Weaving Indigenous Knowledge and Western Science to Investigate the Impacts of Railways on Wildlife

by

Kyle D. Vincent

A thesis submitted in partial fulfillment
of the requirements for the degree of
Master of Science (MSc) in Biology

The oFFICE of Graduate Studies
Laurentian University
Sudbury, Ontario, Canada

THESIS DEFENCE COMMITTEE/COMITÉ DE SOUTENANCE DE THÈSE
Laurentian Université/Université Laurentienne
Office of Graduate Studies/Bureau des études supérieures

Title of Thesis Titre de la thèse	Weaving Indigenous Knowledge and Western Science to Investigate the Impacts of Railways on Wildlife	
Name of Candidate Nom du candidat	Vincent, Kyle	
Degree Diplôme	Master of Science	
Department/Program Département/Programme	Biology	Date of Defence Date de la soutenance September 29, 2022

APPROVED/APPROUVÉ

Thesis Examiners/Examinateurs de thèse:

Dr. Jackie Litzgus
(Co-Supervisor/Co-directeur(trice) de thèse)

Dr. Jesse Popp
(Co-Supervisor/Co-directeur(trice) de thèse)

Dr. Nate Basiliko
(Committee member/Membre du comité)

Dr. Jennifer Grenz
(External Examiner/Examinateur externe)

Approved for the Office of Graduate Studies
Approuvé pour le Bureau des études supérieures
Tammy Eger, PhD
Vice-President Research (Office of Graduate Studies)
Vice-rectrice à la recherche (Bureau des études supérieures)
Laurentian University / Université Laurentienne

ACCESSIBILITY CLAUSE AND PERMISSION TO USE

I, **Kyle Vincent**, hereby grant to Laurentian University and/or its agents the non-exclusive license to archive and make accessible my thesis, dissertation, or project report in whole or in part in all forms of media, now or for the duration of my copyright ownership. I retain all other ownership rights to the copyright of the thesis, dissertation or project report. I also reserve the right to use in future works (such as articles or books) all or part of this thesis, dissertation, or project report. I further agree that permission for copying of this thesis in any manner, in whole or in part, for scholarly purposes may be granted by the professor or professors who supervised my thesis work or, in their absence, by the Head of the Department in which my thesis work was done. It is understood that any copying or publication or use of this thesis or parts thereof for financial gain shall not be allowed without my written permission. It is also understood that this copy is being made available in this form by the authority of the copyright owner solely for the purpose of private study and research and may not be copied or reproduced except as permitted by the copyright laws without written authority from the copyright owner.

Abstract

Railways have been documented to cause mortalities for many different species, but overall, the ecological impacts of railways are under-researched and poorly understood. To date, railway ecology research has mainly focused on large mammals, but to develop effective railway mitigation, it is important to understand risks for underrepresented taxa. My aim was to use a Two-Eyed Seeing approach that weaved Indigenous knowledge and western science to improve understanding of railway ecology for understudied species and to help guide future mitigation efforts. In partnership with two First Nations, community members were invited to share Indigenous knowledge (IK) of wildlife-railway interactions to inform study design, then I conducted weekly visual surveys over three field seasons along two 3.6 km sections of railway in Eastern Georgian Bay, Ontario, recording the locations of live and dead wildlife. I recorded 462 observations of individuals from 42 different species, of which 76% were found dead, and 24% were encountered alive, findings complemented by shared IK. Reptiles and amphibians were the most severely impacted taxa, accounting for 87% of observed mortalities. Additionally, I identified hotspots of turtle and anuran interactions, and found that the locations of interactions were related to adjacent habitat use and railway features. Ultimately, this study highlights the value of collaborative research that uses complementary knowledge systems, indicates that reptiles and amphibians may be particularly susceptible to railway mortality, and identifies areas to target future mitigation both locally and in relation to broad scale landscape features for turtles and anurans.

Key words: Indigenous knowledge, railway ecology, transportation infrastructure, species-at-risk, reptiles, amphibians, conservation, First Nation

Acknowledgments

I would like to start by thanking **Magnetawan First Nation** and **Shawanaga First Nation** for not only being the driving force behind this study, using community concerns to develop critical conservation initiatives, but for supporting me through the entire thesis process and always making me feel like I was a part of your respective field-work families. I would also like to thank both communities for allowing me to conduct my research on the lands of their **Traditional Territories**. The landscapes and wildlife of both First Nations are truly some of the most beautiful sights I've seen, and the significance of having the privilege to work on the lands will never be lost on me. This project would not have been possible without the knowledge shared by community members at both First Nations; it has been so fulfilling to work closely on a project so deeply connected to both communities. From the bottom of my heart, *Chi-miigwetch.*

Dr. Jacqueline Litzgus: I'm so thrilled to have had the opportunity to learn from and work with you over the course of my master's degree. Without your guidance, support, and positive outlook on life, I honestly don't know if I could have navigated some of the challenges we've all faced over the last two years. Your passion for conservation, research, and teaching have inspired and motivated countless students, and I feel so incredibly lucky that I can now count myself among them. You're an inspiration to every young scientist that has the privilege to learn from you.

Dr. Jesse Popp: Thank you for giving me the opportunity to not only join an incredible project, but for giving me the chance to broaden my horizons on what it means to do science research. Your passion for your research and the communities you have partnered with is inspiring and is something that I plan to carry with me as I continue in my career, constantly striving to do science in a responsible and respectful way.

Dr. Nate Basiliko: I want to thank you for being a valuable member of my committee, you always brought valuable insight and an inspiring positivity to our meetings.

Magnetawan First Nation – Lands Department: The constant support from so many wonderful people at MFN played an indescribable role in allowing me to undertake and complete this research. **Cory Kozmik, Samantha Noganosh, Alanna Smolarz, Nadine Perron, Tiffany Garon-Dumoulin,** and **Evyn Martin,** thank you to all of you for making the project not only a resounding success, but an incredibly fun adventure. I will always remember our many conversations on those sunny morning railway walks. It has been such a privilege to be able to return to MFN and continue helping the community and the Lands Department with the Species At Risk program, I feel so lucky to be able to work with you all. A special thank you to the many summer students who have welcomed me onto the lands: **Allen Lewis, Derian Smith, Lucas Fraser,** and **Delsin Noganosh**, your passion for your culture, work with the Lands Department, and positive attitude inspire me to be a better person.

Shawanaga First Nation – Lands Department: You not only served as a support system for me as I conducted my research, but many of you also had to put up with me full time at home as well. The summer spent in Parry Sound was one of the best times of my life, so thank you to **Steven Kell, Erica Fellin, Carter Rouleau** for putting up with me during stressful times and for spending hot days swimming in the bay and cool nights around the fire to help keep me sane; I couldn't have done it without you. A sincere thank you to **Tanner Jones-Ashawasagai** and **Bishop Jones-Ashawasagai** for your help in the field and for keeping me entertained with your conversations on the rails.

Jenna Kentel, **Brooke Carroll**, **Claire Kemp,** and **Kate Yarchuk:** you are all my lab mates, but you've also been some of my closest friends throughout this experience, and I can't even begin to express my gratitude to you. Thank you for helping to push me through the tough times, celebrate the victories, and just generally enjoy the graduate student life. To all other members of the **Litzgus Lab** and **WISE Lab**, thank you for your invaluable advice and constant support!

Family and **friends:** I truly believe that without the constant love and support of my friends and family this project would not have been possible, so a sincere thank you to each one of you. You know who you are! To my parents, **Paul** and **Elaine Vincent**, you know how much your support means to me. I would never be where I am now without your constant love and guidance. Thank you for everything you have done for me.

Kailee Hopkins: Last, but certainly not least, thank you for putting up with me through everything over the last two years. Without your support and love there is no chance I would have been able to finish this project. Whether it was late night phone calls to talk about edits, bouncing last minute ideas off you, or simply needing a chat to take my mind off the stress of school, I knew I could always count on you to be my support system. No matter where we are in life, or what we have been through, know that I appreciate you, thank you for being you.

Table of Contents

List of Tables

Chapter 1

Chapter 2

List of Figures

Chapter 1

Chapter 2

Chapter 3

List of Appendices

Positionality Statement – Research with Respect, Responsibility, and Reciprocity

This interdisciplinary and collaborative research weaves Indigenous knowledge (IK) and Western science (WS) to investigate complex ecological questions identified and prioritized by First Nation community partners. I would like to thank all the knowledge holders from the two Anishinaabek Nations, Shawanaga First Nation (SFN) and Magnetawan First Nation (MFN), who generously shared their knowledge and perspectives on wildlife-railway interactions for this study. This railway ecology research would not have been possible without project initiation, support, and constant guidance by both First Nation communities. I, Kyle Vincent, am a non-Indigenous ally and academic scholar who contributed to this work as a graduate student, from a place of constant respect and learning of community values, priorities, and ways of knowing. I was supported and mentored in this work by a committee comprised of two Indigenous academic scholars, Dr. Jesse Popp, and Angela Belleau, and non-Indigenous ally scholars, Dr. Jacqueline Litzgus, Cory Kozmik, and Steven Kell. Members of the thesis committee come from diverse backgrounds, but our unified goal with this work is to better understand railway ecology while uplifting Indigenous voices and contributing to reconciliation and the rights of Indigenous Peoples, all while highlighting the value of scientific research methods that use complementary knowledge systems conducted in a good way. Throughout the research process, all community protocols were followed, such as offering knowledge holders honoraria and tobacco ties. I embraced all ways of knowing equally and treated all interview participants as equal knowledge holders. Ensuring that I accurately represented the knowledge shared with me, while also disseminating what I learned about railway ecology back to community partners, were my top priorities. To facilitate this reciprocal knowledge transfer, reports, presentations, and pamphlets were authored, highlighting results for each community, and providing opportunity for feedback over the course of the study. Additionally, I showed reciprocity to both First Nation communities by assisting the Lands departments with various other projects including environmental monitoring, wildlife inventories, and outreach events. One of the other top priorities with this work, a priority shared by both First Nation communities, was the inclusion and uplifting of youth in research. Together, we prioritized opportunities for youth from MFN and SFN to participate in railway surveys and learn alongside us as we gained an understanding of railway ecology on both Traditional Territories.

My research labs have a long history of partnership with both SFN and MFN, and I hope this work is another step forward in fostering inclusivity, responsibility, reciprocity, and respect in natural science research.

Chi-miigwetch

* Wherever possible, the names of species encountered during surveys are listed in Anishinaabemowin, translated using the Ojibwe People's Dictionary (https://ojibwe.lib.umn.edu/).

Research Conceptualization

This project was initiated based on concerns and observations about wildlife-railway interactions detailed by First Nation community partners. This knowledge sharing stemmed from discussions about the results of previous railway ecology research in the area by Popp et al. (2018) that documented the railway mortality of elk (*omashkooz* [Anishinaabemowin]; *Cervus elaphus*). Through these informal conversations, many community members shared knowledge of other railway mortalities they had observed, spanning a wide diversity of wildlife, but with a particular focus on concern for impacts to turtles. These initial conversations, which also included mapping areas of known mortality, initiated our collaborative research, and led us to take an approach that considered all species, focused on the spring and summer months to capture reported impacts to herpetofauna, and helped identify locations to establish our study sites. Subsequent research through structured IK sharing interviews and foot surveys would not have been possible without these initial discussions with our First Nation community partners.

General Introduction

Transportation Infrastructure and Wildlife

Increasingly, transportation infrastructure like roads and railways have been recognized for their impacts on the environment and wildlife biodiversity (Andrews et al., 2015; Dorsey et al., 2015; Laurance et al., 2014; Popp and Boyle, 2017). The impacts to wildlife caused by transportation infrastructure are multifaceted and include a combination of indirect and direct impacts like habitat fragmentation, barrier effects, and direct mortality from collisions with vehicles (Van Der Ree et al., 2011; Dorsey et al., 2015; Popp & Boyle, 2017). Most research that has investigated the impacts of these man-made linear features on wildlife populations has focused on roads through the relatively new discipline known as 'road ecology' (Van Der Ree et al., 2011; Popp & Boyle, 2017). Based on research over the last few decades, roads are known to negatively impact a wide variety of wildlife (Fahrig and Rytwinski, 2009; Forman and Alexander, 1998), and are understood to be a substantial threat to biodiversity around the world (Laurance et al., 2014). Although railways are similar linear transportation structures that have existed on the landscape in Canada for nearly 200 years (Bladen, 1932), in contrast to their longevity as transportation structures, research on railway-wildlife interactions is very new and 'railway ecology' is substantially understudied (Popp & Boyle, 2017).

Railways Present Unique Challenges

Because of their somewhat similar form, railways generally have been assumed to share similar environmental impacts to those of roads (Barrientos et al., 2019; Dorsey et al., 2015). However, railways differ from roads in several ways, such as lower traffic volume and longer intervals between vehicles, increased disturbance from noise and vibrations, narrower right-of-way corridors (Barrientos et al., 2019), and the presence of the steel rails themselves, which pose an additional risk of entrapping small animals (Kornilev et al., 2006; Rautsaw et al., 2018). These physical differences might not only result in different effects on wildlife, but in some cases may exacerbate impacts common to both types of infrastructure (Barrientos et al., 2019; Dorsey et al., 2015). For example, one study discovered that train-collisions resulted in twice the number of mortalities of grizzly bears (*Ursus arctos horribilis)* when compared to mortalities resulting from vehicle collisions on roads (Waller and Servheen, 2005).

