Identifying road mortality hotspots and their environmental correlates in the National Capital Greenbelt

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I. Abstract

Roads are known to be a contributing factor to the decline of wildlife species globally. Wildlife road mortality is among the greatest threats to animals who are in proximity to roads. In summer 2018, I conducted wildlife road mortality surveys on 6 roads in the National Capital Commission's Greenbelt over the course of 12 weeks. I divided the surveyed roads into 50-m subsections and associated 6 environmental predictor variables as well as mortality counts to each subsection. I then created taxon specific models to identify predictor variables that explained higher numbers of road mortalities. I found that amphibian mortality increased considerably during and shortly following precipitation, which caused an imbalance for roads that were not surveyed on days with precipitation. Bird mortality was not significantly related to any of the predictor variables. Mammals were found in higher numbers near culverts. Road-killed reptiles were more frequent near marshes, culverts, and open water. Overall, these results allowed to identify sensitive areas within the Greenbelt that should be mitigated to reduce road mortality. Additionally, this study will allow to increase the sampling efficiency in future road mortality studies.

II. Acknowledgements

I would firstly like to thank my thesis supervisor, Gabriel Blouin-Demers for the opportunity to conduct research in his fantastic lab, for the helpful and efficient feedback to my numerous questions and for being an excellent mentor throughout my undergraduate studies. Thanks to Alexander Stone and Matthew Tomlinson of the National Capital Commission for their availability throughout this project as well as for their assistance with ArcGIS analyses. I would also like to thank my field partner, Laura Haniford, for being there every step of the way during data collection, literally.

1. Introduction

Roads have become more numerous and more heavily travelled over time. In southern Ontario, no piece of land is more than 1.5 km away from a road (Fenech et al. 2001). Global projections for the year 2050 predict an increase in total road length by nearly 60% compared to 2010 (Laurance et al., 2014). The effects of roads on wildlife are increasingly being recognized as the relatively young field of road ecology emerges. Some species, such as scavengers, benefit from the presence of roads, but it is estimated that the number of wildlife species negatively affected by roads is about five-fold greater than those positively affected (Fahrig & Rytwinski, 2009). Roads negatively affect animals through the reduction of habitat size (taken up by the road itself), fragmentation of their habitat, population subdivision, road mortality, as well as barrier effects through road avoidance behaviours (Jaeger et al., 2005; Coffin, 2007). Road mortality is among the greater threats to animals in proximity to roads, for certain species roads have caused significant impacts (Fahrig & Rytwinski, 2009) such as skewed sex ratios (Steen & Gibbs, 2004) and affect genetic diversity (Jackson & Fahrig, 2011). Road mortality can be studied at a variety of spatial scales. At the coarsest scale, studies have modelled high-risk areas for road mortality based on landscape features (Gunson et al. 2012). When considering cost and overall effectiveness of mitigation solutions, however, it is generally accepted that tailoring conservation efforts to local conditions is preferred (Stahl et al. 2001; Whittingham et al., 2007). Beaudry et al. 2008 found that road mortality intervention was most effective when implemented at the road segment scale.

Mitigation to reduce road mortalities can include implementing road signage, speed bumps, closing roads seasonally, fencing off sections of road or creating ecopassages such as underpasses or overpasses (Mountrakis & Gunson, 2009). In some cases when road mortality is high, fencing off problem areas – further increasing the barrier effect, can be beneficial to small vertebrates

(Jaeger & Fahrig, 2004). The most effective mitigation technique involves fencing off the road and building ecopassages to reduce both the barrier effect and road mortality (Cunnington et al. 2014). Modifying roads for the purpose of reducing road mortalities is expensive particularly if these are permanent solutions requiring maintenance. To be cost effective, mitigation techniques should thus be implemented in areas where they will most effectively improve the state of road mortality.

Several studies have shown that road mortality locations tend to be spatially aggregated (Clevenger et al. 2003; Boyle et al. 2017). Road mortality "hotspots" refer to parts of a road where mortalities are non-randomly distributed, normally in clusters (Mountrakis & Gunson, 2009; Gunson el al. 2011). Although it is generally true that hotspots are good locations to implement ecopassages (Gunson et al., 2012), it is important to consider temporal variation by compiling data over multiple years (Zimmermann Teixeira et al. 2017). Mortality aggregations tend to be species-specific (Litvaitis & Tash, 2008) depending on life-history traits such as vagility (Carr, Fahrig, Carr, & Fahrig, 2001) and reproductive behaviours (Steen & Gibbs, 2004; Langen et al. 2012). Road surveys are the preferred method for identifying hotspots (Langen et al., 2007). These involve walking or driving along road sections and keeping track of any animals that were hit by vehicles.

Researchers have used statistical modelling to identify landscape and road-related predictors such as proximity to forest stands, anthropogenic buildings count, number of lanes, traffic, and proximity to nearest curves for increased road mortality (Malo et al. 2004; Gunson et al., 2011). These environmental correlates can be used to identify priority locations for road surveys to reduce costs (Boyle et al. 2017). The objective of my study is to identify fine-scale landscape and road predictors to amphibian, bird, mammal, and reptile road mortality in the National Capital

Commission’s Greenbelt. These data will be used by land managers to implement ecopassages to mitigate high mortality areas, and to increase surveying efficiency.

