Retrofit ecopassages effectively reduce freshwater turtle road mortality in the Lake Simcoe Watershed

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Abstract
Although the negative impacts of roads on herpetiles are well documented, broad-scale implementation of effective mitigation measures to address these impacts remains limited. Here, we evaluated whether a novel, cost-effective, retrofit ecopassage design can reduce road mortality of herpetiles in the Lake Simcoe Watershed, using a before-after-control-impact study. We also examined whether the ecopassages impacted the movement of turtles across the landscape using wildlife cameras. Our study indicated that the ecopassages significantly reduced turtle road mortality at the treatment sites but were not effective at mitigating road mortality of other herpetiles. Most turtle road-kill at the ecopassages sites occurred at fence ends, highlighting the need for solutions to address fence-end effects for herpetiles. There was no evidence that the ecopassages reduced turtles’ ability to move between habitats as individuals were observed crossing through the ecopassages. Our results suggest that inexpensive solutions can effectively mitigate road mortality for turtles and taller fencing could improve the design for other species. Ecopassages, such as the ones tested in this study, should be widely implemented in road-kill hotspots across all regions, especially in habitats of rare or at-risk species, in order to protect turtles and other wildlife from the increasing threat of roads.

KEYWORDS
ecopassages, habitat connectivity, herpetiles, mitigation, road ecology, road-kill, turtles

1 | INTRODUCTION
Roads are an essential yet pervasive part of the human landscape, enabling transportation but at the cost of threatening wildlife populations and natural landscape connectivity. The impacts of roads on wildlife have been well-documented and range from vehicle-wildlife collisions and barriers to movement, to habitat fragmentation, loss of gene flow, and genetic isolation (Andrews, Gibbons, & Jochimsen, 2008; Coffin, 2007; Forman & Alexander, 1998; Jochimsen, Peterson, Andrews, & Gibbons, 2004; van der Ree, Smith, & Grilo, 2015).

Globally, over 1,400 species of herpetiles are threatened by roads and human development (Gibbons et al., 2000; IUCN, 2021), including 48% of the reptile and amphibian species in Ontario, Canada (COSEWIC, 2020; COSSARO, 2021). Turtle species are disproportionately impacted by roads due to their annual migration throughout their ranges, slow maturation rates, and low juvenile recruitment, which prevents rapid population recovery (Brooks,
Brown, & Galbraith, 1991; Congdon, Dunham, & van Loben Sels, 1994; Fahrig & Rytwinski, 2009). For example, Piczak, Markle, and Chow-Fraser (2019) showed that between 1985 and 2002, an Ontario population of snapping turtles has declined by almost 80% and is at an increased risk of extirpation due to road mortality. The persistence of turtle populations is threatened in areas of high road density and high traffic volumes (Beaudry, deMaynadier, & Hunter Jr., 2008; Gibbs & Shriver, 2002; Piczak et al., 2019), and road mortality rates are positively correlated to traffic volume (Szerlag & McRobert, 2006). This highlights the need for widespread implementation of effective solutions to mitigate road-kill and preserve freshwater turtle populations.

Numerous types of mitigation measures have been developed to reduce wildlife road mortality globally, with variable success (Rytwinski et al., 2016). Some measures aim to alter motorist behavior (e.g., animal detection systems or temporary road closures), while others target wildlife movement (e.g., fencing or ecopassages). Although wildlife crossing signs are becoming ubiquitous across the landscape, their effectiveness at reducing road mortality is largely untested (Glista, DeVault, & DeWoody, 2009); however, a study on freshwater turtles showed that they did not decrease road mortality in Ontario (Seburn & McCurdy-Adams, 2019). Additionally, research suggests that any positive impact they do have on driver behavior can be reduced by factors such as vandalism and placement within actual wildlife-vehicle collision (WVC) hotspots (Gunson & Schueler, 2012). Conversely, measures that have been shown to reduce WVCs, such as overpasses, underpasses, and fencing, are more uncommon and are less likely to be incorporated into road construction projects, likely due to their prohibitive costs (Glista et al., 2009).