Although railway ecology-focused studies are limited, many wildlife species are documented to be impacted by railways including mammals (Clair et al., 2019; Dasgupta and Ghosh, 2015; Ito et al., 2008; Jerem and Mathews, 2021; Van der Grift, 1999; Waller and Servheen, 2005), birds (Tremblay and St. Clair, 2009), reptiles (Heske, 2015; Iosif, 2012; Kornilev et al., 2006; Platt et al., 2022; Rautsaw et al., 2018), amphibians (Bartoszek and Greenwald, 2009; Clauzel et al., 2013; Heske, 2015), and even insects (Bhattacharya et al., 2002); however, most research has been limited to studies focused on large mammals (Barrientos et al., 2019). More research is needed to thoroughly investigate railway impacts to understudied taxa, especially species vulnerable to other anthropogenic threats, because the impacts of railways are likely to differ among species (Popp & Boyle, 2017), and from those of roads (Barrientos et al., 2019; Dorsey et al., 2015). Developing a better overall understanding of wildlife-railway impacts is important because global railway networks are already substantial, and are expected to expand in the near future (Dorsey et al., 2015; Dulac, 2013).

Understanding Railway Impacts and Mitigation

Though some work has been done to document wildlife railway use and mortality, fewer studies have progressed to the next step of investigating the spatial relationships of wildlife-railway interactions and mitigation efforts to prevent railway-related mortalities from occurring

(Barrientos et al., 2019; Dorsey et al., 2015). A few notable examples include efforts to control vegetation along railway rights-of-way to reduce moose (*mooz; Alces alces*) train collisions (Andreassen, 2005), the use of warning devices to deter wildlife from railways when trains are passing (Backs et al., 2020), and the installation of underpasses or culverts to facilitate escape by small animals trapped between the rails (Matsuzawa, 2018; Pelletier et al., 2005). Although these efforts are a step in the right direction, research into most railway mitigation efforts is limited and more work is needed to identify taxa-specific impacts and solutions, with follow-up studies to quantify their effectiveness (Barrientos et al., 2019; Dorsey et al., 2015; Popp and Boyle, 2017). One important aspect of planning transportation infrastructure mitigation is determining where to install efforts in order to be the most cost and biologically effective (Borda-de-Água et al., 2019; Garrah et al., 2015; Gunson and Teixeira, 2015). Generally, areas along roads and railways with the highest concentrations of mortality or wildlife interaction, otherwise known as 'hotspots' are targeted for mitigation (Gunson and Teixeira, 2015; Langen et al., 2012). However, more effort is needed to understand where hotspots exist along railways, along with understanding what landscape factors influence how wildlife interact with railways spatially, especially for vulnerable taxa, to target future mitigation efforts most effectively.

Weaving Knowledge Systems: Indigenous Knowledge and Western Science

Ecological relationships are often complex and are currently examined almost exclusively from a western science (WS) centric perspective, when they could be benefitting from methods that embrace complementary knowledge systems (Reid et al., 2021). In fact, the benefits of adopting frameworks that include multiple knowledge systems, like Indigenous knowledge (IK) and WS, and promote the coexistence of knowledge in scientific research, have been exhibited in many studies (Alexander et al., 2011, 2019; Bartlett et al., 2012; St. Martin et al., 2007), but the adoption and normalization of these methods in academia is still not commonplace, even with demonstrated tangible benefits to doing so (Ogar et al., 2020). In this thesis, Indigenous knowledge (IK) is defined as the ways of knowing gained and passed down by Indigenous Peoples through generations, accumulated based on an association with the environment and a connection to the land (Battiste and Henderson, 2000; Berkes, 2012; McGregor, 2004, 2021). However, it must be noted that this is the definition adopted only for the purpose of this work, to provide context for the methods used to investigate railway ecology. For many Indigenous Peoples, IK cannot be limited to any one definition; instead it has been described as a way of being, inseparable from knowledge holders and the land (Battiste and Henderson, 2000; McGregor, 2004).

Although many frameworks exist for pairing knowledge systems in ecological research (Reid et al., 2021), the one adopted for this work is known as Two-Eyed Seeing, a concept envisioned and described by Mi’kmaw Elder Albert Marshall (Bartlett et al., 2012). Two-eyed Seeing draws equally on the strengths of both knowledges to create a more holistic understanding of ecology (Reid et al., 2021). An important element of the Two-Eyed Seeing framework is that the two knowledge systems work in parallel to understand a given issue, and are considered equal in contributing to a mutual understanding (Bartlett et al., 2012; Reid et al., 2021). When appropriate, more research should adopt methods that pair knowledge systems to help answer questions respectfully, with a shared interest from First Nation communities and researchers. Doing so will not only benefit scientific discovery and research, but more importantly, will contribute towards reconciliation and help to rebuild trust and respect lost due to the exploitation of Indigenous communities, and a history of conducting IK research with communities in inappropriate ways (Wong et al., 2020).

Objectives and Rationale

Although the breadth of research in the new field of railway ecology is slowly increasing, much remains to be understood, particularly for understudied taxa. The need for an improved understanding of wildlife-railway interactions has not only been noted in the scientific literature (Barrientos et al., 2019; Dorsey et al., 2015; Popp and Boyle, 2017), but also by First Nation communities, in this case two Anishinaabek Nations that witnessed the impacts of railways on wildlife in their Traditional Territories first-hand, and were concerned about potential long-term implications for sensitive species. Through project initiation by our First Nation community partners, I aimed to improve collective understanding of railway ecology by taking a holistic community level approach that weaves Indigenous knowledge (IK) and western science (WS) ways of knowing.

In Chapter 1, I take an exploratory approach to gain a baseline understanding of wildlife-railway interactions by conducting interviews with community members, surveying two sections of railway on-foot to document wildlife interactions, and installing trail cameras along the railway to capture observations of wildlife that might not be detected in walking surveys. IK informed the study, identifying common concerns, observations of wildlife-railway interactions, and knowledge gaps in railway ecology research, which I used to guide my thesis research. Using walking surveys and trail cameras, I compared railway use and mortality among taxonomic groups, and investigated seasonal variation and the influence of temporal variables on railway mortalities for frequently killed groups. Based on community concerns, I predicted that wildlife-railway mortality would affect diverse groups of wildlife, but that mortality would not be equal among groups because some taxa are likely more vulnerable to railway impacts, a result of their unique ecologies and physiologies. This information is critical to improving understanding of railway ecology, filling knowledge gaps in the scientific literature using a novel approach, but also answering fundamental questions for our First Nation partners through a study identified, guided, and initiated by the communities.

In Chapter 2, I used wildlife observations from walking surveys to investigate the influence of spatial variables on turtle and anuran railway interactions. I conducted hotspot analyses to identify whether observed interactions were significantly clustered on the railway in each community, a first step in targeting effective railway mitigation. I then tested whether landscape variables influenced the location of where I observed interactions along the railway, essential data for understanding how understudied taxa are impacted spatially. I predicted that hotspots would exist along the railway in both communities, and that the locations of interactions would be influenced by the presence of adjacent critical habitat (e.g., wetlands for turtles). Determining how landscape variables affect wildlife-railway interactions not only improves understanding of a poorly researched field of ecology, but also helps to inform potential railway mitigation strategies by identifying where they should be targeted on a broader scale. Understanding where to target railway mitigation for turtles and anurans may be especially important because both groups seem to be particularly vulnerable to railways and are already facing global population declines (Böhm et al., 2013; Cox et al., 2022; IUCN, 2020; Lesbarrères et al., 2014).

In Chapter 3, I describe the mortality of a male Midland Painted Turtle (*miskwaadesi; Chrysemys picta marginata*) encountered during walking railway surveys at Shawanaga First Nation (SFN). The individual putatively died from entrapment in creosote tar leached from a railway tie, a cause of mortality for freshwater turtles previously undescribed in the scientific literature. This observation is not only significant because of its novelty and potential threat to turtles, but because it was also a phenomenon described by a community member in IK interviews (Chapter 1), reinforcing the value of using complementary knowledge systems in ecological research.

References

Alexander, C., Bynum, N., Johnson, E., King, U., Mustonen, T., Neofotis, P., Oettlé, N., Rosenzweig, C., Sakakibara, C., Shadrin, V., Vicarelli, M., Waterhouse, J., Weeks, B., 2011. Linking indigenous and scientific knowledge of climate change. Bioscience. 61(6), 477–484 https://doi.org/10.1525/bio.2011.61.6.10 61.

Alexander, S.M., Provencher, J.F., Henri, D.A., Taylor, J.J., Lloren, J.I., Nanayakkara, L., Johnson, J.T., Cooke, S.J., 2019. Bridging Indigenous and science-based knowledge in coastal and marine research, monitoring, and management in Canada. Environ. Evid. 81(8), 1–24. https://doi.org/10.1186/S13750-019-0181-3

Andreassen, H.P., 2005. The effect of scent-marking, forest clearing, and supplemental feeding on moose-train collisions. J. Wildl. Manage. 69, 1125–1132. https://doi.org/10.2193/0022-541X

Andrews, K.M., Nanjappa, P., Riley, S.P.D., 2015. Roads and ecological infrastructure: Concepts and applications for small animals. Johns Hopkins University Press, Baltimore, Maryland.

Backs, J.A.J., Nychka, J.A., St. Clair, C.C., 2020. Warning systems triggered by trains increase flight-initiation times of wildlife. Transp. Res. Part D Transp. Environ. 87, 102502. https://doi.org/10.1016/j.trd.2020.102502

Barrientos, R., Ascensão, F., Beja, P., Pereira, H.M., Borda-de-Água, L., 2019. Railway ecology vs. road ecology: similarities and differences. Eur. J. Wildl. Res. https://doi.org/10.1007/s10344-018-1248-0

Bartlett, C., Marshall, M., Marshall, A., 2012. Two-Eyed Seeing and other lessons learned within a co-learning journey of bringing together indigenous and mainstream knowledges and ways of knowing. J. Environ. Stud. Sci. 2, 331–340. https://doi.org/10.1007/s13412-012-0086-8

Bartoszek, J., Greenwald, K.R., 2009. A population divided: railroad tracks as barriers to gene flow in an isolated population of marbled salamanders (*ambystoma opacum*). Herpetol. Conserv. Biol. 4, 191–197.

Battiste, M., Henderson, J.Y. (Sa'ke'j), 2000. Protecting Indigenous knowledge and heritage. Purich Publishing, Saskatoon, Saskatchewan.

Berkes, F., 2012. Sacred Ecology. Routledge, New York.

Bhattacharya, M., Primack, R.B., Gerwein, J., 2002. Are roads and railroads barriers to bumblebee movement in a temperate suburban conservation area? Biol. Conserv. 109, 37–45. https://doi.org/10.1016/S0006-3207(02)00130-1

Bladen, M.L., 1932. Construction of Railways in Canada to the Year 1885. Contrib. to Can. Econ. 5, 43. https://doi.org/10.2307/136530

Böhm, M., Collen, B., Baillie, J.E.M., 2013. The conservation status of the world's reptiles. Biol. Conserv. 157, 372–385. https://doi.org/10.1016/J.BIOCON.2012.07.015

Borda-de-Água, L., Ascensão, F., Sapage, M., Barrientos, R., Pereira, H.M., 2019. On the identification of mortality hotspots in linear infrastructures. Basic Appl. Ecol. 34, 25–35. https://doi.org/10.1016/j.baae.2018.11.001

Clair, C.C.S., Backs, J., Friesen, A., Gangadharan, A., Gilhooly, P., Murray, M., Pollock, S., 2019. Animal learning may contribute to both problems and solutions for wildlife–train collisions. Philos. Trans. R. Soc. B 374. https://doi.org/10.1098/RSTB.2018.0050

Clauzel, C., Girardet, X., Foltête, J.C., 2013. Impact assessment of a high-speed railway line on species distribution: Application to the European tree frog (Hyla arborea) in Franche-Comté. J. Environ. Manage. 127, 125–134. https://doi.org/10.1016/J.JENVMAN.2013.04.018

Cox, N., Young, B.E., Bowles, P., Fernandez, M., Marin, J., Rapacciuolo, G., Böhm, M., Brooks, T.M., Hedges, S.B., Hilton-Taylor, C., Hoffmann, M., Jenkins, R.K.B., Tognelli, M.F., Alexander, G.J., Allison, A., Ananjeva, N.B., Auliya, M., Avila, L.J., Chapple, D.G., Cisneros-Heredia, D.F., Cogger, H.G., Colli, G.R., de Silva, A., Eisemberg, C.C., Els, J., Fong G, A., Grant, T.D., Hitchmough, R.A., Iskandar, D.T., Kidera, N., Martins, M., Meiri, S., Mitchell, N.J., Molur, S., Nogueira, C. de C., Ortiz, J.C., Penner, J., Rhodin, A.G.J., Rivas, G.A., Rödel, M.O., Roll, U., Sanders, K.L., Santos-Barrera, G., Shea, G.M., Spawls, S., Stuart, B.L., Tolley, K.A., Trape, J.F., Vidal, M.A., Wagner, P., Wallace, B.P., Xie, Y., 2022. A global reptile assessment highlights shared conservation needs of tetrapods. Nat. 605, 285–290. https://doi.org/10.1038/s41586-022-04664-7

Dasgupta, S., Ghosh, A.K., 2015. Elephant–railway conflict in a biodiversity hotspot: determinants and perceptions of the conflict in northern West Bengal, India. Hum. Dimens. Wildl. 20, 81–94. https://doi.org/10.1080/10871209.2014.937017

Dorsey, B., Olsson, M., Rew, L.J., 2015. Ecological effects of railways on wildlife. Handb. Road Ecol. 219–227. https://doi.org/10.1002/9781118568170.ch26

Dulac, J., 2013. Global land transport infrastructure requirements: estimating road and railway infrastructure capacity and costs to 2050. Int. Energy Agency 1–54.