2. Methods

2.1 Study Site and Road Sections

I studied wildlife road mortality along roads in the National Capital Greenbelt, which is a federally protected natural area of approximately 20 ’000 hectares owned and managed by the National Capital Commission. The Greenbelt surrounds the city of Ottawa and has numerous high traffic roads that pass through it. I selected 6 roads: Albion, Anderson, Leitrim, Lester, Moodie and Old Richmond (see Figures 1, 2 and 3) that intersect or run beside Provincially Significant Wetlands (PSWs) within the Greenbelt. To reduce the amount of time required to survey the roads, we only surveyed sections that were directly intersecting or running next to PSWs (Ontario Ministry of Natural Resources, 2016). A previous study conducted in 2014 by the National Capital Commission (NCC) indicated that mortalities were more frequently observed along these areas. This created 10 road sections that were for 12 weeks from May 11th to July 27th, 2018 on a total of 25 separate days. The number of site visits varied among road sections, Anderson 1 having been visited most frequently with 15 surveys and Leitrim having been visited least with 4 surveys (Table 1).

2.2 Road Surveys

Road mortality surveys involved walking at a constant pace along each side of a road section and looking for injured or dead animals on the surface or shoulder of the road. Each wildlife mortality was identified to the lowest taxonomic level possible; a photo was taken to verify uncertainties in identification, and the location of each animal was recorded using a GPS (Garmin etrex 20, 5-m accuracy). Since turtle carcasses can persist along the road shoulder for a long time, the approximate size of each carapace was noted to avoid repeat sightings. The locations as well as photos were also useful in ruling out repeat observations.

Although I did record the duration of every survey, since walking speed was relatively constant, the time spent surveying a road section was more indicative of its length rather than the relative effort. Instead, the number of survey days for each road section was used as the proxy for effort. Weather conditions such as air temperature, precipitation, and cloud cover were also recorded for each survey.

2.3 Environmental Correlates

To identify the environmental characteristics that were related to a higher number of road mortalities, I divided each road section into smaller "subsections" of equal length. The length of each subsection was meant to be short enough to capture variation within the entire road section and local vegetation, but also long enough to be meaningful for mitigation purposes and to ensure independence among subsections. High mortality counts within neighbouring subsections would lead them to fail spatial independence tests, which would require increasing the length of the subsections (see results) to meet these assumptions. I subdivided each road section into 50-m subsections, creating 289 subsections in total. Using a geographic information system (ArcMap 10.6.1, ESRI), I buffered each subsection by 50 m to create 5000 m^2 polygons that were intersected in the middle by the road (Figure 4). I separated the mortality data by taxon, and attributed amphibian, bird, mammal and reptile counts separately to each subsection. Additionally, I corrected mortality counts for the number of site visits (taxon mortality/number of days the road was surveyed).

In fall 2018, I visited each subsection and categorized the dominant vegetation (Forest, Marsh or Anthropogenic), presence of open water year-round, presence of a culvert, ditch slope (defined as either deep V (3:1, 2:1 and 1:1) or shallow V (4:1 or greater)), and the proportion of the polygon covered by the OMNR PSW layer.

2.4 Statistical Analyses

With road subsections as the unit of replication, I ran general linear models separately for amphibians, birds, mammals, and reptiles using effort-corrected mortality counts as the continuous dependent variable and road section, presence of water, presence of culverts, OMNR wetland cover, ditch angle, and vegetation type as predictor variables. I used spatial statistic tools in a GIS (ArcMap 10.6.1, ESRI) to calculate Moran's I and ensure spatial independence among subsections. The Akaike's Information Criterion function in R was used to evaluate the best fitting model for each taxon (R Core Team 2019). I determined significant environmental predictors for road mortality with the best fitting model and used a follow-up Tukey HSD tests to identify the specific variables associated with increased mortality (R Core Team 2019). Finally, I calculated effect sizes for each significant predictor variable.

3. Results

A total of 1116 wildlife road mortalities were observed during my survey. Amphibians represented 82.2% of the total observations with 918 mortalities, reptiles represented 8.6% of the observations with 96 mortalities, birds represented 4.8% of the observations with 54 mortalities, and mammals represented 4.3% of the observations with 48 mortalities. In total, 45 species were identified during our survey, 4 of which were federally listed species at risk: Blanding's turtle (2), Snapping Turtle (3), Eastern Wood-Pewee (1), and Least Bittern (2).

Due to the large number of amphibian mortalities, the spatial independence assumption could not be met when the amphibian data were divided into subsections (Moran's I test $p < 0.05$). When running the general linear model with 50-m subsections, however, the best fitting model included road section, wetland area, and ditch slope as environmental predictors (Table 2). All three environmental predictors in the model were significant; road section ($F = 16.993$, $p < 0.001$ $R^2 = 0.3557$), wetland area ($F = 4.4917$, $p = 0.035$, $R^2 = 0.0159$), and ditch slope ($F = 7.3352$, $p < 0.001$, $R^2 = 0.0258$). The subsections along Albion 1 had 1.029 mortalities · subsection^{-1} · day^{-1} ($n = 41$ of 289) which was the highest among road sections. Deep V ditch slope had 0.3791 greater mortalities · subsection^{-1} · day^{-1} ($n = 169$ of 289) compared to the shallow V ditch slope. Anecdotally, there were much higher amphibian mortalities when surveys were conducted within 24h of precipitations (Figure 5). Only Albion 1, Anderson 1-4, and Old Richmond were surveyed within 24h of precipitations and no road sections were surveyed more than once within the 24h window.