Although wildlife ecopassages (overpasses or underpasses with associated fencing) have been successful at mitigating road impacts on turtle populations (Dodd, Barichivich, & Smith, 2004; Grico, Bissonette, & Cramer, 2010; Heaven, Litzgus, & Tinker, 2019; Rytwinski et al., 2016), their uptake in road projects has been slow (Glista et al., 2009) and widespread adoption of effective mitigation measures is urgently needed, especially in urbanizing areas. Transportation projects may be constrained by factors including budget, unfamiliarity with ecopassage design and construction, and the availability of purpose-built materials. Simple and relatively inexpensive solutions can overcome some of these barriers to help build roads that inherently reduce negative impacts on wildlife.

In this study, we used WVC hotspot mapping to prioritize areas for construction of retrofit wildlife ecopassages, which used relatively inexpensive barrier fencing to funnel wildlife through existing road drainage infrastructure. We applied a Before-After-Control-Impact experimental design to test the effectiveness of the retrofit ecopassages at reducing herpetile road mortality and used trail cameras to determine whether the fencing was restricting turtle movement between wetlands. This study focused on two local turtle species, snapping turtles (Chelydra serpentina) and Midland painted turtles (Chrysemys picta marginata). Both species are semi-aquatic freshwater turtles that occur commonly throughout North America. They occupy slow moving, shallow and well vegetated waterbodies and wetlands with organic substrates during the active season, and nest in open upland areas with loose substrate such as shorelines, sand dunes, roadsides or railroad embankment (COSEWIC, 2018; ECCC, 2016). Both species exhibit highly stochastic egg and juvenile mortality rates, along with high adult survivorship. As a result of this reproductive strategy, the loss of breeding adults from road mortality can significantly threaten population survival. Both C. picta marginata and C. serpentina are listed as special concern in Canada and the latter is also considered special concern provincially; road mortality is listed as a significant threat to both species (COSEWIC, 2020; COSSARO, 2021).

2 | METHODS

2.1 | Study area

This study was conducted in the Lake Simcoe (44°26’23.5″N 79°21’43.1″W) Watershed (Figure 1), a peri-urban area located north of Toronto, Ontario within the Greater Golden Horseshoe, Canada’s most populous region (metropolitan population ~9.1 million; Statistics Canada, 2016). Land uses in the 2,600 km² watershed are primarily agriculture (47%) and natural heritage cover (40%), but urban area (currently 12%) has increased in recent decades (Palmer, Hiirtart-Baer, North, & Rennie, 2013a, 2013b; Palmer, Winter, Young, Dillon, & Guildford, 2011). With an extensive natural heritage system bisected by numerous roads, the watershed contains over 1,800 km of potential herpetile WVC hotspots along its roadways (LSRCA, 2015).

Our study occurred along 10 stretches of paved, two-lane roads (mean width = 20.8 m), with speed limits of either 60 or 80 km/hr (Figure 1). All sites were compared by measuring road segment length (the length of road studied), road width (width of paved surface plus gravel shoulder), and openness ratio (the ratio of length to diameter or width of crossing structure [e.g., culvert or bridge]). Openness ratio provides an estimate of the suitability of a crossing structure for wildlife use and the recommended ratio for turtles is no less than 0.1, but ideally ≥0.25 (CVC, 2017).
**FIGURE 1** Map showing herpetile ecopassage and control site locations around the Lake Simcoe Watershed, located within Southern Ontario.
2.2 Mitigation design

To assess the effectiveness of retrofit ecopassages at reducing herpetile road mortality, a before-after-control-impact study was completed between 2015 and 2017. Five sites were selected throughout the watershed in April 2015 to serve as treatment sites, based on previously completed WVC hotspot modeling (LSRCA, 2015). This weighted average land cover model predicted herpetile hotspots based on the amount of suitable habitat within typical herpetile movement landscapes, following the methods used in Gunson, Ireland, and Schueler (2012). In addition to these sites, another five hotspots were selected as control sites, based on their similarity and proximity to the treatment sites. Treatment and control sites were on average 2.3 km apart, minimizing any interaction between them or potential for turtles to travel around the fence at treatment sites to cross at control sites. All sites were located at wetland road crossings with adequate crossing infrastructure (i.e., openness ratio ≥ 0.2).