Fahrig, L., Rytwinski, T., 2009. Effects of roads on animal abundance: An empirical review and synthesis. Ecol. Soc. 14. https://doi.org/10.5751/ES-02815-140121

Forman, R.T.T., Alexander, L.E., 1998. Roads and their major ecological effects, Source: Annual Review of Ecology and Systematics.

Garrah, E., Danby, R.K., Eberhardt, E., Cunnington, G.M., Mitchell, S., 2015. Hot spots and hot times: Wildlife road mortality in a regional conservation corridor. Environ. Manage. 56, 874–889. https://doi.org/10.1007/s00267-015-0566-1

Gunson, K., Teixeira, F.Z., 2015. Road-wildlife mitigation planning can be improved by identifying the patterns and processes associated with wildlife-vehicle collisions, in: Handbook of Road Ecology. John Wiley & Sons, Ltd, pp. 101–109.

Heske, E.J., 2015. Blood on the tracks: Track mortality and scavenging rate in urban nature preserves. Urban Nat. 1–12.

Iosif, R., 2012. Railroad-associated mortality hot spots for a population of Romanian Hermann's Tortoise (*Testudo hermanni boettgeri*): a gravity model for railroad-segment analysis. Procedia Environ. Sci. 14, 123–131. https://doi.org/10.1016/j.proenv.2012.03.012

Ito, T.Y., Okada, A., Buuveibaatar, B., Lhagvasuren, B., Takatsuki, S., Tsunekawa, A., 2008. One-sided barrier impact of an international railroad on Mongolian gazelles. J. Wildl. Manage. 72, 940–943. https://doi.org/10.2193/2007-188

IUCN, 2020. The IUCN red list of threatened species v.2020-1. URL https://www.iucnredlist.org

Jerem, P., Mathews, F., 2021. Passing rail traffic reduces bat activity. Sci. Reports | 11, 20671. https://doi.org/10.1038/s41598-021-00101-3

Kornilev, Y. V, Price, S.J., Dorcas, M.E., 2006. Between a rock and a hard place: Responses of Eastern Box Turtles (*Terrapene carolina*) when trapped between railroad tracks, Herpetological Review.

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. Biodivers. Conserv. 21, 3017–3034. https://doi.org/10.1007/S10531-012-0352-9/FIGURES/4

Laurance, W.F., Clements, G.R., Sloan, S., O'Connell, C.S., Mueller, N.D., Goosem, M., Venter, O., Edwards, D.P., Phalan, B., Balmford, A., Van Der Ree, R., Arrea, I.B., 2014. A global strategy for road building. Nat. 2014 5137517 513, 229–232. https://doi.org/10.1038/nature13717

Lesbarrères, D., Ashpole, S.L., Bishop, C.A., Blouin-Demers, G., Brooks, R.J., Echaubard, P., Govindarajulu, P., Green, D.M., Hecnar, S.J., Herman, T., Houlahan, J., Litzgus, J.D., Mazerolle, M.J., Paszkowski, C.A., Rutherford, P., Schock, D.M., Storey, K.B., Lougheed, S.C., 2014. Conservation of herpetofauna in northern landscapes: Threats and challenges from a Canadian perspective. Biol. Conserv. 170, 48–55. https://doi.org/10.1016/j.biocon.2013.12.030

Matsuzawa, Y., 2018. 38th annual symposium on sea turtle biology & conservation – "Beyond protection of the sea turtle." Mar. Turt. Newsl. 154, 22–23.

McGregor, D., 2021. Indigenous Knowledge Systems in environmental governance in Canada. KULA Knowl. Creat. Dissemination, Preserv. Stud. 5, 1–10. https://doi.org/10.18357/kula.148

McGregor, D., 2004. Coming full circle: Indigenous Knowledge , environment, and our future. Am. Indian Q. 28, 385–410.

Ogar, E., Pecl, G., Mustonen, T., 2020. Science must embrace traditional and indigenous knowledge to solve our biodiversity crisis. One Earth 3, 162–165. https://doi.org/10.1016/J.ONEEAR.2020.07.006

Pelletier, S.K., Carlson, L., Nein, D., Roy, R.D., 2005. Railroad crossing structures for spotted turtles: Massachusetts Bay Transportation Authority – Greenbush rail line wildlife crossing demonstration project.

Platt, S., Measures, E., Rohr, D., Thu, K., Wint, Z., Tainwater, T., 2022. *Chelydra serpentina* (Snapping Turtle) and *Chrysemys picta* (Painted Turtle) nesting habitat. Herpetol. Rev. 53, 101–103.

Popp, J., Boyle, S., 2017. Railway ecology: Underrepresented in science? Basic Appl. Ecol. 19, 84–93. https://doi.org/10.1016/j.baae.2016.11.006

Rautsaw, R.M., Martin, S.A., Vincent, B.A., Lanctot, K., Rebecca Bolt, M., Seigel, R.A., Parkinson, C.L., 2018. Stopped dead in their tracks: The impact of railways on Gopher Tortoise (*Gopherus polyphemus*) movement and behavior. Copeia 106, 135–143. https://doi.org/10.1643/CE-17-635

Reid, A.J., Eckert, L.E., Lane, J.F., Young, N., Hinch, S.G., Darimont, C.T., Cooke, S.J., Ban, N.C., Marshall, A., 2021. “Two-Eyed Seeing”: An Indigenous framework to transform fisheries research and management. Fish Fish. 22, 243–261. https://doi.org/10.1111/FAF.12516

St. Martin, K., McCay, B.J., Murray, G.D., Johnson, T.R., Oles, B., 2007. Communities, knowledge and fisheries of the future. Int. J. Glob. Environ. Issues 7, 221–239. https://doi.org/10.1504/IJGENVI.2007.013575

Tremblay, M.A., St. Clair, C.C., 2009. Factors affecting the permeability of transportation and riparian corridors to the movements of songbirds in an urban landscape. J. Appl. Ecol. 46, 1314–1322. https://doi.org/10.1111/J.1365-2664.2009.01717.X

Van der Grift, E., 1999. Mammals and railroads: impacts and management implications. Lutra 42, 77–98.

Van Der Ree, R., Jaeger, J.A.G., Van Der Grift, E.A., Clevenger, A.P., 2011. Effects of roads and traffic on wildlife populations and landscape function: road ecology is moving toward larger scales. Ecol. Soc. 16(1), 48.

Waller, J., Servheen, C., 2005. Effects of transportation infrastructure on grizzly bears in northwestern montana. J. Wildl. Manage. 69, 985–1000. https://doi.org/10.2193/0022-541x(2005)069[0985:eotiog]2.0.co;2

Wong, C., Ballegooyen, K., Ignace, L., Johnson, M.J., Swanson, H., 2020. Towards reconciliation: 10 Calls to Action to natural scientists working in Canada. https://doi.org/10.1139/facets-2020-0005 5, 769–783. https://doi.org/10.1139/FACETS-2020-0005

Chapter 1: Indigenous Knowledge Informs Railway Ecology Research: Implications for Reptile and Amphibian Conservation

Abstract

Trains are known to cause mortalities of several animal species, but the ecological impacts of railways are understudied. Most research on wildlife-train collisions has focused on large mammals, but understanding railway-specific risks for underrepresented taxa, especially vulnerable species, is important for developing effective mitigation strategies. We aimed to fill knowledge gaps using a Two-Eyed Seeing approach that weaved Indigenous knowledge and Western science to investigate wildlife interactions with railways. This project was initiated in partnership with two First Nations communities based on their concerns about wildlife mortalities on railways, particularly for Species At Risk. To inform study design, community members were invited to share knowledge concerning wildlife-railway impacts in individual semi-structured interviews. Following conversations with the communities, weekly visual surveys were conducted over three field seasons along two 3.6 km sections of railway in Eastern Georgian Bay, Ontario, recording the locations of all wildlife observed alive or dead. In total we recorded 462 observations of individuals from 42 different species, of which 76% were found dead, and 24% were encountered alive; these findings complemented the shared Indigenous knowledge. Reptiles and amphibians were the most severely impacted taxa, accounting for 87% of observed mortalities. We observed seven different at-risk species interacting with the railway, including four at-risk turtle species and one at-risk snake species which were found dead on the tracks. Ultimately, this study highlights the value of collaborative research that embraces complementary knowledge systems and indicates that reptiles and amphibians may be particularly susceptible to railway mortality.

Key words: Indigenous knowledge, railway ecology, wildlife, reptiles, amphibians, trains

1.0 Introduction

Railways are a common form of transportation infrastructure across our landscape, and their global foot print is expected to increase in the future (Dulac, 2013). Although railway ecology has received less attention than road ecology in the scientific literature (Popp and Boyle, 2017), wildlife are known to interact with railways, and train collisions have been documented for many taxa including mammals, birds, reptiles, and amphibians (Dasgupta and Ghosh, 2015; Dornas et al., 2019; Gilhooly et al., 2019; Heske, 2015; Iosif, 2012; Rautsaw et al., 2018; van der Grift, 1999). However, most research has focused on large mammals, leaving the full extent of railway impacts on other taxonomic groups poorly understood (Popp and Boyle, 2017; Santos et al., 2017). The underrepresentation of other wildlife in railway ecology may have implications for conservation efforts if those understudied taxa are particularly susceptible to negative railway effects, on top of other unmitigated threats. For example, reptiles and amphibians are highly vulnerable to the effects of roads, which have contributed to substantial population declines (Cunnington et al., 2014; Gibbs and Shriver, 2002; Lesbarrères et al., 2014). If railways also negatively impact reptiles and amphibians, understanding the magnitude of mortalities and the factors that contribute to them could be essential to managing these sensitive populations.

Ecological research can benefit from methods that embrace multiple knowledge systems to investigate complex issues, and the value and success of these inclusive techniques have been well demonstrated (Bartlett et al., 2012; Reid et al., 2021; St. Martin et al., 2007). In its broadest sense, and for the purpose of this paper, Indigenous knowledge (IK) can be defined as the knowledge accumulated by Indigenous Peoples, passed down through generations, and is often associated with the environment and ecological systems based on a close connection to the land (Battiste and Henderson, 2000; Berkes, 2012). However, it is important to note that IK cannot be separated from knowledge holders or the environment, and for many Indigenous Peoples, IK cannot be limited to a single definition, but instead a way of being (Battiste and Henderson, 2000; McGregor, 2021, 2004; Reid et al., 2021). Western science (WS) tends to simplify complex ecosystems in order to understand them, whereas Indigenous knowledges instead often examine environments and ecological interactions more holistically (Beckford et al., 2010; Grenz, 2020; Kimmerer, 2000; Mcgregor, 2014; Peloquin and Berkes, 2009). While several frameworks to support knowledge co-existence in applied research exist (Reid et al., 2021), we pair IK and WS through a concept conceived by Mi'kmaw Elder Albert Marshall, known as Two-Eyed Seeing (Bartlett et al., 2012). Two-Eyed Seeing refers to a method of drawing on the strengths of two knowledge systems in parallel, considering both knowledges equally to produce a more holistic understanding (Bartlett et al., 2012; Reid et al., 2021). Both IK and WS have great value in helping investigate complex and applied ecological issues, so adopting an inclusive research frame work, such as Two-eyed Seeing, can allow researchers to take an approach that weaves knowledge systems responsibly and respectfully (Bartlett et al., 2012).