For reptile mortality, subsection length was increased to 100-m to allow for spatial independence (Moran's $I = 0.035$, $p > 0.05$). The best fitting model for reptiles included the following environmental predictors: road section, presence of open water, and vegetation type (Table 3). Significant predictor variables were road section ($F = 4.2195$, $p < 0.001$, $R^2 = 0.2315$) and vegetation type ($F = 4.7291$, $p < 0.001$, $R^2 = 0.1305$). Post-hoc tests revealed that the road section with the highest reptile mortality was Anderson 1 with 0.32667 mortalities · subsection^{-1} · day^{-1}. The number of reptile mortalities increased by 0.1771 mortalities · subsection^{-1} · day^{-1} with the presence of "marsh" vegetation type ($n = 27$ of 141) on at least one side of the subsection. When the dominant vegetation type on both sides of subsection was marsh, the average increased to 0.2986 mortalities · subsection^{-1} · day^{-1} ($n = 14$ of 141). Although it was not found to be significant, subsection with presence of open water (n = 7 of 141) had 0.258 greater mortalities · subsection^{-1} · day^{-1} than those without open water.

For mammal mortality, subsection length remained at 50-m since they were spatially independent (Moran's I = 0.02, $p > 0.05$). The best fitting model (Table 4) only included culverts as the environmental predictor, and this variable was found to be significant ($F = 14.66$, $p < 0.001$, $R^2 = 0.045$). Subsections with culverts (n = 12 of 289) had 0.0592 more mortalities · subsection^{-1} · day^{-1} than those without them.

Subsection length remained at 50-m for birds since they were spatially independent (Moran's I = 0.06, $p > 0.05$). The best fitting model for bird mortalities (Table 5) only included open water as the environmental predictor, and this variable was not found to be significant ($F = 2.716$, $p > 0.05$). The model explained very little of the variance (Adjusted $R^2 = 0.0094$).

4. Discussion

Amphibians were the most common taxon observed during this study but were only observed in large numbers during 3 of the 25 survey days. Amphibians are among the taxon with the lowest carcass persistence along the road (Santos et al. 2011; Ratton et al. 2014) and are difficult to identify when they are present, since they aren't resistant to vehicle passing over them. As such, most animals classified as "amphibians" were of an unknown anuran species. The recency of precipitation seemed to be related to peaks in amphibian mortality abundance, which has been observed in prior studies as well (Hels, 2001). Another potential explanation for the large number of amphibians seen during only a few surveys could be related to anuran migratory patterns. For instance, northern leopard frogs migrate out of natal wetlands in July (Langen et al. 2009) which coincides with my high amphibian observations. This species-specific characteristic may cause roads to have a greater effect on northern leopard frog population than other anurans (Ashley & Robinson, 1996; Carr, & Fahrig, 2001). I found that amphibian road mortality was significantly related to the local wetland area, deep V ditch slopes and to certain road sections. Apart from "road section", these results are not consistent previous studies, which have identified high road traffic and forest cover as the main predictor variables for anuran road mortality in North America (Fahrig et al. 1995; Eigenbrod et al. 2008). The road section with the greatest number of anuran road mortalities was Albion road, which anecdotally had the highest traffic volume of all roads tested in the Greenbelt, and the dominant vegetation along each side of Albion road was "forest". However, vegetation type was not found to be a significant predictor for amphibian mortality in my model. As mentioned, due to the high variability in amphibian mortality during our survey, the presence of high mortality numbers along Albion road could simply be due to the survey date coinciding with precipitation or anuran migration. This creates an imbalance in the observations, which causes the model to associate high amphibian mortality with environmental predictors found along road that were sampled during these high mortality events. This issue is particularly important for taxa with low persistence along the side of the road.

Reptiles were found more frequently road-killed near culverts and where marsh was the dominant vegetation type. These results are consistent with previous studies, Langen et al., 2009 and Ashley & Robinson, 1996 found that wetland within 100 m of their survey sites was a significant predictor for reptile mortality. Additionally, they found that sections of road with wetlands on either side were more likely to have reptile hotspots associated to them. This was the case in my study for marsh type habitat, its presence was significantly related to reptile mortality, but when both sides of a subsection were marsh dominated, reptile mortality was highest. The presence of open water was also found to be a significant predictor variable in this study, which is likely due to its occurrence near wetlands and favourable reptile habitat. Additionally, open water along Anderson road was always accompanied by culverts that intersected the road. Increased turtle mortality around culverts could indicate that turtles are using culverts to cross the road, or water ways that drain into culverts to get to the road surface for nesting. Turtle sex ratios were not measured during this study, but it is well known that females are drawn to the road shoulder for nesting (Steen & Gibbs, 2004;Dorland et al. 2014). The last significant predictor variable in the reptile model was “road section”. The purpose of including a road parameter in the model was to consider variation among road characteristics. Anderson 1 was the road section with the highest number of reptile mortalities per subsection, but traffic was likely similar among other road sections on Anderson road, since they were so close together. Additionally, most reptile mortality (89.5%) was observed along Anderson road. Thus, any variation in reptile mortality in this study was due to habitat and landscape variables and not due to traffic. Like the amphibian model, some road sections had much higher reptile mortality when compared to others (nearly 90% of the reptiles were seen on Anderson road). The model is not as unbalanced in this case, due to the longer carcass persistence of turtles (Santos et al., 2011).