In April 2016, retrofit ecopassages were installed at the five treatment sites, prior to the turtle nesting season (in southern Ontario typically May–June). The ecopassages consisted of Animex wildlife exclusion fencing installed below-grade alongside the roadway and attached to existing stream crossing infrastructure (Figure 2). Animex fencing is purpose-built wildlife fencing made from postconsumer recycled HDPE-2 and is relatively inexpensive compared to other fencing materials. It is able to withstand most regular roadside and weather conditions but can fail over time without ongoing maintenance due to slumping, washouts or vegetation overgrowth. The fencing was 41 cm high with a 10 cm angled lip at the top to prevent animals from climbing over. The bottom lip of the fence was buried to prevent wildlife from digging underneath and the fencing was secured to the ground using plastic t-bars. The fencing was installed following the roadside embankment guide (Animex, 2018) (Figure 3), except that wire and fasteners were not used to allow flexibility in the fencing to account for embankment heaving through winter (Animex, personal communication). Fence ends were extended beyond the wetlands and then turned back on themselves, as space permitted, to direct wildlife back towards the crossing infrastructure and minimize any fence-end effects (Figure 3).

2.3 Data collection

The effectiveness of the ecopassages at reducing wildlife road mortality was assessed by conducting walking road-kill surveys for 1 year prior to construction (2015) and 2 years postconstruction (2016–2017). Study sites were surveyed twice weekly throughout the active season (May–October), totaling 424 surveys over the study period. The surveys consisted of walking along the road shoulder and exclusion fencing and identifying all wildlife to the lowest taxonomic level possible given the state of each carcass, georeferencing the location with a Garmin etrex handheld GPS unit, and

![Figure 2](image-url) Herpetile ecopassage fence installation showing the below-grade design (a, b), and the connection to existing road crossing infrastructure (i.e., bridges (c) and culverts (d))
documenting the state of the animal (alive vs. road-killed). Two-minute vehicle counts were also completed at randomized times during each survey to estimate the traffic at each site. While this study focused on herpetile species, all instances of wildlife observation were documented during the field surveys.
To assess the use of ecopassages, Cuddeback Long Range IR trail cameras were installed in 2016 on t-posts facing each end of the culvert at the three treatment sites with culvert crossings (Table 1). Cameras were not used at the two bridge crossings since due to the large area and high river flows, they were deemed to not be effective at capturing turtles crossing at these sites. The cameras were set to time-lapse, taking one photo each minute continuously throughout the monitoring period. Cameras were checked during each survey to change the batteries and SD cards and all images were saved onto a hard drive for later analysis.

| Site ID | Road stretch length (m) | Road width (m) | Speed limit (km/hr) | Crossing type | Openness ratio * | 3-year mean traffic rate (vehicles/min) |
|---------|-------------------------|----------------|---------------------|---------------|------------------|----------------------------------------|
| LA      | 210                     | 24.8           | 80                  | Corrugated steel pipe | 0.58             | 5.4                                    |
| L7      | 102                     | 12.5           | 60                  | Bridge        | 1.3              | 2.0                                    |
| 48W     | 91                      | 32.9           | 80                  | Corrugated steel pipe | 0.20             | 4.7                                    |
| 48E     | 150                     | 31.5           | 80                  | Corrugated steel pipe | 0.22             | 4.7                                    |
| RR      | 128                     | 12.0           | 80                  | Bridge        | 11.0             | 7.1                                    |
| Control |                         |                |                     |               |                  |                                        |
| LAC     | 100                     | 16.8           | 60                  | Box culvert   | 0.21             | 6.5                                    |
| L8      | 95                      | 6.3            | 60                  | Bridge        | 1.7              | 0.32                                   |
| 48C     | 71                      | 27.8           | 80                  | Corrugated steel pipe | 0.20             | 4.6                                    |
| 48S     | 154                     | 14.7           | 80                  | Bridge        | 5.6              | 8.2                                    |
| HD      | 129                     | 11.3           | 60                  | Box culvert   | 0.21             | 5.4                                    |