The aim of our study was to investigate the impacts of railways on wildlife using an exploratory method that weaved IK and WS and considered all wildlife species within the study area. IK that was shared through interviews with First Nation community members identified concerns regarding railway impacts on local wildlife, common observations of wildlife-railway use and mortality, and helped identify knowledge gaps that exist in the field of railway ecology. Our second objective, guided by the knowledge that was shared, was to use an exploratory study to quantify wildlife-railway use and resulting mortality by conducting weekly walking surveys of the railway paired with the deployment of motion-triggered cameras which was guided by the outcome of community discussions. We also tested the persistence of train-killed wildlife to inform our survey results, as weekly surveys were likely to underestimate counts as carcasses are removed by scavengers. Our final objective was to examine temporal variation for frequently killed taxa so we could better understand which variables have the greatest influence on mortality counts, to inform our understanding of railway ecology in general, but also so we could make informed suggestions on when to target railway surveys to maximize detection of susceptible wildlife. We expected that railway-related mortality would impact a wide variety of animals, but that the frequency of observed mortalities would not be equal among taxa. We predicted that the taxa most frequently killed on the railway would be those that have movement ecologies that lead to more frequent interactions with the railway, and those that may be more susceptible to railway specific impacts, such as turtles, whose limited mobility puts them at risk of not only being struck and killed by trains, but also becoming trapped between the parallel tracks (Helms and Stains, 1966; Kornilev et al., 2006).

2.0 Methods

2.1 Interviews

We interviewed community members from Magnetawan First Nation (MFN) and Shawanaga First Nation (SFN) to document local knowledge, perspectives, concerns, and common observations about the interactions of railways and local wildlife populations. We used a semi-structured interview approach where participants were interviewed individually using a pre-determined list of questions, but conversations were allowed to develop and flow naturally between questions. Pre-determined interview questions focused on observations of railway interactions with wildlife, observations of live wildlife on the railway, observations and locations of suspected train-related wildlife mortality, and accounts of personal use of the railway within the community (Table 1.1).

Interview participants were recruited by advertising at each community and inviting any interested adult at the respective First Nation to participate. Additionally, an honorarium of $100 was provided as an incentive to interview participants, and we followed community protocol by offering tobacco ties. It was made clear to participants prior to starting interviews that they were free to skip questions or end the interview at any time but that they would still receive the honorarium. We did not attempt to sample from community members with specific railway experience (e.g. only community members who regularly walk the railway); instead, all interview participants who agreed to participate in the study were considered equal knowledge holders, and all railway-related responses were evaluated equally. We conducted interviews with community members between June and October of 2019 (Ethics approvals: Laurentian University #6013806 and Mount Allison University #102249). All participants provided written permission through standardized consent forms for their interviews to be recorded and agreed that the knowledge they provided could be analyzed and distributed to inform our study and to improve our understanding of railway ecology.

Validating the results of our IK study with both communities was a top priority for our project, a step that is integral in conducting collaborative research in a good way with First Nations communities (Wong et al., 2020). To facilitate feedback from community remembers, reports were created and distributed to each community (Vincent and Popp, 2020a, 2020b). Further, community members were invited to attend virtual results sharing presentations in January 2021. Both methods of results sharing/validation were accompanied by forms on which feedback was encouraged to ensure the research accurately represented the perspectives shared during the knowledge gathering sessions.

2.2 Study Area

The railway study was conducted over 3 years at two sites located approximately 30 km apart on the Traditional Territories of: 1) Shawanaga First Nation (SFN), Ontario, Canada and 2) Magnetawan First Nation (MFN), Ontario, Canada. Both communities are located along the eastern coast of Georgian Bay and are bisected by the same single-track railway operated by Canadian Pacific Railway (CPR) but used by both CPR and Canadian National Railway (CNR). The railway runs through the area in an approximately north – south direction in parallel to the nearby Ontario Highway 69. Train traffic on this section of railway is usually northbound, using a separate railway system operated by CNR outside of the study area to return south.

The survey areas at both study sites consisted of a 3.6 km section of the railway bisecting each community (Figure 1.1). The study site at SFN extends 3.6 km northwest from Shawanaga Road North, while the study site at MFN extends 3.6 km south from Ontario Highway 529. Both study sites are located within the Great Lakes-St. Lawrence Forest region and consist of a variety of terrain and habitat types including a mix of forests, wetlands, and rock barrens typical of this area along the Georgian Bay coast (Morningstar et al., 2021a, 2021b).

2.3 Rail Surveys

Wildlife-railway use and resulting mortality were investigated using walking surveys at both study sites. Our goal was to survey each site weekly, but survey frequency varied slightly among years depending on CPR flagger availability, shutdowns due to COVID-19, and three separate train derailments that occurred at our study sites (Table 1.3). Surveys were typically conducted by 2 -3 observers at each site over the course of three field seasons (2019: May – October, 2020: June – October, 2021: April – October). Because the railway we surveyed is actively used, survey days and start times depended on the availability of CPR staff and train traffic; however, when possible, we started surveys at the same time and on the same day each week (Table 1.3).

For walking surveys, two observers walked on opposite sides of the railway tracks and scanned for live or deceased wildlife found anywhere within the center rail or right-of-way (Figure 1.1). Survey start and end times, and weather conditions (cloud cover, precipitation, etc.) were recorded for every survey. We also recorded the air temperature, railbed temperature, and railway tie temperature at the beginning, middle, and end of each survey. Air temperature was measured with a probe thermometer (accuracy ± 1°C), while railbed and tie temperature were measured with a digital infrared thermometer (Avantek TG-3Y, accuracy ± 2°C).

Live and dead wildlife encountered during surveys were identified to species and referenced with a GPS unit (Garmin GPSMAP 62s) to record the location of the observation (accuracy ±3 m). The identified species, time of observation, relative location on the railway (center tracks, east or west side of right-of-way), elevation, suspected cause of mortality when found dead (e.g. train collision, heat stress), and behaviour of live individuals (e.g. attempting to cross tracks, basking etc.) were also recorded. When live animals were encountered, air, railbed, and railway tie temperature at their location on the tracks were also recorded. Turtles are inventoried as part of on-going conservation programs implemented by both MFN and SFN, thus, when turtles were encountered, individuals were sexed, measured, photographed, and marked with a unique notch code (Cagle, 1939). Live turtles encountered during surveys were released in wetlands in the direction they were moving prior to processing; if direction of travel was not obvious, they were released in the next closest suitable habitat.

2.4 Carcass Persistence

We conducted carcass persistence trials on the railway because removal by scavengers and decomposition can lead to overly conservative mortality estimates. We tested carcass removal rates in 2020 and 2021 by opportunistically leaving fresh un-scavenged carcasses, collected during walking surveys, in front of trail cameras. We used trail cameras for these experiments because we could not access the railway to monitor carcass persistence daily, and this method also allowed us to document scavenger species. Carcasses were placed near the ends of railway ties so they would be visible to the cameras. We defined carcass removal as the date and time on a trail camera photo when the carcass was removed by a scavenger, or on the next photo where the carcass was no longer visible (because scavengers were not always captured by the camera).

2.5 Camera Traps

From June 2020 to October 2021, 7 trail cameras (Bushnell Aggressor 14mp Low Glow) were installed along both 3.6 km sections of railway in MFN and SFN to capture wildlife activity and the frequency of trains. Cameras were installed on trees adjacent to the railway at each site at ~500 m intervals to minimize autocorrelated capture events. Several sections of the railway pass through expansive wetlands and rock barrens that lacked trees suitable for camera placement. In those situations, cameras were installed on the next closest useable tree while keeping distance to subsequent cameras in mind.

Cameras were always set to face the railway at a height that allowed them to capture both large and small animals (~ 1 – 2 m off the ground, depending on distance to the railway), covering the full spectrum of wildlife we might encounter in the study area. Cameras were randomly assigned to either the east or west side of the railway to avoid sampling bias, although with a wide field-of-view and limited visual obstructions on the railway, wildlife on either side of the tracks triggered the cameras.

Cameras were set to capture a burst of 3 images when motion was detected, followed by a pause of 3 minutes where no photos would be taken to prevent an excess number of train photos, while also preserving battery life and minimizing recaptures of the same individual animals over a short period of time. Memory cards were replaced every 1 – 2 weeks during the field season. Batteries were also checked every 2 weeks during the field season and changed as necessary, usually every 2 – 4 months. Memory cards and batteries were checked and replaced every 2 – 3 months during the winter to ensure cameras had sufficient memory and battery power to run continuously.

2.6 Data Analysis

The audio recordings of interviews were transcribed using GoTranscript services (https://gotranscript.com/, Middlesex, UK), and Trint software (https://trint.com/, London, UK). Interview data were examined separately for each First Nation, but results were pooled between communities when common themes were identified. When unique community concerns/perspectives were identified, we explicitly attributed those results to the respective community. Transcripts were manually reviewed using the qualitative data analysis software program, Nvivo (version 1.4.1). When interview questions were open-ended, we identified common and reoccurring themes, and coded them with thematic keywords. Additionally, closed-ended questions were categorized based on participant responses (yes, no, or unsure), or by the relative number of mentions from interviews (Table 1.1). We also used direct quotes from interviews where appropriate to avoid generalizing or misrepresenting shared knowledge. Direct quotes were attributed to specific community members if they consented to have their name shared. Quotes from participants who wished to remain anonymous were not named but were instead attributed as a "Community Member" from their respective First Nation.

To understand which taxa were reported to interact with the railway most often, we examined mentions of live and dead observations of species from each taxon and calculated the relative proportion of interviews with mentions from each group.

Counts of live and dead wildlife observed during surveys were grouped into seven taxonomic groups (amphibians, turtles, squamates, birds, large mammals, medium mammals, and small mammals) for analysis due to low sample size at the species level. Species included in subgroups generally share ecologies and therefore likely interact with railways in similar ways. Counts per taxa were pooled between study sites and among years to provide an overall summary of total mortalities and live observations for each taxon. The relative proportion of mortalities and live observations attributed to each taxon were also summarized for comparison. To provide a conservative estimate of mortalities per kilometer per year for each taxon, summed mortality counts were also divided by the total distance surveyed and averaged across all three years.

Trail camera photos were processed using Timelapse Image Analyzer (version 2.2.5.1) software (https://saul.cpsc.ucalgary.ca/timelapse/, Calgary, CA). All images were manually reviewed, and any wildlife-railway interactions were identified and tabulated. To minimize temporal autocorrelation and reduce the chance of resampling the same individuals, photos of the same species recorded within one hour by the same camera, and photos containing more than one individual of the same species were considered a single capture event (Bowkett et al., 2008; Popp and Hamr, 2018). The number of capture events per taxon were pooled among cameras and sites to provide an overall summary of railway interaction frequency for each group. Proportions of capture events for the most frequently documented species were also calculated.

All data analyses from visual surveys were conducted using the program R (R Core Team, 2021). Assessment of survey data using Shapiro tests and qq-plots on residuals revealed that our response variable was right skewed, and thus, not normally distributed. We used Kruskal-Wallis non-parametric tests to determine if counts per survey were significantly different among taxonomic groups across all three years. We further examined significant differences in counts per survey using Dunn post-hoc tests for pairwise comparisons between groups.

We used generalized linear models (GLM) to explore the influence of temporal variables on railway-wildlife mortality (Zuur et al., 2009). Due to small sample size, we only assessed temporal variation for amphibians, and turtles, and only used data from 2020 and 2021 because those years were surveyed most consistently throughout the active season (Table 1.3), and railbed temperature and total precipitation data were not available for 2019. The effect of five independent variables, year (2020, 2021), community (SFN, MFN), mean railbed temperature*,* total precipitation the day before a survey, and Julian date were included in our full model of mean mortality counts per survey (2020; $n = 29$ surveys, 2021; $n = 45$ surveys). Precipitation values were not normally distributed when examined with Shapiro tests, so log-transformations were attempted. Log-transforming total precipitation didn’t normalize the data, but did improve the fit, so log transformed values were used for further analysis. We tested for collinearity between predictors using Spearman tests and found that no predictors were correlated, therefore we used all variables in our model selection process. As our count data were zero-inflated and over dispersed, we used a negative binomial distribution to model amphibian mortality, and a

Poisson distribution to model turtle mortality (Zuur et al., 2009). Model fit was tested by building our most complicated model for each taxon, then examining residuals. Akaike's Information Criterion correction (AICc) selection was used to evaluate models using a backwards step selection (Burnham and Anderson, 2002). Models with the lowest AICc score were retained as the best models to explain variance in the mortality count data for each taxonomic group.

Because a large proportion of turtle mortalities were putatively caused by heat stress, we further examined their relationship to railbed temperature using a logistic regression. We transformed our 2020 and 2021 count data to a binary response so we could model the relationship of railbed temperature on survey days when we found turtle mortalities versus days when no dead turtles were found. Using a logistic regression model and associated odds ratio, and 95% confidence intervals, we calculated the probability of observing a turtle railway-mortality for each degree increase in railbed temperature.

We used a non-parametric product-limit survival analysis (Kaplan-Meier curve) to calculate the maximum carcass persistence time per taxon, and to provide an estimate of persistence probability between our surveys using the survival package (Therneau, 2022). Although we tested carcass persistence of all turtles, amphibians, squamates, and mammals, due to small sample size, we only produced Kaplan-Meier survival curves for amphibians (*n* = 19) and turtles (*n* = 8).

3.0 Results

3.1 Interview Results: Community Use

A total of 32 community members (SFN *n* = 17; MFN *n* = 15) participated in the IK study and shared knowledge and perspectives on the railway and its relationship to their communities and wildlife (Table 1.2). All but one community member from MFN indicated they either currently use or have used the railway for land access to their traditional territories in the past (Table 1.2). Many community members from both First Nations mentioned beneficial uses of the railway, including walking for recreation, access for harvesting berries and medicinal plants, and access to hunting and fishing grounds. Community members from SFN emphasized that the railway provided easy access to the river for harvesting Walleye (*ogaa*; *Sander vitreum*).