Mammal mortality was explained by the presence of culverts in this study. The effect size of this environmental correlate was very low however ($R^2 = 0.045$) which means that culvert presence is likely not biologically meaningful. The reason culverts were significant predictors is likely due to beaver and muskrat mortality near wetlands. To the best of my knowledge, no other study has observed a relationship between mammals and culverts, but small mammal road mortality has been related to its proximity to urban areas and forest cover in the past (Gunson et al., 2011).

Bird mortality was not significantly related to any of the predictor variables in the model. This suggests bird road mortality was not captured because other variables that were not considered are more important. However, another study showed that water and wetlands are related to an increase in road mortality rates in birds (Gomes et al. 2009).

The main limitation of this study was the lack of consistency among number of surveys and in the frequency of surveys. An uneven number of survey days will clearly reduce the number of road mortality observations, which increases the weight of environmental correlates found on roads frequently surveyed. This is particularly problematic for small vertebrates that do not persist along the road for a long time such as amphibians. Additionally, future models should include weather variables to account for the increase in anuran mortality during precipitation. Future studies should also collect population data which allows for evaluating road mortality rates relative to local abundance, this further informs land managers on where the priorities are for mitigation. Finally, utilizing spatial generalized linear models would eliminate spatial autocorrelation issues, which can be problematic when road mortalities are abundant.

In conclusion, amphibian mortality was found to increase significantly during or shortly after precipitation, but due to an imbalance in the study design, environmental variables affecting amphibian presence were not reliable. Reptile mortality was related to marsh vegetation type, the presence of open water and did not seem to be affected by traffic rate. Mammal road mortality was partially explained by culvert presence and the model did not explain bird mortality variation. Effectively informing road mitigation requires numerous years of data, as such, more data collection is required before suggesting locations to implement ecopassages, but this study has confirmed that roads intersecting wetlands and marshes should be priorities for road surveys.

5. References

Ashley, P. E., & Robinson, J. T. (1996). Road Mortality of Amphibians, Reptiles and Other Wildlife on the Long Point Causeway, Lake Erie, Ontario. *The Canadian Field-Naturalist*, *110*(February), 403–412.

Beaudry, F., deMaynadier, P. G., & Hunter, M. L. (2008). Identifying road mortality threat at multiple spatial scales for semi-aquatic turtles. *Biological Conservation*, *141*(10), 2550–2563. https://doi.org/10.1016/j.biocon.2008.07.016

Boyle, S. P., Litzgus, J. D., & Lesbarrères, D. (2017). Comparison of road surveys and circuit theory to predict hotspot locations for implementing road-effect mitigation. *Biodiversity and Conservation*, *26*(14), 3445–3463. https://doi.org/10.1007/s10531-017-1414-9

Carr, L. W., Fahrig, L., Carr, L. W., & Fahrig, L. (2001). Effect of Road Traffic on Two Amphibian Species of Differing Vagility. *Conservation Biology*, *15*(4), 1071–1078.

Clevenger, A. P., Chruszcz, B., & Gunson, K. E. (2003). Spatial patterns and factors influencing small vertebrate fauna road-kill aggregations. *Biological Conservation*, *109*, 15–26.

Coffin, A. W. (2007). From roadkill to road ecology : A review of the ecological effects of roads. *Journal of Transport Geography*, *15*, 396–406. https://doi.org/10.1016/j.jtrangeo.2006.11.006

Cunnington, G. M., Garrah, E., Eberhardt, E., & Fahrig, L. (2014). Culverts alone do not reduce road mortality in anurans. *Écoscience*, *21*(1), 69–78. https://doi.org/10.2980/21-1-3673

Dorland, A., Rytwinski, T., & Fahrig, L. (2014). Do roads reduce painted turtle (Chrysemys picta) populations? *PLoS ONE*, *9*(5). https://doi.org/10.1371/journal.pone.0098414

Eigenbrod, F., Hecnar, S. J., & Fahrig, L. (2008). The relative effects of road traffic and forest cover on anuran populations. *Biological Conservation*, *141*(1), 35–46. https://doi.org/10.1016/j.biocon.2007.08.025

Fahrig, L., Pedlar, J. H., Pope, S. E., Taylor, P. D., & Wegner, J. F. (1995). Effect of Road Traffic on Amphibian Density. *Biological Conservation*, *73*, 177–182.