*Openness ratio for corrugated steel pipe = ($\pi r^2$)/length and box culvert or bridge = (height $\times$ width)/length.

![Figure 4](image.png)

**FIGURE 4** Bar graphs showing that ecopassages (a) significantly decreased the mean number of adult (grey) and hatchling (black) turtles killed per kilometer of road at the treatment sites, whereas (b) there was an overall increase at the control sites. Ecopassages were installed between the 2015 and 2016 field seasons. Error bars represent the standard error of the mean total number of road-killed turtles per km of road.

2.4 | Data analyses

The total observed live and road-killed wildlife was summed over each monitoring year per site and was then normalized by dividing by the length of each site, giving an observed rate per km of road. This allowed direct comparison between sites as the lengths of each varied. As some observed road-kill was not identifiable to species level based on the state of the carcass, and due to small sample sizes, wildlife was grouped into categories (e.g., turtles, snakes, birds) for analysis.
Rates of observed road-kill for each wildlife group were compared between years using a repeated measures analysis of variance (ANOVA) and significant results were further examined with a Holm-Sidak post hoc test. Traffic rates at each site were averaged over each study year and these were compared using a Friedman repeated measures ANOVA on ranks to determine whether changes in traffic patterns could explain any interannual variability in road mortality rates.

Due to time constraints and difficulty detecting smaller animals such as frogs and other amphibians, a subset of trail camera photos was only analyzed for turtle occurrences rather than all herpetiles. A randomized subset of trail camera photos (55.6%) was manually analyzed for the presence of turtles to estimate turtle use of ecopassages. A full crossing of the ecopassage was confirmed when a turtle was observed on both sides of the culvert or bridge.

### RESULTS

#### 3.1 | Site descriptions

The mean length and width of road segments studied at all sites were 123 and 19 m, respectively, and openness ratio ranged from 0.20 to 11.0 (Table 1). The 3-year mean traffic rates at each site varied from 0.32 to 8.2 vehicles per minute (mean = 7.8; median = 4.7) (Table 1), and there was no significant change in traffic volume at any site between study years ($p = .154$).

#### 3.2 | Road mortality at ecopassages and control sites

Of the 92 turtles observed road-killed during the study, 75% were snapping turtles (*C. serpentina*), 21% were Midland painted turtles (*C. picta marginata*), and the remainder were unidentifiable species.
Turtle mortality was significantly (\(p = .048\)) reduced at the treatment sites following ecopassage construction compared to an overall increase at the control sites (Figure 4). The repeated measures ANOVA indicated a significant difference between years at the treatment sites, with the post hoc test identifying a significant difference between road-kill rates in 2015 and 2017 (\(p = .034\)). There was also a significant (\(p = .029\)) decrease in adult turtle mortality at the treatment sites, compared to no significant change at the control sites after the ecopassages were installed (Figure 4). There was a significant difference in adult road-kill rates between 2015 and both 2016 and 2017 at the treatment sites (\(p = .034\) and \(p = .025\), respectively). There was no significant change in traffic rates between study years at any of the sites (\(p > .05\)).

Fence-end effects were observed at the ecopassage sites. Of the five turtles killed at the treatment sites, following ecopassage construction, two occurred at gaps in the fencing (e.g., for driveways) and three occurred at the fence end.