Although community members generally indicated the railway improved land access, several also mentioned negative impacts. Participants from both First Nations shared that the railway contaminates medicines that grow along the tracks and reduces access to certain areas due to the increased danger of walking along or crossing the railway. One community member from MFN also mentioned that excessive sound from passing trains interferes with hunting practices.

3.2 Interview Results: Wildlife Use

Most community members we interviewed indicated they had observed wildlife both alive and dead on the railway; although, mentions of live wildlife were more common in both communities (Table 1.2). A wide variety of animals from various taxonomic groups (large mammals, medium mammals, small mammals, turtles, squamates, amphibians, and birds) were reported in wildlife-railway observations by participants.

Large mammals were reported in the greatest proportion of interviews and included observations of Wolves and Coyotes (*ma'iingan*; *Canid spp*), White-tailed Deer (*waawaashkeshi*; *Odocoileus viriginianus*), Moose (*mooz*; *Alces alces*), and American black bear (*makwa*; *Ursus americanus*). Turtles were the next most common taxon discussed in interviews at SFN and were tied with medium mammals as the next most mentioned taxon at MFN (Figure

1.2). Participants mentioned observations of two species of turtle; Blanding's Turtle (*Emydoidea blandingii*), and Midland Painted Turtle (*miskwaadesi; Chrysemys picta).* Mentions of medium mammals focused on observations of beaver (*amik; Castor canadensis*), porcupine (*gaag; Erethizon dorsatum*), and raccoon (*esiban; Procyon lotor*).

3.3 Interview Results: Impact to Wildlife

All community members that we interviewed suggested railways have a negative impact on wildlife (Table 1.2). The negative impacts mentioned by interview participants focused on mortality from collisions with trains, mortality from entrapment between the rails (turtles and other small wildlife), habitat fragmentation, and noise disturbance from train activity.

> *We've put railways which compromise their paths and all the migration [...] It compromises the life of all animals.* – Community Member, Shawanaga First Nation

While all participants mentioned that railways negatively impact wildlife, some also shared that the railway may positively impact some species by offering a movement corridor; suggesting the railway facilitates easier movement, allowing wildlife to conserve energy while crossing challenging terrain. However, interview participants also noted a negative trade-off: wildlife using the railway as a movement corridor puts them at risk of collisions with trains.

> *They [railways] impact wildlife positively and negatively. For one, they'll let them travel far distances without having to use a lot of energy [...] So, giving them easier access to move great distances, but also negatively, wildlife will get hit by trains.* – Community Member, Shawanaga First Nation

3.4 Interview Results: Wildlife Mortality

Most community members reported observing deceased wildlife on the railway, although the proportion of participants who answered "yes" to this question was higher at SFN than at MFN (Table 1.3). A wide variety of wildlife were observed dead on the railway by community members including White-tailed Deer, Moose, Coyote, domestic dogs, American Black Bear, Porcupine, Raccoon, Muskrat (*wazhashk; Ondrata zibethicus*), rodents (*Rodentia spp.*), groundhog (*Marmota monax*), bald eagle (*migizi; Haliaeetus leucocephalus*), snakes, frogs, and turtles.

> *You see a lot of Blanding's turtles, you see snakes over there, you see the odd bear, you see deer sometimes, you see lots of dogs down there that get hit, raccoons, there's a lot of animals to get hit on the tracks.* – Jerry Smith, Magnetawan First Nation

Although train collisions were the most common cause of mortality reported by community members for most taxa, this was not the case for turtles. Several community members had observed turtles stuck between the rails of the railway, where they presumably died from heat-stress or subsequently being struck by trains. Turtle railway mortalities were emphasized by both communities, but this was most evident at SFN where turtles were mentioned in 60% of interviews.

> *When I go down river, walk down the tracks, I see all kinds of dead turtles on the tracks. In between rails they used to get stuck in there… They can't get up and they get trapped between two rails and run over by trains.* -Vern Pawiss, Shawanaga First Nation

3.5 Quantifying Wildlife-Railway Use and Mortality

Including both live and dead individuals, we documented 462 wildlife observations on the railway encompassing at least 42 different species over the course of the study. In total, we conducted 97 surveys covering a combined distance of 349.2 km of railway (Table 1.3). Most individuals we encountered were found dead, making up 76 % of observations across all taxa, while live encounters only accounted for 24 % of observations. We documented a wide variety of wildlife on the railway (Appendix B), but reptiles and amphibians accounted for the majority of observations and made up 87 % of observed mortalities (Figure 1.3). Mean wildlife observation counts per survey (live and dead) were significantly different among taxonomic groups ($\chi^2_7 = 171.53$, $p < 0.001$).

Amphibians, comprised of eight different species, were the taxonomic group encountered most frequently in surveys (Figure 1.3). Variation in amphibian observations was also the highest among taxa, ranging from 0 to 50 individuals in a single survey (Figure 1.5), with a mean count of 3.02 ± 0.63 total observations per survey across all years, which was significantly higher than all other groups ($p < 0.001$). Apart from one live terrestrial eft stage of the Eastern Newt (*Notophthalmus viridescens*) observed walking along the railway, all amphibian observations were frogs and toads. Green frogs (*omagakii; Lithobates clamitans*) were the most frequently encountered wildlife overall and made up 48 % of all amphibian mortalities. Amphibian mortality counts were highest in April ($\bar{X} = 13.0 \pm 12.34$ per survey (mean ± SE)), were at their lowest in May ($\bar{X} = 0.60 \pm 0.30$ per survey), and then generally increased towards the end of the active season (Figure 1.6). The high count mean and associated SE in April can be attributed to one particularly deadly survey where we counted 50 frog mortalities (Spring Peepers (*Pseudacris crucifer*) 44; Green Frogs 3; Wood Frog (*Lithobates sylvaticus*) 2; and

Northern Leopard Frog (*gidagimakakii; Lithobates pipiens*) 1), averaging to 14 frogs/km and a count two-fold greater than the next highest survey, when examining all three years of data.

We documented three different species of turtles along the railway including Blanding's Turtle, Midland Painted Turtle, and Snapping Turtle (*mikinaak; Chelydra serpentina*). Observations of turtles during surveys ranged from 0 to 4 individuals/survey ($\bar{X} = 0.67 \pm 0.12$), and average count values were not significantly different from those of squamates ($p = 1.00$) but were different from all other groups ($p < 0.001$; Figure 1.5). Counts of turtle mortalities peaked in June ($\bar{X} = 1.0 \pm 0.41$/survey) and tapered off towards the end of September (Figure 1.6). We did not observe any turtle mortalities in April or October over the course of the study, though we did encounter live turtles on the railway in October.

Although overall counts of squamates were not significantly different than those of turtles, a much lower proportion of squamate observations were mortalities (22 % for squamates vs. 45 % for turtles; Figure 1.3). Counts of squamates ranged from 0 to 5 individuals/ survey ($\bar{X} = 0.47 \pm 0.08$). All squamate mortalities ($n = 10$) were snakes from six different species (Appendix B). Snake mortality was highest in August but was generally similar among months (Figure 1.6).

Counts of birds per survey were generally low compared to amphibians, turtles, and squamates, but were not significantly different from mean counts of mammal observations ($\bar{X} = 0.16 \pm 0.04$; Figure 1.5). Bird mortalities were detected in all months surveyed; however, no obvious peaks or decreases in observations were seen throughout the season (Figure 1.6). One notable bird mortality was a Turkey Vulture (*wiinaange; Cathartes aura*) that putatively died after being hit by a train while feeding on the carcass of a train-killed moose.

Mammal observations (large, medium, and small) were lowest among all taxa, and count values were not significantly different among mammal subgroups or from bird counts (Figure 1.5). Moose were the mammal most frequently killed by trains, with 4 observations of moose kills from 2019 – 2021. Other notable mammal railway mortalities include a Black Bear and two Red Foxes; all individuals showed signs of collisions with trains.

We encountered 8 different at-risk species (4 turtles, 3 snakes, 1 lizard) currently listed under the federal Species at Risk Act (SARA) interacting with the railway (Table 1.6). Railway mortalities were documented for four of those species (7 Blanding's Turtles, 8 Snapping Turtles, 12 Midland Painted Turtles, and 1 Eastern Massasauga (*zhiishiigwe; Sistrurus catenatus*).

3.6 Camera Traps

In total, we recorded 4,328 capture events of at least 43 different species among all cameras and sites (Appendix C). Mammals made up the vast majority of all wildlife-railway interactions documented by camera traps. Large mammals comprised of Wolves, Black Bears, White-tailed Deer, Moose, and domestic dogs, were the subgroup most frequently documented on the railway (Figure 1.4). Wolves made up the majority of those observations, accounting for 34 % of all capture events. Medium mammals were documented second most often, but Red Foxes were the only medium mammal species to use the railway regularly (34 % of all capture events). Bird observations were also diverse, with corvids being the most frequent avian railway users, captured in 6 % of all images (Table 1.7). Sandhill Cranes (*ajijaak; Antigone canadensis*) and Turkey Vultures were also frequently documented interacting with the railway. Images of herpetofauna were rare, with only 4 amphibian and 4 turtle captures respectively. However, turtle observations were relatively diverse, as the 4 individuals were from three different species (Midland Painted Turtle, Snapping Turtle, and Blanding's Turtle).

3.7 Carcass Persistence Models

The maximum carcass persistence time based on our trials was 6 days for amphibians (*n* = 19) and 14 + days for turtles (*n* = 8; Figure 1.11). After only one day, the probability of an amphibian carcass persisting on the railway was 68 ± 11 %. After two days, amphibian carcass persistence probability dropped to 30 ± 11 %. For turtles, the one-day carcass persistence probability was 62 ± 17 % but had high variation. After one day, the probability of a turtle carcass persisting on the railway was substantially higher than that of frogs, especially when the possible probabilities of persistence at the upper end of the 95 % confidence interval are considered (Figure 1.11). Scavenger species were missed in all but one trial for amphibians, where a chipmunk (*agongos; Tamias sp.*) removed a Green Frog carcass in less than 48 hours. Turtle scavengers were documented in all but one instance and consisted of aerial scavengers (corvids and turkey vultures) and humans.

It should be noted that although 7 of the 8 turtle carcasses were removed from camera view, meeting our criteria for 'removal', 4 of their carcasses were retrieved post trial after a search of the deployment area. However, the carcasses that were retrieved were often found outside the right-of-way and may not have been detected in subsequent surveys. The turtle carcass that persisted the longest (an adult Midland Painted Turtle) was heavily scavenged after one week. As bony tissue was all that remained the following week, the carcass persistence trial was ended at 14 days.

Although we did not have a large enough sample size to produce survival curves for squamates, we did test 4 snake carcasses for persistence (2 Eastern Gartersnakes, 1 Smooth Greensnake, 1 Northern Watersnake). All but one individual was removed from camera view within the first day. The carcass of the Smooth Greensnake persisted for 7 days before being scavenged by a raccoon. All other snake carcasses were removed by aerial scavengers (corvids and turkey vultures).

3.8 Influence of Temporal Variables on Amphibian and Turtle Mortalities

The influence of temporal variables on amphibian and turtle mortalities were assessed using GLMs and AICc model selection. The preferred model for counts of amphibian mortalities during surveys explained 15 % of the deviance and included two significant predictors: the fixed effects of precipitation the day before a survey and survey year (Table 1.5). Counts of turtle mortalities were best explained by a top candidate model that explained 23 % of the deviance and included two significant predictors: the fixed effects of railbed temperature and survey site.

3.9 Turtle Mortality

Turtles were the only taxonomic group that showed strong evidence of mortalities not solely caused by collisions with trains. In fact, most turtle mortalities we documented died putatively from heat stress after becoming trapped between the rails of the railway (Figure 1.7). The three individuals that we suspect died from train collisions were all adult Snapping Turtles, and all showed clear physical trauma, such as fractured carapaces and severe lacerations. In contrast, the turtles that we suspect died of heat stress showed no signs of physical trauma, were usually desiccated, and were often found with all limbs extended from the body; a sign of heat stress related death in freshwater turtles (Hutchison et al., 1966; Figure 1.8). Logistic regression showed a significant positive relationship between the probability of observing a turtle mortality and railbed temperature ($Z = 2.331$, $p = 0.020$). We found that for every degree increase in railbed temperature, the odds ratio of observing a turtle mortality increases by a constant factor of 9 % (95 % CI: 1.4 % - 17.5 %; Figure 1.10).

