, 1997). Monitoring passage structures post-mitigation is imperative to determining their effectiveness, though most wildlife crossing structures do not have any post-mitigation studies conducted to determine their effectiveness (Mata *et al.,* 2005). Understanding what does and does not work in mitigation measures can inform future planning, which can save time and resources; current practises rely on trial-and-error to mitigate the serious effects posed by roads (Jackson, 2003; Smit, Brandjes, & Veenbaas, 2007). Further study of the effectiveness of crossing structures is needed to inform road mortality mitigation projects (Glista *et al*., 2009).

iii. Injury assistance

Unfortunately, injury and mortality is inevitable for both reptile and amphibian species, particularly when exclusion fencing is not in place. However, there are services available to assist injured wildlife, such as the Kawartha Turtle Trauma Centre (KTTC) in Peterborough, Ontario. The KTTC is a registered charity that aims to conserve Ontario’s turtle species through veterinary aid and rehabilitation, with the goal of returning them to the specific habitat from which they were taken (Kawartha Turtle Trauma Centre, 2015). The KTTC can repair fractured carapaces and jaws, incubate eggs and provide a nursery, allow safe and sometimes time-consuming injury recovery, and will release turtles back into the habitat from whence they came.

The KTTC assisted more than 800 turtles in 2013, up from 50-80 turtles per annum prior to 2010 (KTTC, 2015). The word about the centre has spread rapidly, as has public awareness for the importance of turtles in wetland ecosystems. It must be taken into consideration that the success of this type of charity is dependent on donations and funding, and is therefore contingent on public concern. It would be greatly beneficial if other programs such as this were implemented across Canada to treat not only injured turtles but other reptiles and also amphibians.

There is limited data available on localised projects and programs such as the assistance measures offered by the KTTC. An in-depth review of such programs would be very interesting, while empirical evidence regarding their successes could be used to inform the creation of future programs to further herptile injury assistance.

A juvenile snapping turtle suffered a cracked carapace after being struck by an automobile near Minden, Ontario, Canada. This turtle was transported to the Kawartha Turtle Trauma Centre for veterinary aid but did not survive (Griffin, 2014).

Section V: Study challenges

Studies that attempt to quantify the effects of roads on populations of affected reptile and amphibian species tend to run into challenges similar in nature. This section will briefly discuss some of the various difficulties encountered in studying the implications of road-induced habitat fragmentation.

i. Species differences

A major difficulty in determining the effects of roads on herptiles are the vast number of differences found between species' requirements, preferences, and behavioural patterns. Behavioural responses to roadways and oncoming traffic depend on the species, its reason for traversing the road, and the amount of traffic. Most studies presume that herptiles cross road surfaces at a steady, unaltered speed (Ashley, Kosloski, & Petrie, 2007). While migrating species may cross the surface at a constant rate, others stop to thermoregulate, while some halt in response to oncoming traffic (Ashley, Kosloski, & Petrie, 2007; Andrews, Gibbons, & Jochimsen, 2008).

The installation of mitigation measures to promote road permeability, limit road mortality, and improve genetic diversity may interfere with the life cycles and needs of other species in the same vicinity (Jackson, 2003).

ii. Study type and replicability

While road impact studies collect information and data regarding reptile and amphibian individual and species responses, the methods employed by the study design are essential to the strength of the results. Studies which are not replicable have significantly lower levels of inference (van der Grift *et al*., 2012). Ensuring that studies are of large enough spatial and temporal scales to draw conclusions is also important, as too much extrapolation can lead to unfounded inferences. Additionally, replicability allows for the reduction of uncertainty and a faster conclusion regarding the effectiveness of mitigation measures (van der Grift *et al*., 2012).

The most effective study type for uncovering the impacts of roads on herptile individuals and populations is a BACI study – Before-After-Control-Impact, in which data is collected both before and after mitigation measures are implemented, and before-and-after at similar, non-mitigated sites (van der Grift *et al*., 2012). Although BACI studies have been deemed the most robust, a synthesis of studies has concluded that only fifteen of 122 studies examined incorporated both before and after information; some studies claimed to incorporate before-and-after results, though this was not evident in the presentation of monitoring data (van der Ree *et al*., 2007).

iii. Post-mitigation monitoring

As noted, the funds available for monitoring herptile reactions to crossing structures are often of limited availability and sums. Monitoring mitigation efforts for too short of a duration can result in skewed effectiveness conclusions, indicating that structures are not effective (van der Grift *et al.*, 2012). The level of effectiveness of mitigation efforts typically increases over time as the environment adapts to new infrastructure – vegetation succession occurs, making areas more hospitable as herptile habitats.

A synthesis of the types of studies conducted on road mitigation measures indicates that post-mitigation monitoring has ranged from four days to twenty years. Removing the outlying twenty-year study, the average study duration from 121 studies is just 1.7 years, with a monitoring frequency varying from daily, to once a week, to fifteen days a month (van der Ree *et al*., 2007). Study design influences the length and depth of post-construction monitoring.