The ecopassages did not significantly reduce road-kill rates of other non-target herpetile species. The number of amphibians and snakes killed at the study sites remained relatively unchanged at all sites immediately after ecopassage construction (2016). However, amphibian road-kill rates increased at both treatment (\(p = .005\)) and control (non-significant, \(p > .05\)) sites in 2017.

Throughout the 3-year monitoring period, a total of 804 individuals across 32 species and within five orders were observed road-killed at all study sites combined (Table 2). This included the 2 turtle species, as well as 2 snake, 4 amphibian, 12 mammal, and 12 bird species. Between 2015 and 2017, a mean of 111.7 herpetiles were killed per kilometer of road at the treatment sites, compared to a mean of 263.7 individuals at the control sites.

There were observed peaks in road mortality throughout the monitoring period with the majority (67%) of all road-kill occurring in September (Figure 5). Most (73%) of the turtle road mortality occurred in September with smaller peaks in May and June. Turtle hatchlings made up 88% of the turtles road-killed in the fall, while adult road mortality peaked in June. Months with insufficient data were not included in this summary and data were corrected for the number of surveys per month.

3.3 Use of culverts by turtles

Throughout the study period, over 1.7 million photos were captured using eight trail cameras over 219 days. Of these photos, 55.6% were manually analyzed for turtle incidences, and a total of 448 occurrences of turtles were observed at the ecopassage sites, consisting of two species, C. picta marginata and C. serpentina. Additionally, 106 complete turtle ecopassage crossings were documented based on sightings of the same species on both sides within 3 min of each other. The most common behaviors observed with the trail cameras were basking, swimming, nesting, and crossing through culverts.

4 DISCUSSION

4.1 Effectiveness of ecopassages at mitigating road mortality

Our study found that simple, relatively inexpensive, retrofit ecopassages can significantly reduce road mortality of semi-aquatic turtles within identified road-kill hot spots. The recycled plastic fencing excluded turtles from the roadway and decreased the road mortality rate by 90% compared to control sites (Figure 4). This is consistent with other studies, which have demonstrated that drainage culverts coupled with exclusion fencing can reduce turtle road-kill by 16–99% (Aresco, 2005; Crawford, Moore, Norton, & Maerz, 2017; Dodd et al., 2004; Markle, Gillingwater, Levick, & Chow-Fraser, 2017; Smith & Dodd Jr., 2003). A similar study in Ontario by Heaven et al. (2019) found that a barrier wall made of high-density polyethylene pipe cut in half and attached to pre-existing culverts reduced the number of turtles accessing the roadway by 94%. Similarly, Aresco (2005) demonstrated that a concrete barrier wall limiting turtle access to a busy Florida highway bisecting two lakes decreased turtle road mortality by 99%. Our ecopassages also significantly (82%) reduced road mortality for adult turtles (Figure 4), which can drastically improve population outcomes. Only 17% of the turtles observed road-killed during our study were breeding adults; however, their removal from the population can disproportionately threaten local populations due to their reproductive strategy (Brooks et al., 1991), and minimizing their loss is a conservation priority.

The importance of monitoring ecopassages over several years was highlighted by the results of our study. We observed a non-significant decrease in turtle road-kill at both the treatment and control sites immediately following installation (2016). This overall decrease could be due to the hot and dry conditions that year (mean annual temperature = 8.6°C compared to 20-year climate normal of 6.8°C, Environment Canada, 2020), during which turtles may aestivate to maintain thermoregulation, and thus travel across roads less frequently (Rees, Roe, & Georges, 2009). However, in 2017, turtle road-kill rates were significantly lower at the ecopassages sites, while rates increased at control sites. Overall, turtle road-kill decreased following ecopassages construction, compared
to no measurable change at the control sites. Since traffic rates at each site did not vary significantly between years, our results suggest that this reduction in turtle road mortality is attributed to the ecopassage fencing.