4.0 Discussion

Indigenous Knowledge (IK) informed our study by identifying community concerns and common observations of wildlife-railway interactions. Interviews with community members revealed that most participants described railways as negatively impacting wildlife, that a wide variety of animals use the railway but also die from collisions with trains, and that some taxa, like turtles, may be more susceptible to railway-mortalities. Visual surveys complemented community perspectives, as we found at least 42 different species along the railway, and 76 % of those observations were mortalities. Most wildlife-railway deaths were amphibians and reptiles which comprised 87 % of all observed mortalities. Although these data are concerning, our weekly counts likely underestimate railway mortality, as tested amphibian and turtle carcasses had low probabilities of persistence over the course of a week, the average time between our surveys at each site. The occurrence of frog mortalities was most influenced by precipitation and survey year, while turtle mortalities varied most as a function of railbed temperature and survey site. Our results highlight the value of weaving knowledge systems in the context of ecological research, suggest already vulnerable amphibian and reptile populations may be particularly susceptible to railway impacts, and reinforce the importance of conducting surveys frequently and across seasons to capture the full magnitude of railway effects on wildlife.

4.1 Community Concerns and Observations

The results of the IK study provided evidence that diverse wildlife from multiple taxa regularly interact with railways, leading to mortality caused by train collisions and railway entrapment, highlighting the concern among community members that initiated this research. One of the benefits of weaving IK and WS in ecology research is that knowledge holders often have a strong connection to and understanding of the land gained over time (Battiste and

Henderson, 2000; Berkes, 2012; McGregor, 2004). This was evident in our study, as all but one community member shared that they use or have used the railway on their traditional territory for access to things like foods, medicines, and walking for recreation. Weaving IK and WS allowed us to consider community knowledge and observations about the railway developed over time that we may not have captured over the course of the 3-year study, giving us a more holistic understanding of wildlife-railway interactions. For example, there was clear consensus by participants from both communities that railways negatively impact wildlife; with most interviews focusing on observations of large mammals and turtles. Railway impacts to large mammals have received some attention in the literature (Gilhooly et al., 2019; St. Clair et al., 2020), but turtle-railway interactions are not as well understood (Popp and Boyle, 2017; Rautsaw et al., 2018). Several community members reported that turtles die by rail entrapment and heat stress rather than collisions with trains, a phenomena consistent with findings in WS (Kornilev et al., 2006; Rautsaw et al., 2018), and also the leading suspected cause of turtle mortality from our walking surveys. IK identified a novel cause of mortality for freshwater turtles, entrapment in creosote tar leached from a railway tie (Vincent et al., 2022), previously unreported in the scientific literature but described by a community member from SFN in interviews. Using multiple knowledge systems improves ecology research (Priadka et al., 2022; Tengö et al., 2014), and our study highlights the value of weaving IK and WS in the context of railway ecology.

4.2 Railway Surveys

Walking surveys at SFN and MFN reflected the concerns of community members, as we identified at least 42 different species, with 76 % of observations being dead wildlife. As reported by community members, we documented wildlife-railway interactions that resulted in mortalities caused by train collisions and entrapment between the rails. As predicted, counts of wildlife-railway observations differed among taxa with amphibians being the most observed group, followed by turtles and squamates, then birds and mammals. The dominance of amphibian observations in surveys is consistent with many road ecology studies (Ashley and Robinson, 1996; Boyle et al., 2021; Garrah et al., 2015). Reptiles and amphibians, which contributed the majority of mortality counts (87 %), appeared to show peaks throughout the season consistent with taxa specific ecologies noted in other studies, such as a peak around nesting season for turtles (Garrah et al., 2015), and peaks in early spring and late summer that correspond to mass movement and dispersal between habitats for amphibians (Ashley and Robinson, 1996; Glista et al., 2008).

Although turtle-railway mortalities have been documented (Helms and Stains, 1966; Kornilev et al., 2006; Rautsaw et al., 2018), few studies have included the scope of quantifying railway kills over multiple years. In one notable study, Heske (2015) surveyed over 12 km of railway biweekly over two years in Chicago and only observed only 26 turtles, 12 % of which were dead. For comparison, we documented 66 turtles over three years on a smaller stretch of railway, and 45 % were found dead. It is concerning that the proportion of turtles found dead was substantially higher in our study, suggesting that rates of mortality for turtles can be variable, but more railway studies that consider mortalities at a community level are needed to further investigate this trend.

4.3 Camera Traps

Like the railway surveys, camera trap results complemented the knowledge shared by First Nation community members, as we captured a wide variety of wildlife interacting with the railway, primarily using it as a travel corridor but also crossing the tracks between habitats.

Interestingly, many of the 43 species documented by trail cameras were seldom documented during railway surveys (Appendix C); this was particularly true for all three size classes of mammals, as well as birds. Red foxes and wolves walked the railway with high regularity, accounting for a combined 68 % of all wildlife capture events. This result is consistent with the findings of Popp and Hamr (2018), who also found that wolves and red foxes were the most frequent railway users captured by trail cameras in the Eastern Georgian Bay area.

Although we did find evidence of red fox mortalities during railway surveys ($n = 2$), they were rare, and we did not find any wolf mortalities over the course of our study. The relatively high documented railway interactions in relation to low observed railway mortality rates suggest canids use railways as movement corridors and likely face lower mortality risk than other taxonomic groups. However, the low mortality of canids detected in our study may have been influenced by the length of our railway transects or differences in habitat, as railway mortalities of canids and other carnivores have been documented in studies that examine longer stretches of railway, over longer periods of study (Gilhooly et al., 2019; St. Clair et al., 2020). Future research should focus on canid-railway interactions and how these linear features may positively or negatively affect movement and population dynamics.

Our camera trap results also stress the importance of using different survey methods to detect diverse wildlife communities in railway ecology research. Camera traps were successful at documenting the occurrence of species from all taxonomic groups of interest; however, detection rates of amphibians and reptiles were extremely low. This can likely be attributed to the passive infrared sensor used in trail cameras, which are limited in their ability to detect the movement of ectotherms (Meek et al., 2014). The implication is that if our methods had only considered camera trapping, we would not have accurately captured the magnitude of herpetofauna-railway interactions. Similarly, only using visual railway surveys would have underrepresented the diversity of wildlife using the railway, particularly for groups like canids and ungulates that are not killed as often by trains. Overall, camera trapping was more effective at capturing evidence of mammal-railway interactions, while foot surveys were better at capturing herpetofauna-railway interactions.

4.4 Carcass Persistence

Our carcass persistence trials revealed that amphibian and reptile carcasses are scavenged quickly from the railway, with low probabilities of persistence within the time between our surveys (1 week). This trend was most apparent for frog and toad carcasses, none of which lasted more than 6 days; in fact, 26 % of the individuals we tested disappeared within the first 24 hrs. This finding is consistent with the results of other studies in which amphibians were often scavenged faster than other taxa from roads (Barrientos et al., 2018; Teixeira et al., 2013), and railways (Heske, 2015). Interestingly, we only documented one frog carcass scavenger, leaving the sources of removal for the remaining carcasses unknown. Aerial scavengers have been suggested as possible culprits for unphotographed carcass removals of rattlesnakes from roads (Winton et al., 2018), which may also be the case for our study. Frog and toad carcasses also decomposed quickly and were often found highly desiccated with signs of invertebrate scavenging (Vincent pers. obvs.), suggesting amphibian carcasses may breakdown before they can be removed by scavengers.

We did not expect turtle carcasses to be removed from the railway as quickly as we observed, with 25 % of tested carcasses disappearing from camera view within 24 hrs. However, this finding is consistent with the carcass persistence of turtles on roads tested by Santos et al., (2011), where probability of persistence after one day was 82 %. The turtle carcass that persisted longer than 2 weeks in our study was highly scavenged, leaving only bony tissue, with the carapace and plastron being most obvious. Based on our results, we suggest that turtles scavenged in situ may persist for long periods of time, but scavengers can and do remove entire carcasses, introducing sampling bias. The low carcass persistence we estimated suggests that our counts per survey should be considered as a conservative minimum estimate of railway mortality, and that future studies should target daily surveys to adequately document the influences of scavengers and decomposition on detected mortality rates.

4.5 Influence of Temporal Variables on Railway Mortality

The results of our GLMs for amphibians and turtles both showed significant influence of temporal variables on mortality counts in years 2020 and 2021. Amphibian mortality was related to total precipitation the day before a survey, a relationship suggested in other road and railway ecology studies (Garrah et al., 2015; Heske, 2015), and survey year. The influence of year can be attributed to the substantially higher count of amphibians in 2021 (Table 1.4). Unfortunately, because our surveys did not span the entire active season in 2020, it is not possible to estimate how much of the difference might be attributed to natural variation year to year, or whether the difference was simply a function of missing early spring anuran movements in 2020.

Turtle mortality counts were most influenced by railbed temperature and survey site. The variation attributed to survey site is likely due to the overall higher counts of turtles encountered during surveys at MFN; however, the reason for that difference is not totally clear. Possible explanations for this difference include potential variation in baseline turtle populations between sites, or perhaps differences in habitat and other spatial variables which may influence the likelihood of a turtle interacting with the railway (Chapter 2). The finding that railbed temperature has an influence on turtle mortality aligns with both IK shared by community members in interviews, and suggestions from previous studies that turtles trapped in railbeds have great difficulty escaping over the rails, and can quickly succumb to heat stress (Kornilev et al., 2006; Rautsaw et al., 2018). Further examination of the relationship between railbed temperature and turtle mortality using logistic regression confirmed this trend. The probability of observing a turtle mortality increased significantly as railbed temperature increased. It should be noted that although models for amphibians and reptiles were significant, they explained relatively low variation in mortality counts (15 % and 23 % respectively).

Amphibians and reptiles appear to be disproportionately affected by railways, resulting in high mortality counts throughout the year. As these taxonomic groups are already some of the most threatened globally (Böhm et al., 2013; Lesbarrères et al., 2014), additional pressure from railways may exacerbate existing population declines. This is particularly true for turtles, as their life history strategies cannot support the loss of many adult turtles from a population, in fact even annual morality as low as 2 – 3 % can lead to population declines in the long term (Congdon et al., 1993; Gibbs and Shriver, 2002). Although our railway survey results help to fill important knowledge gaps about wildlife-railway interactions and impacts for taxa previously under-represented in the railway ecology literature, they also reinforce the need for more railway-focused studies that survey at shorter intervals, ideally once per day to minimize the effect of carcass removal, and that cover the entire active season for target wildlife.

5.0 Conclusion

This railway ecology research only occurred because our First Nation community partners initiated the study based on their concerns and observations of wildlife-railway interactions. As a result of discussions with MFN and SFN knowledge holders that informed our study, we were able to document wildlife-railway interactions and resulting mortalities over three years along two 3.6 km sections of railway on the eastern coast of Georgian Bay, Ontario, Canada. Previous railway ecology studies in the area have focused primarily on large and medium mammals (Hamr et al., 2022; Popp et al., 2018; Popp and Hamr, 2018); ours is the first study to take a wildlife community level approach that includes taxa underrepresented in railway ecology literature. Although we found that a wide variety of wildlife interact with the railway, amphibians and reptiles were the most common railway mortalities at our study sites (87 %), which may have long-term negative impacts on these taxa, as populations of herpetofauna in the area are already facing population declines from threats like road mortality and habitat loss. To our knowledge, ours is also the first railway ecology study to weave Indigenous knowledge and western science to gain a more holistic understanding of wildlife-railway interactions. One of our goals was also to normalize collaborative approaches that use complementary knowledge systems; not only improving scientific research but also uplifting and supporting Indigenous voices while working towards reconciliation. We suggest that more research would benefit from working respectfully and reciprocally with First Nations to answer ecological questions prioritized by those communities.

References

Ashley, E.P., Robinson, J.T., 1996. Road mortality on the Long Point causeway. Can. Field-Nat. 110, 403–412.

Barrientos, R., Martins, R.C., Ascensão, F., D'Amico, M., Moreira, F., Borda-de-Água, L., 2018. A review of searcher efficiency and carcass persistence in infrastructure-driven mortality assessment studies. Biol. Conserv. 222, 146–153. https://doi.org/10.1016/j.biocon.2018.04.014

Bartlett, C., Marshall, M., Marshall, A., 2012. Two-Eyed Seeing and other lessons learned within a co-learning journey of bringing together Indigenous and mainstream knowledges and ways of knowing. J. Environ. Stud. Sci. 2, 331–340. https://doi.org/10.1007/s13412-012-0086-8

Battiste, M., Henderson, J.Y. (Sa'ke'j), 2000. Protecting Indigenous knowledge and heritage. Purich Publishing, Saskatoon, Saskatchewan.

Beckford, C., Jacobs, C., Williams, N., Nahdee, R., 2010. Aboriginal environmental wisdom, stewardship, and sustainability: Lessons from the Walpole Island First Nations, Ontario, Canada. J. Environ. Educ. 41, 239–248. https://doi.org/10.1080/00958961003676314

Berkes, F., 2012. Sacred Ecology. Routledge, New York.