Section VI: Conclusions

Reptile and amphibian species at risk are typically highly-sensitive organisms which are greatly affected by habitat damage, fragmentation, and loss. Given their innocuous existences, humans often forget about the ecological roles herpetofauna play in providing ecosystem services which people rely on for the basic functions of life and environment. They are also part of a complex system of processes and interactions that are not yet fully understood. The regulation of ecological cycles of both the organisms and their habitats provide essential services for humans, yet they are often overlooked when considering the implementation of projects, such as the construction of roads.

The protection of species at risk in Canada is limited to the federal *Species at Risk Act* and some provincial legislation, both of which have their strengths and weaknesses. The critical habitat of species at risk should be protected under SARA, yet the law is effective only on federal lands; there are many other weaknesses in the design of this law, too. While legislation is not typically considered a form of mitigation, it enforces the protection of species and their habitats, helping ensure that mitigation is not needed.

Although awareness of reptile and amphibian importance is inadequate, some projects have been implemented to protect them from the damage caused by humans. Legislation is the first level of protection, while more on-the-ground works are being completed. The installation of exclusion fencing is becoming a more popular method of keeping reptiles and amphibians off of road surfaces, while injury assistance is provided by groups such as the Kawartha Turtle Trauma Centre to assist those animals who are involved in collisions. Canada’s species at risk would benefit greatly from increased levels of awareness of the important ecological and economical roles they play, from future habitat protection and exclusion fencing projects, and from the veterinary care that the KTTC has so successfully used to save hundreds of Ontario turtles.

Of the three types of physical projects covered in this paper, the combined use of exclusion fencing and tunnels or culverts is the most economically friendly, and has the greatest potential for use by reptiles and amphibians. While culverts create crossing structures as a by-product of their existence, those that are constructed specifically for the movement of wildlife should meet certain criteria to best facilitate use by herpetofauna. These considerations include length, substrate, moisture, light, location, and preservation of the surrounding environment. Specifications of barriers must be tailored to the target species in order to most efficiently protect organisms from road mortality, limit gender skewing and promote genetic diversity, promote habitat connectivity, and reduce other indirect effects.

The mitigation of the impacts associated with road-induced habitat fragmentation on herptiles requires careful planning, pre- and post-construction monitoring, and solid study design and type. Ensuring that studies are of sufficient duration will give credence to the findings and limit the likelihood of inaccurate conclusions, while replicability improves the level of inferences that can be drawn from results. Future studies should observe the effectiveness of crossing structures rather than just use or non-use; this will require knowledge of target species and which issues are attempting to be mitigated.

APPENDIX

1. Vulnerability of amphibians, as explained by Cushman, 2006, p. 232.

The apparent vulnerability of amphibians may be due to a complex of factors, including:

a. Relatively low vagilities, which amplifies the effects of habitat fragmentation;
b. High vulnerability to death when moving across roads and through inhospitable terrain, which depresses population growth rates; and
c. Often narrow habitat tolerances, which exacerbates the effects of habitat loss, degradation, and edge effects.

2. Terrageny, as explained by Ewers *et al*, 2013, p. 1222.

The model begins with a single species pool that is present in a continuous landscape. As habitat loss and fragmentation progress, the continuous landscape is divided into isolated 'child' fragments and we use the SAR to predict the proportion of the species pool that will persist in each fragment. The total number of species that persist in the fragmented landscape is given by the sum of species richness in each fragment, minus the species that are shared among fragments. Because habitat has been lost, the total number of species persisting in the fragments is lower than it was in the original species pool, meaning local ions have occurred. We assume species are randomly distributed among child fragments, and that a 'grandchild' fragment can only inherit species from its parent. Through repeated fragment separation events that more finely divide the habitat within the landscape, this repeated random sampling from parent fragments can lead to species being confined to a single fragment within the landscape, becoming endemic to that particular fragment.

3. Cultural response regarding importance of herptiles, written by Larry Halverson, retrieved from http://www.env.gov.bc.ca/wld/BMP/herptile/HerptileBMP_final.pdf

Ode To A Toad

Poor Old Toad
Tries to cross the road.
Here comes a car.
Didn't get far.

Crawling down a path
Sad aftermath,
Big shoe tread
Leaves another dead.

Poor old toad,
Miserable abode
Cold damp hole
Place got no soul.

Poor little beast
Ugly to say the least
It's just not so
Let your inhibitions go.

Look one in the eyes
You might be surprised.
Friendly little grin
Now is that such a sin?

Touch his lumpy back
But don't throw back!
You won't get a wart
Nothing of the sort.

Part of Nature's plan
He is a friend to man.
Toad saves us dollars
By eating creepy crawlers.

So if you encounter toad
Recall this simple ode.
Little toad should rate
We should appreciate.

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