Fahrig, L., & Rytwinski, T. (2009). Effects of Roads on Animal Abundance: an Empirical Review and Synthesis. *Ecology & Society*, *14*(1), 1–20. https://doi.org/Artn 21

Fenech, A., Taylor, B., Hansell, R., & Whitelaw, G. (2001). Major road changes in Southern Ontario 1935-1995: Implications for protected areas. *Proceedings of the International Conference on the Science and Management of Protected Areas*. Retrieved from http://www.utoronto.ca/imap/papers/major_road_changes.pdf

Gomes, L., Grilo, C., Silva, C., & Mira, A. (2009). Identification methods and deterministic factors of owl roadkill hotspot locations in Mediterranean landscapes. *Ecological Research*, *24*(2), 355–370. https://doi.org/10.1007/s11284-008-0515-z

Gunson, K. E., Ireland, D., & Schueler, F. (2012). A tool to prioritize high-risk road mortality locations for wetland-forest herpetofauna in southern Ontario, Canada. *North-Western Journal of Zoology*, *8*(2), 409–413. https://doi.org/121401

Gunson, K. E., Mountrakis, G., & Quackenbush, L. J. (2011). Spatial wildlife-vehicle collision models: A review of current work and its application to transportation mitigation projects. *Journal of Environmental Management*, *92*(November), 1074–1082. https://doi.org/10.1080/13658810802406132

Hels, T. (2001). The Effect of Road Kills on Amphibian Populations. *Biological Conservation*, *99*(3), 24–42.

Jackson, N. D., & Fahrig, L. (2011). Relative effects of road mortality and decreased connectivity on population genetic diversity. *Biological Conservation*, *144*(12), 3143–3148. https://doi.org/10.1016/j.biocon.2011.09.010

Jaeger, J. A. G., Bowman, J., Brennan, J., Fahrig, L., Bert, D., Bouchard, J., … Von Toschanowitz, K. T. (2005). Predicting when animal populations are at risk from roads: An interactive model of road avoidance behavior. *Ecological Modelling*, *185*(2–4), 329–348. https://doi.org/10.1016/j.ecolmodel.2004.12.015

Jaeger, J. A. G., & Fahrig, L. (2004). Effects of road fencing on population persistence. *Conservation Biology*, *18*(6), 1651–1657. https://doi.org/10.1111/j.1523-1739.2004.00304.x

Langen, T. A., Gunson, K. E., Scheiner, C. A., & Boulerice, J. T. (2012). Road mortality in freshwater turtles: Identifying causes of spatial patterns to optimize road planning and mitigation. *Biodiversity and Conservation*, *21*(12), 3017–3034. https://doi.org/10.1007/s10531-012-0352-9

Langen, T. A., Machniak, A., Crowe, E. K., Mangan, C., Marker, D. F., Liddle, N., & Roden, B. (2007). Methodologies for Surveying Herpetofauna Mortality on Rural Highways. *The Journal of Wildlife Management*, *71*(4), 1361–1368. https://doi.org/10.2193/2006-385

Langen, T. A., Ogden, K. M., & Schwarting, L. L. (2009). Predicting Hot Spots of Herpetofauna Road Mortality Along Highway Networks. *Journal of Wildlife Management*, *73*(1), 104–114. https://doi.org/10.2193/2008-017

Laurance, W. F., Clements, G. R., Sloan, S., Connell, C. S. O., Mueller, N. D., Goosem, M., … Arrea, I. B. (2014). A global strategy for road building. *Nature*. Nature Publishing Group. https://doi.org/10.1038/nature13717

Litvaitis, J. A., & Tash, Æ. J. P. (2008). An Approach Toward Understanding Wildlife-Vehicle Collisions. *Environmental Management*, *42*, 688–697. https://doi.org/10.1007/s00267-008-9108-4

Malo, J. E., Suárez, F., & Díez, A. (2004). Can we mitigate animal – vehicle accidents using predictive models ? *Journal of Applied Ecology*, *41*, 701–710.

Mountrakis, G., & Gunson, K. (2009). Multi-scale spatiotemporal analyses of moose-vehicle collisions: A case study in northern Vermont. *International Journal of Geographical Information Science*, *23*(11), 1389–1412. https://doi.org/10.1080/13658810802406132

Ratton, P., Secco, H., & Alves, C. (2014). Carcass permanency time and its implications to the roadkill data, 543–546. https://doi.org/10.1007/s10344-014-0798-z

R Core Team (2018). R: A language and environment for statistical computing. R Foundation for

Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

Santos, S. M., Carvalho, F., & Mira, A. (2011). How long do the dead survive on the road? Carcass persistence probability and implications for road-kill monitoring surveys. *PLoS ONE, 6*(9). https://doi.org/10.1371/journal.pone.0025383

Stahl, P., Vandel, J. M., Herrenschmidt, V., & Migot, P. (2001). Predation on livestock by an expanding reintroduced lynx population : long-term trend and spatial variability. *Journal of Applied Ecology*, *38*(1996), 674–687.