Böhm, M., Collen, B., Baillie, J.E.M., 2013. The conservation status of the world's reptiles. Biol. Conserv. 157, 372–385. https://doi.org/10.1016/J.BIOCON.2012.07.015

Bowkett, A.E., Rovero, F., Marshall, A.R., 2008. The use of camera-trap data to model habitat use by antelope species in the Udzungwa Mountain forests, Tanzania. Afr. J. Ecol. 46, 479–487. https://doi.org/10.1111/j.1365-2028.2007.00881.x

Boyle, S.P., Keevil, M.G., Litzgus, J.D., Tyerman, D., Lesbarrères, D., 2021. Road-effect mitigation promotes connectivity and reduces mortality at the population-level. Biol. Conserv. 261, 109230. https://doi.org/10.1016/J.BIOCON.2021.109230

Burnham, K.P., Anderson, D.R., 2002. Model Selection and Multimodel Inference: A Practical Information-theoretic Approach, Second. Ed. Springer Verlag, New York.

Cagle, F.R., 1939. A system of marking turtles for future identification. Copeia 1939, 170–173.

Congdon, J. D., A. E. Dunham, and R. C. van Loben Sels., 1993. Delayed sexual maturity and demographics of Blanding's turtles (*Emydoidea blandingii*): implications for conservation and management of long-lived organisms. Conserv. Biol. 7, 826-833

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

Dasgupta, S., Ghosh, A.K., 2015. Elephant–railway conflict in a biodiversity hotspot: determinants and perceptions of the conflict in northern West Bengal, India. Hum. Dimens. Wildl. 20, 81–94. https://doi.org/10.1080/10871209.2014.937017

Dornas, R.A.P., Teixeira, F.Z., Gonsioroski, G., Nóbrega, R.A.A., 2019. Strain by the train: Patterns of toad fatalities on a Brazilian Amazonian railroad. Sci. Total Environ. 660, 493–500. https://doi.org/10.1016/j.scitotenv.2018.12.371

Dulac, J., 2013. Global land transport infrastructure requirements: Estimating road and railway infrastructure capacity and costs to 2050. Int. Energy Agency 1–54.

Garrah, E., Danby, R.K., Eberhardt, E., Cunnington, G.M., Mitchell, S., 2015. Hot spots and hot times: Wildlife road mortality in a regional conservation corridor. Environ. Manage. 56, 874–889. https://doi.org/10.1007/s00267-015-0566-1

Gibbs, J.P., Shriver, W.G., 2002. Estimating the effects of road mortality on turtle populations. Conserv. Biol. 16, 1647–1652.

Gilhooly, P.S., Nielsen, S.E., Whittington, J., St. Clair, C.C., 2019. Wildlife mortality on roads and railways following highway mitigation. Ecosphere 10. https://doi.org/10.1002/ECS2.2597

Glista, D.J., Devault, T.L., Dewoody, J.A., 2008. Vertebrate road mortality predominantly impacts amphibians. Herpetol. Conserv. Biol. 3, 77–87.

Grenz, J. B. (2020) Healing the land by reclaiming an Indigenous ecology: a journey exploring the application of the Indigenous worldview to invasion biology and ecology (Doctoral dissertation, University of British Columbia).

Hamr, J., Lieske, D.J., Martin, M., Nickel, C.B., Popp, J.N., 2022. The efficacy of highway wildlife collision mitigation in preventing elk mortality in central Ontario. J. Wildl. Manage. 86, e22184. https://doi.org/10.1002/JWMG.22184

Helms, D., Stains, H., 1966. Kill of mammals and birds and entrapment of turtles on railroad tracks. Trans. Illinois Acad. Sci. 59, 297.

Heske, E.J., 2015. Blood on the tracks: Track mortality and scavenging rate in urban nature preserves. Urban Nat. 1–12.

Hutchison, V.H., Vinegar, A., Kosh, R.J., 1966. Critical thermal maxima in turtles. Herpetologica. 22, 32–41.

Iosif, R., 2012. Railroad-associated mortality hot spots for a population of Romanian Hermann's Tortoise (*Testudo hermanni boettgeri*): a gravity model for railroad-segment analysis. Procedia Environ. Sci. 14, 123–131. https://doi.org/10.1016/j.proenv.2012.03.012

Kimmerer, R.W., 2000. Native knowledge for native ecosytems. J. For. 98, 4–9.

Kornilev, Y. V, Price, S.J., Dorcas, M.E., 2006. Between a rock and a hard place: Responses of Eastern Box Turtles (*Terrapene carolina*) when trapped between railroad tracks, Herpetol. Rev. 37(2), 145-148.

Lesbarrères, D., Ashpole, S.L., Bishop, C.A., Blouin-Demers, G., Brooks, R.J., Echaubard, P., Govindarajulu, P., Green, D.M., Hecnar, S.J., Herman, T., Houlahan, J., Litzgus, J.D., Mazerolle, M.J., Paszkowski, C.A., Rutherford, P., Schock, D.M., Storey, K.B., Lougheed, S.C., 2014. Conservation of herpetofauna in northern landscapes: Threats and challenges from a Canadian perspective. Biol. Conserv. 170, 48–55. https://doi.org/10.1016/j.biocon.2013.12.030

McGregor, D., 2014. Lessons for collaboration involving Traditional Knowledge and environmental governance in Ontario, Canada. Alternative 10, 340–353.

McGregor, D., 2021. Indigenous Knowledge Systems in environmental governance in Canada. KULA Knowl. Creat. Dissemination, Preserv. Stud. 5, 1–10. https://doi.org/10.18357/kula.148

McGregor, D., 2004. Coming full circle : Indigenous Knowledge , environment, and our future. Am. Indian Q. 28, 385–410.

Meek, P.D., Ballard, G., Claridge, A., Kays, R., Moseby, K., O'Brien, T., O'Connell, A., Sanderson, J., Swann, D.E., Tobler, M., Townsend, S., 2014. Recommended guiding principles for reporting on camera trapping research. Biodivers. Conserv. 23, 2321–2343. https://doi.org/10.1007/S10531-014-0712-8

Morningstar, D., Agnew, C., Catcher, L., Chung, K., 2021a. Summary report: Desktop ecological land classification for Magnetawan First Nation. Cambridge, Ontario. Unpublished report.

Morningstar, D., Agnew, C., Chung, K., Catcher, L., 2021b. Summary report: Desktop ecological land classification for Shawanaga First Nation. Cambridge, Ontario. Unpublished report.

Peloquin, C., Berkes, F., 2009. Local knowledge, subsistence harvests, and social-ecological complexity in James Bay. Hum. Ecol. 37, 533–545. https://doi.org/10.1007/s10745-009-9255-0

Popp, J., Boyle, S., 2017. Railway ecology: Underrepresented in science? Basic Appl. Ecol. 19, 84–93. https://doi.org/10.1016/j.baae.2016.11.006

Popp, J., Hamr, J., 2018. Seasonal use of railways by wildlife. Divers. Spec. Issue Impacts Linear Infrastructures Wildl. 10. https://doi.org/10.3390/d10040104

Popp, J., Hamr, J., Chan, C., Mallory, F.F., 2018. Elk (*Cervus elaphus*) railway mortality in Ontario. Can. J. Zool. 96, 1066–1070. https://doi.org/10.1139/cjz-2017-0255

Priadka, P., Moses, B., Kozmik, C., Kell, S., Popp, J.N., 2022. Impacts of harvested species declines on Indigenous Peoples' food sovereignty, well-being and ways of life: a case study of Anishinaabe perspectives and moose. Ecol. Soc. Publ. online Mar 07, 2022 | doi10.5751/ES-12995-270130 27, art30. https://doi.org/10.5751/ES-12995-270130

R Core Team, 2021. R: A language and environment for statistical computing. R foundation for statistical computing. Vienna, Austria. URL: https://www.r-project.org/.

Rautsaw, Rhett M., Martin, S.A., Vincent, B.A., Lanctot, K., Rebecca Bolt, M., Seigel, R.A., Parkinson, C.L., 2018. Stopped dead in their tracks: The impact of railways on gopher tortoise (*Gopherus polyphemus*) movement and behavior. Copeia 106, 135–143. https://doi.org/10.1643/CE-17-635

Reid, A.J., Eckert, L.E., Lane, J.F., Young, N., Hinch, S.G., Darimont, C.T., Cooke, S.J., Ban, N.C., Marshall, A., 2021. "Two-Eyed Seeing": An Indigenous framework to transform fisheries research and management. Fish Fish. 22, 243–261. https://doi.org/10.1111/FAF.12516

Santos, S., Carvalho, F., Mira, A., 2017. Current knowledge on wildlife mortality in railways, in: Borda-de-Água, L., Barrientos, R., Baja, P., Pereira, H. (Eds.), Railway Ecology. Springer, Cham, Switzerland, pp. 11–22.

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, 1–12. https://doi.org/10.1371/JOURNAL.PONE.0025383

St. Clair, C.C., Whittington, J., Forshner, A., Gangadharan, A., Laskin, D.N., 2020. Railway mortality for several mammal species increases with train speed, proximity to water, and track curvature. Sci. Rep. 10, 1–13. https://doi.org/10.1038/s41598-020-77321-6

St. Martin, K., McCay, B.J., Murray, G.D., Johnson, T.R., Oles, B., 2007. Communities, knowledge and fisheries of the future. Int. J. Glob. Environ. Issues 7, 221–239. https://doi.org/10.1504/IJGENVI.2007.013575

Teixeira, F.Z., Coelho, A.V.P., Esperandio, I.B., Kindel, A., 2013. Vertebrate road mortality estimates: Effects of sampling methods and carcass removal. Biol. Conserv. 157, 317–323. https://doi.org/10.1016/J.BIOCON.2012.09.006

Tengö, M., Brondizio, E.S., Elmqvist, T., Malmer, P., Spierenburg, M., 2014. Connecting diverse knowledge systems for enhanced ecosystem governance: The multiple evidence base approach. Ambio 43, 579–591. https://doi.org/10.1007/S13280-014-0501-3/FIGURES/2

Therneau, T., 2022. A package for survival analysis in R. URL: https://cran.r-project.org/package=survival.

Van der Grift, E., 1999. Mammals and railroads: impacts and management implications. Lutra 42, 77–98.

Vincent, K. D., Popp, J. N., 2020a. Railway ecology and impacts to wildlife: An Indigenous knowledge study with Magnetawan First Nation. Unpublished report.

Vincent, K. D., Popp, J. N., 2020b. Railway ecology and impacts to wildlife: An Indigenous knowledge study with Shawanaga First Nation. Unpublished report.

Vincent, K. D., J. N. Popp, S. J. Kell, A. Belleau, J. D. Litzgus. 2022. *Chrysemys picta marginata* (Midland Painted Turtle) novel railway mortality. Herpetol. Rev. 53(2): 308-309.

Winton, S.A., Taylor, R., Bishop, C.A., Larsen, K.W., 2018. Estimating actual versus detected road mortality rates for a northern viper. Glob. Ecol. Conserv. 16, e00476. https://doi.org/10.1016/j.gecco.2018.e00476

Wong, C., Ballegooyen, K., Ignace, L., Johnson, M.J., Swanson, H., 2020. Towards reconciliation: 10 calls to action to natural scientists working in Canada. https://doi.org/10.1139/facets-2020-0005 5, 769–783. https://doi.org/10.1139/FACETS-2020-0005

Zuur, A., Ieno, E., Walker, N., Saveliev, A., Smith, G., 2009. Mixed effects models and extensions in ecology with R. Springer Science+Business, New York.

Tables and Figures

Table 1.1. Interview questions and hierarchy of how responses were categorized and coded using Nvivo based on common themes and observations from semi-structured individual interviews with community members from Shawanaga First Nation (SFN) and Magnetawan First Nation (MFN). Mentions of species in interviews were grouped by taxon to categorize wildlife based on similar ecologies (large mammals, medium mammals, small mammals, turtles, snakes, amphibians, and birds).

Results	Interview Questions	Categories/Themes
1. Community Use	1. a) Do you use the railway for access to the land? 1. b) Do you find railways increase or restrict your ability to access certain locations for cultural purposes such as harvest sites and medicines? How?	1. a) Yes, no; categorized by common land-use activities 1. a) Increase, restrict, neutral
2. Wildlife Use	2. a) Have you observed any animals using the railway as a possible movement corridor?	2. a) Yes, no; relative number of mentions categorized by taxa
3. Impact to Wildlife	3. a) Do you think railways impact wolves or other wildlife?	3.a) Yes, no, unsure
4. Wildlife Mortality	4. a) Have you seen any deceased animals along the railway?	4. a) Yes, no; relative number of mentions categorized by taxa

Table 1.2. Number of community members from Shawanaga First Nation (SFN) and Magnetawan First Nation (MFN) that participated in the Indigenous Knowledge (IK) study focused on wildlife railway impacts, and yes or no responses (proportions) to interview questions ([1]Do you use the railway for land access?; [2]Do you think railways negatively impact wildlife?; [3]Have you observed any animals using the railway as a movement corridor?; [4]Have you seen any deceased animals along the railway?)

Community	Participants	Use Railway[1]		Impact Wildlife[2]		Observed Live Wildlife[3]		Observed Dead Wildlife[4]	
		Yes	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**
SFN	*n* = 17	17 (100%)	0	17 (100%)	0	16 (94%)	1 (6%)	14 (82%)	3 (18%)
MFN	*n* = 15	14 (93%)	1 (7%)	15 (100%)	0	12 (80%)	3 (20%)	9 (60%)	6 (40%)

Table 1.3. Survey start time range, date range, number of surveys, total distance travelled, and mean survey time (h = hours, m = minutes) for visual walking railway surveys at Shawanaga First Nation (SFN) and Magnetawan First Nation (MFN), ON, Canada over 3 years (2019, 2020, 2021).