The 51 cm tall exclusion fencing was not effective at mitigating road-kill of other nontarget wildlife, including amphibians and snakes, likely because it was too short to restrict the road access of these species. While the number of road-killed amphibians and snakes initially decreased the year after installation, the road-kill rate increased the following year, significantly for amphibians. 2017 was an especially wet year (total annual precipitation of 1115.4 mm, compared to the 20-year climate normal of 967.9 mm; Environment Canada, 2020), which may explain the high numbers of amphibians road-killed at all sites that year. Studies using taller exclusion fencing have successfully reduced road mortality of other herpetiles. Markle et al. (2017) found that 100–122 cm tall exclusion fencing can decrease snake road access by 53% and Woltz, Gibbs, and Ducey (2008) suggested that 0.6–0.9 m high fencing is best for excluding a range of turtle and amphibian species. Ecopassage design should consider the needs and behavior of all wildlife populations present in a project area, especially any at-risk species, to provide the most ecosystem benefits.

4.2 Fence-end effects and maintaining a continuous barrier

Ongoing maintenance to ensure a continuous exclusion fence and ensuring turtles cannot circumnavigate the fence ends are critical aspects of ecopassage design. We found that all turtles road-killed following ecopassage construction occurred at fence ends or unavoidable gaps in fencing (e.g., driveways). This is similar to other studies that found higher road mortality rates associated with fence ends or gaps in fencing (Cserkész, Ottlecz, Cserkész-Nagy, & Farkas, 2013; Heldin & Petrovan, 2019). Gaps can undermine the integrity of the mitigation structure, by allowing wildlife access to the roadway and effectively trapping them if there is no escape measure (Baxter-Gilbert, Riley, Lesbarres, & Litzgus, 2015). Although some fence gaps were inevitable in our design, the below-grade installation of the fencing (Figure 3) provides a means for wildlife to easily return to adjacent habitat should they gain access to the roadway, reducing the likelihood of WVCs. Although the number of turtles killed at our ecopassages fence-ends was small, further limiting gaps and addressing fence-ends can improve project outcomes and decrease negative population impacts.

Curving the fence-end back on itself at an angle can minimize fence-end effects by redirecting wildlife away from the road and towards the crossing structure (Heaven et al., 2019; Markle et al., 2017). Our design incorporated this concept where space allowed (Figure 3), but they were not fully effective as several turtles were road-killed at the fence ends. Other measures designed to address the challenge of fence ends and gaps in continuous fencing (e.g., cattle guards, acoustic animal repellents) have only been investigated for mammalian species (Cserkész et al., 2013). Given the prevalence of these challenges, there is a need for the development of solutions to address this issue for turtles and other herpetiles. Equally important to mitigation design is the use of durable materials and ongoing maintenance to avoid fence breaches and maintain the long-term integrity of the structure (Baxter-Gilbert et al., 2015). Inspections of our fencing after installation revealed damage from road and utility maintenance equipment and large sections of fencing were replaced where it was no longer functional. As a peak in turtle road mortality was observed in May–June, fences should be inspected and repaired as early as possible each spring. The additional time and costs associated with inspection and maintenance should also be included in the initial budget of any mitigation project design to ensure it is completed.

4.3 Effectiveness of ecopassages at maintaining habitat connectivity for turtles

Using trail camera data, this study did not provide any evidence that the ecopassages impaired turtle movement at the sites, and 106 complete crossings were observed. Road networks often bisect turtle populations, impeding their ability to move throughout their range annually to access their various habitat requirements (Beaudry et al., 2008; Fahrig & Rytwinski, 2009). Effective barrier fencing should exclude road access and funnel wildlife towards the crossing structure without impacting overall habitat connectivity, otherwise it can increase the risk of population fragmentation and decline (Rytwinski et al., 2016; van der Ree, Gagnon, & Smith, 2015). Our fencing was designed for local turtle species (i.e., C. serpentina and C. picta marginata), and although our results show that it was not a barrier for other herpetile species, its impact on the movement of other non-target species was not fully evaluated. However, Markle et al. (2017) demonstrated through trail cameras that snakes also passed through ecopassages in Ontario, suggesting that they can also be effective for other reptile species.