Steen, D. A., & Gibbs, J. P. (2004). Effects of roads on the structure of freshwater turtle populations. *Conservation Biology*, *18*(4), 1143–1148. https://doi.org/10.1111/j.1523-1739.2004.00240.x

Whittingham, M. J., Krebs, J. R., Swetnam, R. D., Vickery, J. A., Wilson, J. D., & Freckleton, R. P. (2007). Should conservation strategies consider spatial generality? Farmland birds show regional not national patterns of habitat association. *Ecology Letters*, *10*, 25–35. https://doi.org/10.1111/j.1461-0248.2006.00992.x

Zimmermann Teixeira, F., Kindel, A., Hartz, S. M., Mitchell, S., & Fahrig, L. (2017). When road-kill hotspots do not indicate the best sites for road-kill mitigation. *Journal of Applied Ecology*, *54*(5), 1544–1551. https://doi.org/10.1111/1365-2664.12870

6. Appendix

Figure 1. Road sections surveyed in the Mer Bleue Sector of the National Capital Commissions' Greenbelt. The road sections shown are on Anderson Road in Ottawa, Ontario.

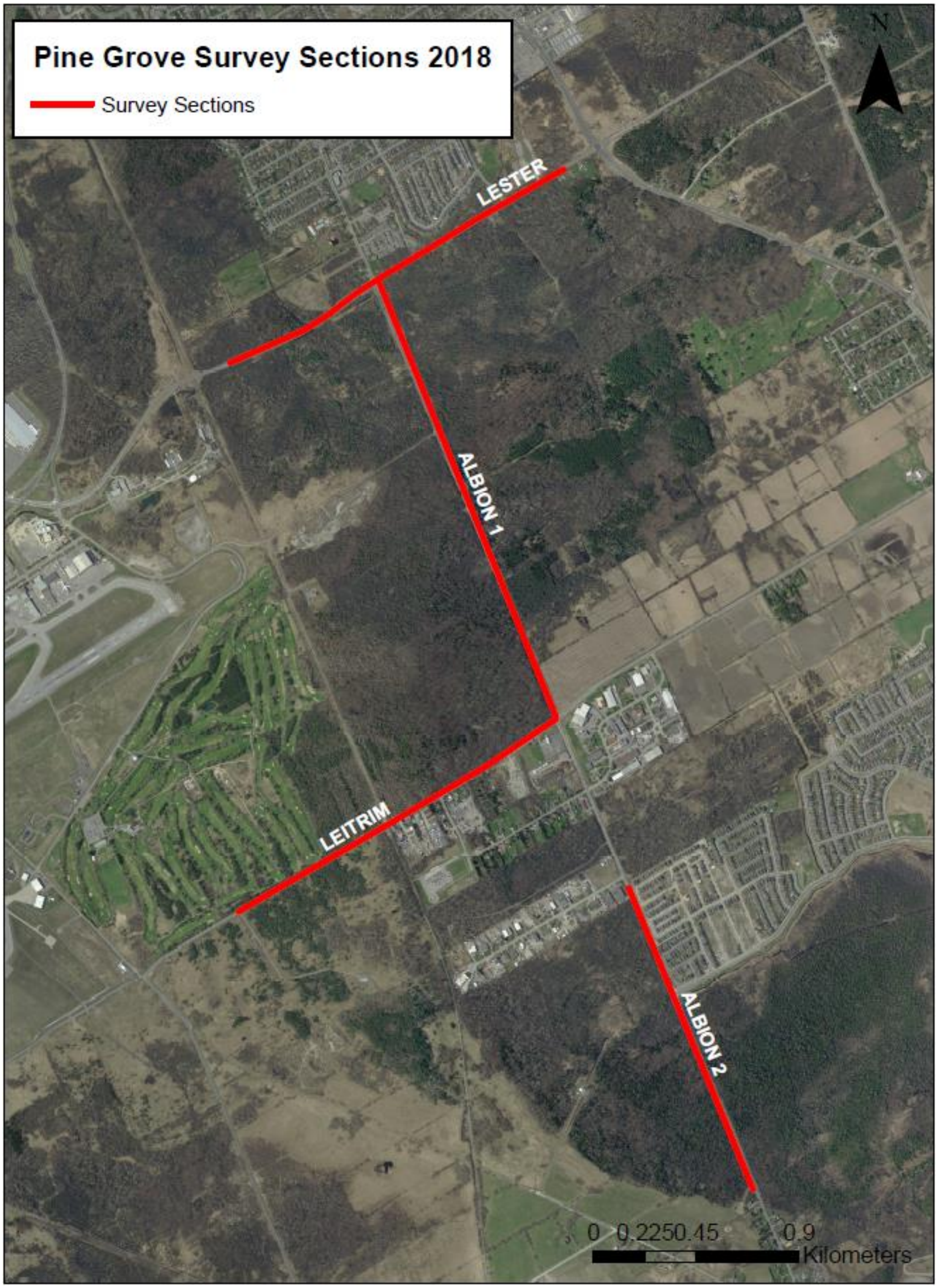

Figure 2. Road sections surveyed in the Pine Grove Sector of the National Capital Commissions' Greenbelt.

Figure 3. Road sections surveyed in the Stony Swamp Sector of the National Capital Commissions' Greenbelt. The road sections shown are on Old Richmond Road and Moodie Drive in Ottawa, Ontario.

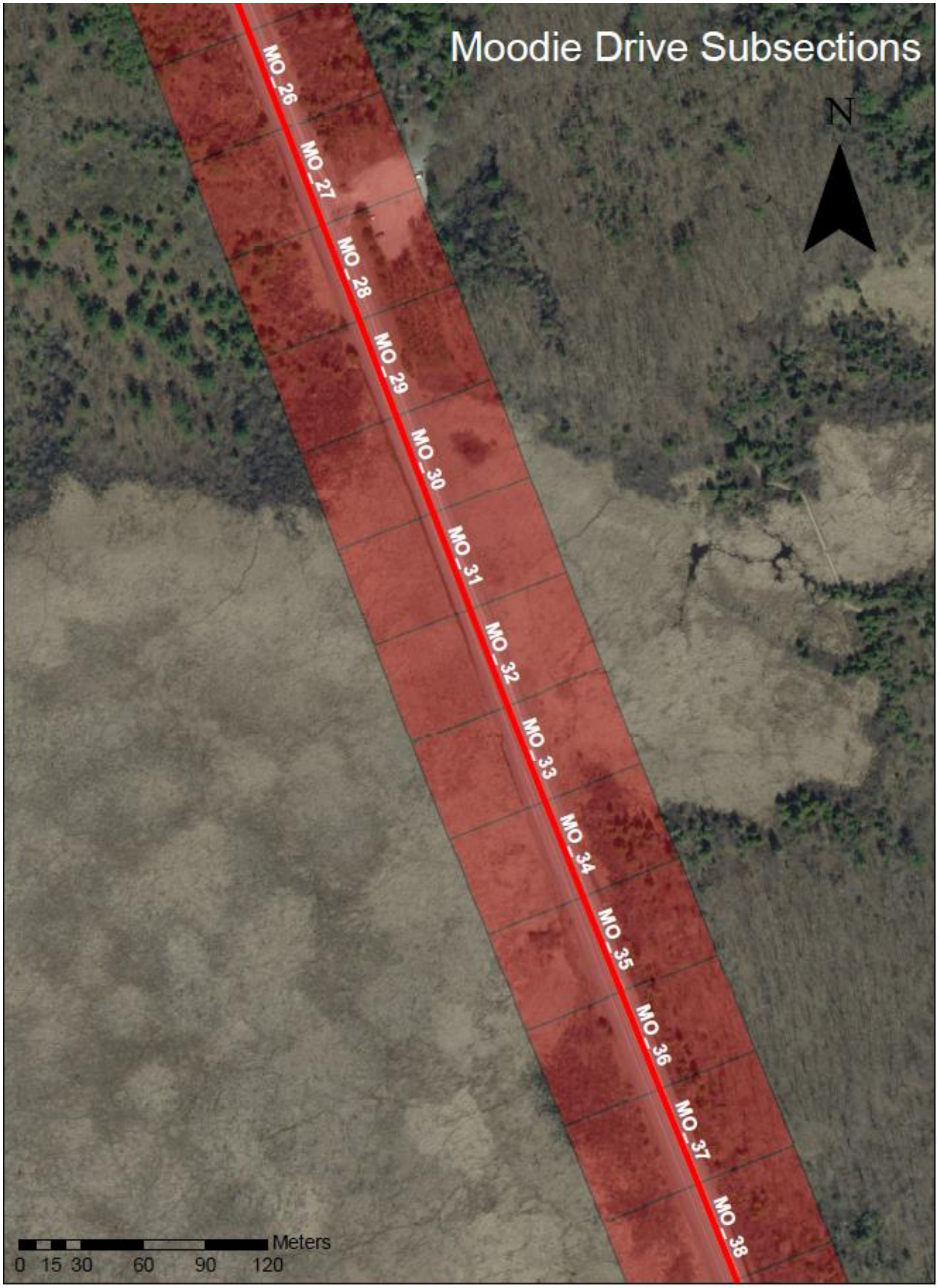

Figure 4. Example of the road subsections created within a road section. Each subsection was attributed environmental correlate data that was found within the 50 m x 100 m polygon.