As we only reviewed a subset of photos, there were also likely occurrences not captured and we could not
fully assess turtle behavior at the study sites. Time-lapse cameras have been shown to be cost-effective tools for monitoring the movement of herpetiles (Pagnucco, Paszkowski, & Scrimgeour, 2011), however where time and funding allows, the use of additional technologies, such as PIT-tags and/or radio telemetry would enable greater understanding of how turtles behave in relation to ecopassages, especially for sites with aquatic crossing infrastructure where movement and species identification can be harder to detect with cameras (Markle et al., 2017).

4.4 Implications of widespread mitigation solutions

Although there is ever-growing recognition of the threat of road mortality to the persistence of wildlife species, in particular for semi-aquatic turtle populations, the implementation of effective broad-scale solutions has been limited, likely due to the capital cost of construction. Combining the prioritization of road segments based on hotspot modeling with the use of simple, inexpensive ecopassage solutions can enable easier adoption of mitigation measures. In the Lake Simcoe Watershed, several municipalities have used our results and road mortality hotspot mapping to inform road ecology decision making, including ecopassage construction and the timing of roadside mowing and grading to avoid turtle nests. The transportation department of a local regional municipality has normalized the consideration of wildlife mitigation measures into road projects and made it “business as usual” (G. Sullivan, Environmental Specialist, York Region, personal communication). Applying these types of incremental changes to how roads are built and maintained can greatly minimize their negative impact on turtle and other wildlife populations.

The average rate of turtle road mortality on unmitigated roads observed in our study was 36.9 killed/km/year and 3.89 killed/km/year on mitigated roads, which is comparable to similar road ecology studies in North America (Ashley & Robinson, 1996; Crump, Robertson, & Rommel-Crump, 2016; Smith & Dodd Jr., 2003). In these studies, turtle road-kill rates in Ontario, Florida, and Texas ranged from 50 to 72 killed/km/year. However, MacKinnon, Moore, and Brooks (2005) recorded much lower rates (2.9 killed/year), while Aresco (2005) observed markedly higher rates (1,263 killed/km/year) on unmitigated roads in Ontario and Florida, respectively. Based on local herpetile road mortality hotspot mapping (LSRCA, 2015), we estimate that ecopassages like those used in this study could protect approximately 64,000 turtles annually on the 8,255 km of roads in the Lake Simcoe Watershed each year, an area covering approximately 2,600 km². Additionally, using taller fencing to exclude other herpetiles from roadways could protect an additional estimated 316,000 individual animals in the watershed each year. Applying similar solutions to other regions in Canada and around the world could help reduce road impacts that imperil so many freshwater turtle populations.

5 Conclusion

As road networks continue to expand, the need for mitigating their negative impacts on wildlife communities is also increasing, threatening many species. This study demonstrated the effectiveness of a simple, relatively inexpensive solution at reducing turtle road mortality and maintaining habitat connectivity. The widespread use of solutions such as this one should be implemented in road-kill hotspots across all regions, especially in habitats of rare or at-risk species, in order to protect turtles and other wildlife from the increasing threat of roads.

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CONFLICT OF INTEREST

The authors declare no potential conflict of interest.

AUTHOR CONTRIBUTIONS

Conceptualization, data collection and analysis, writing and revision: Kaitlyn Read. Conceptualization, writing, and revision: Bill Thompson. Both authors gave final approval for publication.

DATA AVAILABILITY STATEMENT

The data used in this research are available upon request from the corresponding author.

ETHICS STATEMENT

No ethics approval was required for this research.

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