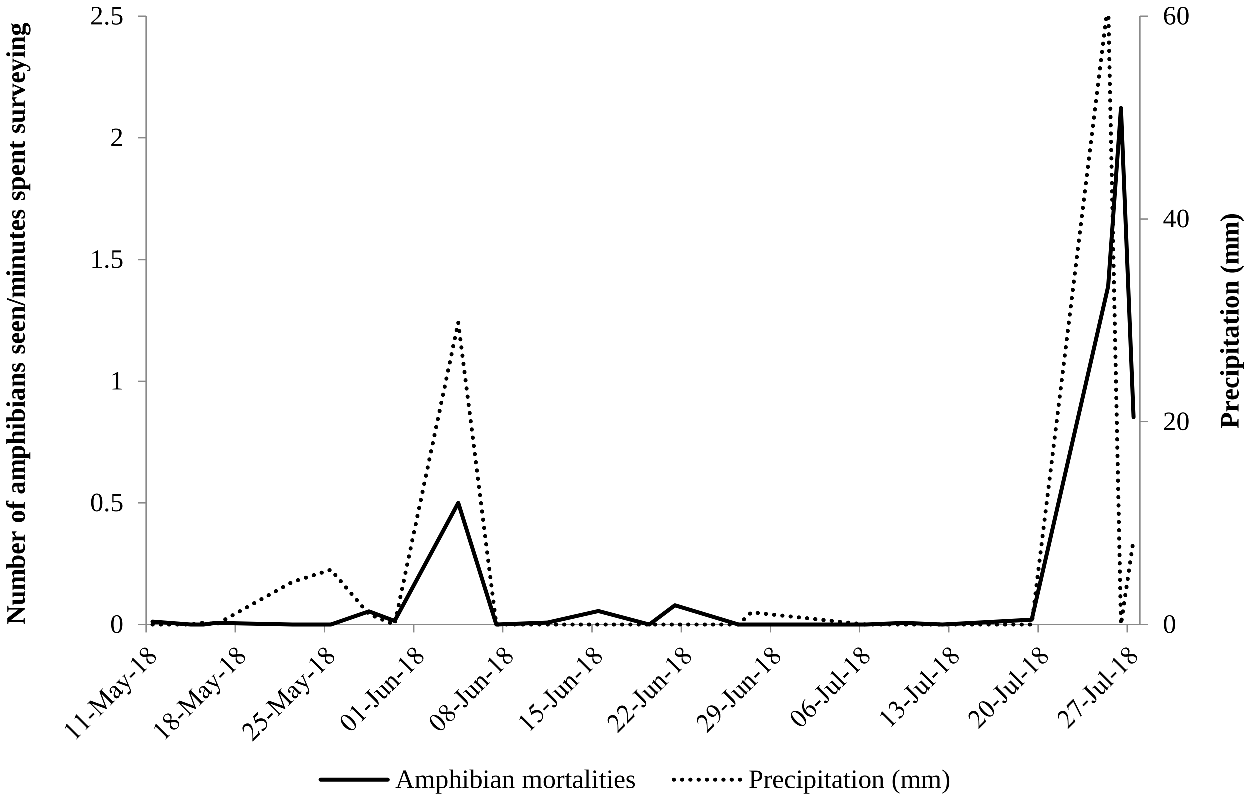

Figure 5. Total amphibian mortalities compared to total precipitation (mm) for a given day. Amphibian mortalities were time corrected (number of mortalities divided by total survey time) for each day. Precipitation data is from Meteorological Service of Canada, Environment and Climate Change Canada.

Table 1. Summary of the total number of site visits for each road section. The sampling period started on May 11th and ran for 12 weeks until July 27th, 2018. Surveys were conducted on 25 separate days.

Road Section	Days Surveyed	Length of Section (m) [a]
Albion 1	8	2050
Albion 2	7	1550
Anderson 1	15	900
Anderson 2	14	1050
Anderson 3	14	500
Anderson 4	13	800
Leitrim	4	1600
Lester	5	2000
Moodie	6	2000
Old Richmond	7	2000

[a] Section length is the unidirectional measurement of the road section.

Table 2. Model selection for an analysis of environmental correlates and amphibian road mortality. The Akaike's information criteria (AIC) was used to determine the best fitting model, which is the model with the lowest AIC score.

Model	*k*	AIC
Amphibians ~ Road + Wetland + Water + Culverts + Ditch + Veg_Type	7	-363.64
Amphibians ~ Road + Wetland + Water + Culverts + Ditch	6	-366.97
Amphibians ~ Road + Wetland + Water + Ditch	5	-368.92
Amphibians ~ Road + Wetland + Ditch	4	-370.46

Note: *k* is the number of parameters in the model.

Table 3. Model selection for an analysis of environmental correlates and reptile road mortality. The Akaike's information criteria (AIC) was used to determine the best fitting model, which is the model with the lowest AIC score.

Model	*k*	AIC
Reptiles ~ Road + Wetland + Water + Culverts + Ditch + Veg_Type	7	-1361.9
Reptiles ~ Road + Wetland + Water + Culverts + Veg_Type	6	-1363.8
Reptiles ~ Road + Water + Culverts + Veg_Type	5	-1365.2
Reptiles ~ Road + Water + Veg_Type	4	-1365.5

Note: *k* is the number of parameters in the model.

Table 4. Model selection for an analysis of environmental correlates and mammal road mortality. The Akaike's information criteria (AIC) was used to determine the best fitting model, which is the model with the lowest AIC score.

Model	*k*	AIC
Mammals ~ Road + Wetland + Water + Culverts + Ditch + Veg_Type	7	-1690.6
Mammals ~ Wetland + Water + Culverts + Ditch + Veg_Type	6	-1696.4
Mammals ~ Wetland + Water + Culverts + Ditch	5	-1700.6
Mammals ~ Wetland + Water + Culverts	4	-1701.3
Mammals ~ Wetland + Culverts	3	-1701.8
Mammals ~ Culverts	2	-1701.9

Note: *k* is the number of parameters in the model.

Table 5. Model selection for an analysis of environmental correlates and bird road mortality. The Akaike's information criteria (AIC) was used to determine the best fitting model, which is the model with the lowest AIC score.

Model	*k*	AIC
Birds ~ Road + Wetland + Water + Culverts + Ditch + Veg_Type	7	-1687.6
Birds ~ Wetland + Water + Culverts + Ditch + Veg_Type	6	-1694.7
Birds ~ Wetland + Water + Culverts + Ditch	5	-1701.8
Birds ~ Wetland + Water + Culverts	4	-1703.3
Birds ~ Wetland + Water	3	-1703.9
Birds ~ Water	2	-1704.5

Note: *k* is the number of parameters in the model.