Site	Survey start time ranges (24h)			Dates			Number of surveys			Total distance surveyed (km)			Mean time per survey ± SE		
	2019	2020	2021	2019	2020	2021	2019	2020	2021	2019	2020	2021	2019	2020	2021
MFN	9:30-15:20	8:45-12:21	9:00-11:06	05/21-08/06	06/30-10/26	04/13-10/13	10	15	22	36	54	79.2	1h 41m ± 13m	1h 59m ± 8m	2h 9m ± 9m
SFN	9:30-14:20	8:12-13:23	10:35-13:02	06/17-08/08	06/29-10/26	04/12-10/12	13	14	23	46.8	50.4	82.8	1h 49m ± 6m	1h 24m ± 8m	2h ± 5m

Table 1.4. Total number of wildlife mortalities (*n*) observed during walking surveys of railways at Shawanaga First Nation (SFN) and Magnetawan First Nation (MFN) in 2019, 2020, and 2021. Counts of mortalities were grouped by taxon, summed between sites, and divided by the total distance surveyed that year (kills/km/survey).

	2019		2020		2021	
	May – August		June – October		April – October	
Taxon	*n*	kills/km/survey	*n*	kills/km/survey	*n*	kills/km/survey
Amphibians	18	0.22	59	0.57	190	1.17
Turtles	14	0.16	7	0.07	8	0.05
Squamates	0	0.00	2	0.02	8	0.05
Birds	4	0.05	2	0.02	6	0.04
Large Mammals	4	0.05	3	0.03	0	0.00
Medium Mammals	1	0.01	1	0.01	3	0.02
Small Mammals	3	0.04	3	0.03	5	0.03

Table 1.5. Summary results of generalized linear modelling that tested the effect of six independent variables, mean railbed temperature (*Railbed Temp*), *Site*, log-transformed total precipitation the day before a survey (*Precip*), Julian date (*Date)*, and *Year* on railway-mortality counts of amphibians and turtles. Data used for modelling were collected during surveys at Shawanaga First Nation (SFN) and Magnetawan First Nation (MFN) in 2020 and 2021.

Models	AICc	ΔAICc	Variance	Predictors and Confidence Intervals (CI)
Amphibian Mortality ~ **Precip** + **Year**	333.68	0	0.15	**Precip:** 0.439 (0.154 – 0.744), **Year**: 0.993 (0.314 – 1.667)
Amphibian Mortality ~ **Precip** + **Year** + Railbed Temp	335.07	1.39	0.16	
Amphibian Mortality ~ **Precip** + **Year** + Site + Railbed Temp	336.68	1.61	0.16	
Amphibian Mortality ~ **Precip** + **Year** + Site + Railbed Temp + Date	338.6	1.92	0.16	
Turtle Mortality ~ **Railbed Temp** + **Site**	88.7	0	0.23	**Railbed Temp**: 0.030 (0.043 – 0.162), **Site**: -1.586 (-2.805 - -0.522)
Turtle Mortality ~ **Railbed Temp** + **Site** + Date	90.46	1.76	0.24	
Turtle Mortality ~ **Railbed Temp** + **Site** + Year + Date	92.43	1.97	0.24	
Turtle Mortality ~ **Railbed Temp** + **Site** + Year + Date + Precip	94.43	2	0.24	

*Variance explained by each model was calculated: 1 – (Residual deviance/Null deviance).

Table 1.6. Number (proportion) of species encountered during visual railway surveys (2019 – 2021) at Shawanaga First Nation (SFN) and Magnetawan First Nation (MFN) that are federally listed as at-risk under the Species at Risk Act (SARA). Species observations are ordered based on SARA status.

Common name	Scientific name	SARA status	Live	Mortalities
Blanding’s Turtle	*Emydoidea blandingii*	Threatened	11 (61%)	7 (39%)
Eastern Massasauga	*Sistrurus catenatus*	Threatened	6 (88%)	1 (14%)
Eastern Hog-nosed Snake	*Heterodon platirhinos*	Threatened	2 (100%)	0 (0%)
Snapping Turtle	*Chelydra serpentina*	Special concern	6 (43%)	8 (57%)
Five-lined Skink	*Plestiodon fasciatus*	Special concern	8 (100%)	0 (0%)
Midland Painted Turtle	*Chrysemys picta*	Special concern	17 (59%)	12 (41%)
Eastern Ribbonsnake	*Thamnophis sauritus*	Special concern	1 (100%)	0 (0%)

Table 1.7. Proportion (%) of capture events for the ten species most frequently documented interacting with the railway at Shawanaga First Nation (SFN) and Magnetawan First Nation (MFN) from June 2020 – October 2021. Capture events were recorded passively by trail cameras (*n* = 14) installed along the railway at ~500 m intervals in both First Nation communities. Species presented account for 94.4 % of total capture events.

Common name	Scientific name	Proportion of capture events
Red fox	*Vulpes vulpes*	34.1 %
Canid sp.	*Canid spp.*	33.9 %
Black bear	*Ursus americanus*	6.7 %
Corvids	*Corvus spp.*	5.6 %
Raccoon	*Procyon lotor*	4.2 %
White-tailed deer	*Odocoileus virginianus*	3.8 %
Red squirrel	*Tamiasciurus hudsonicus*	3.5 %
Sandhill Crane	*Antigone canadensis*	1.1 %
Moose	*Alces alces*	1 %
Turkey vulture	*Cathartes aura*	0.5 %

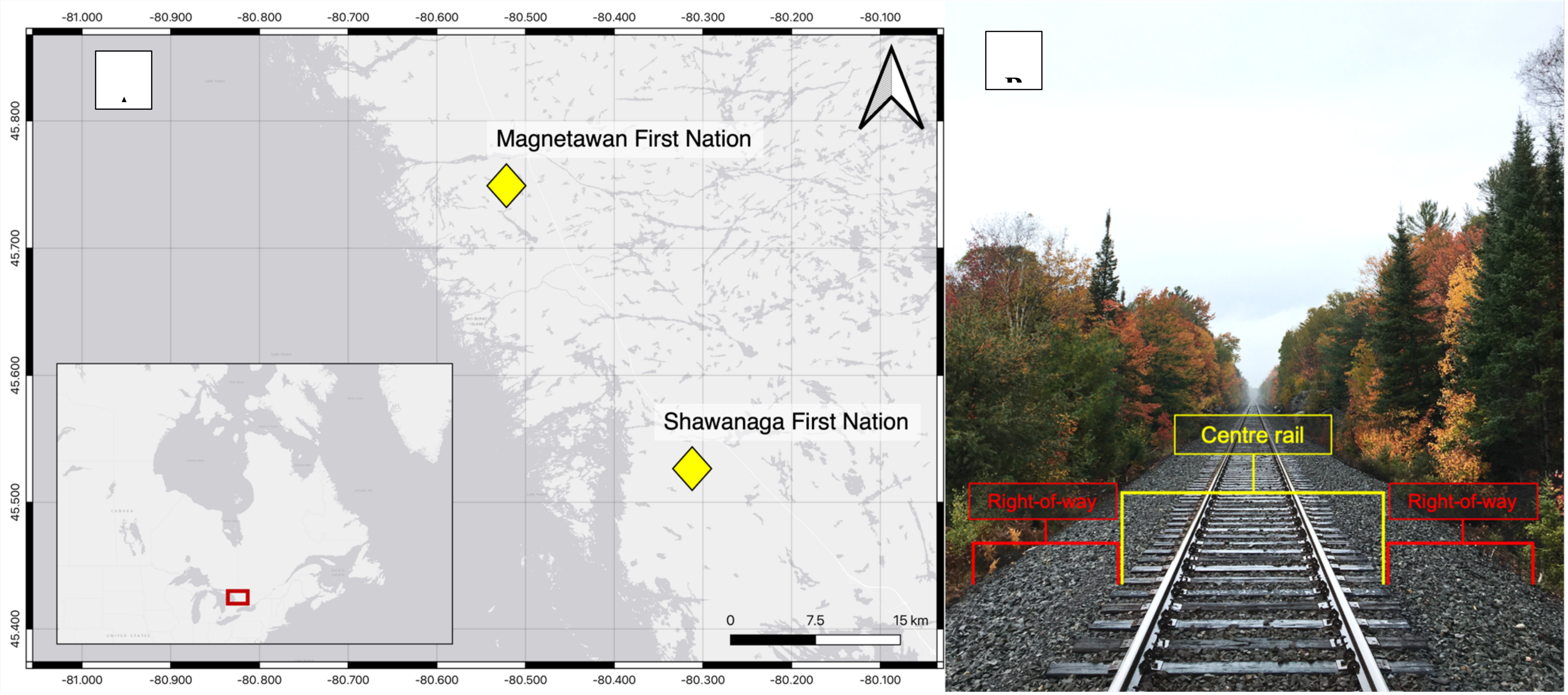

Figure 1.1. (A, left) Study area and associated study sites at Shawanaga First Nation (SFN) and Magnetawan First Nation (MFN), ON, Canada, where railway surveys were conducted during the field seasons of 2019 – 2021. Surveyed railway segments at each study site measured 3.6 km in length. (B, right) Example of the surveyed sections of single-track railway surveyed at each site including the centre rails and right-of-way.

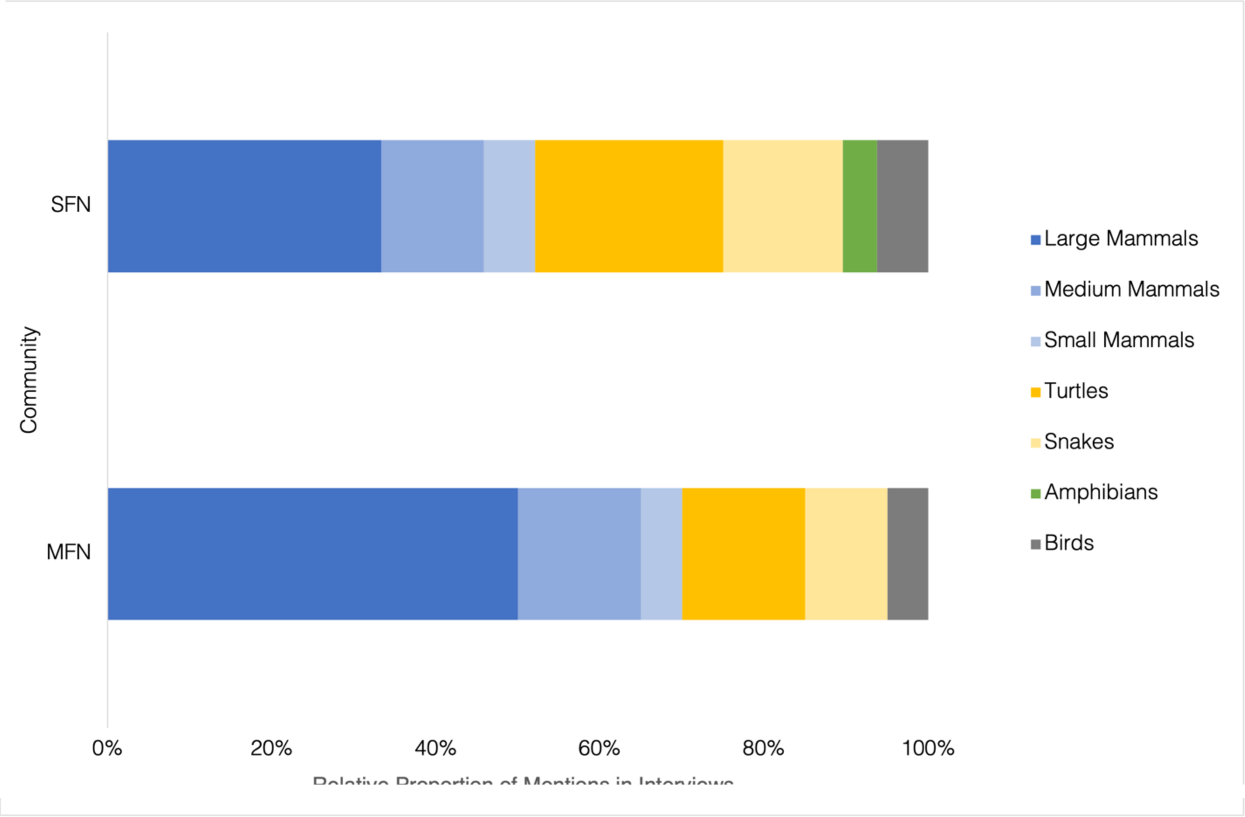

Figure 1.2. Relative proportion of mentions of wildlife from various taxa seen both alive and dead on the railway by participants of the Indigenous Knowledge study conducted with Shawanaga First Nation (SFN) and Magnetawan First Nation (MFN) in 2019.

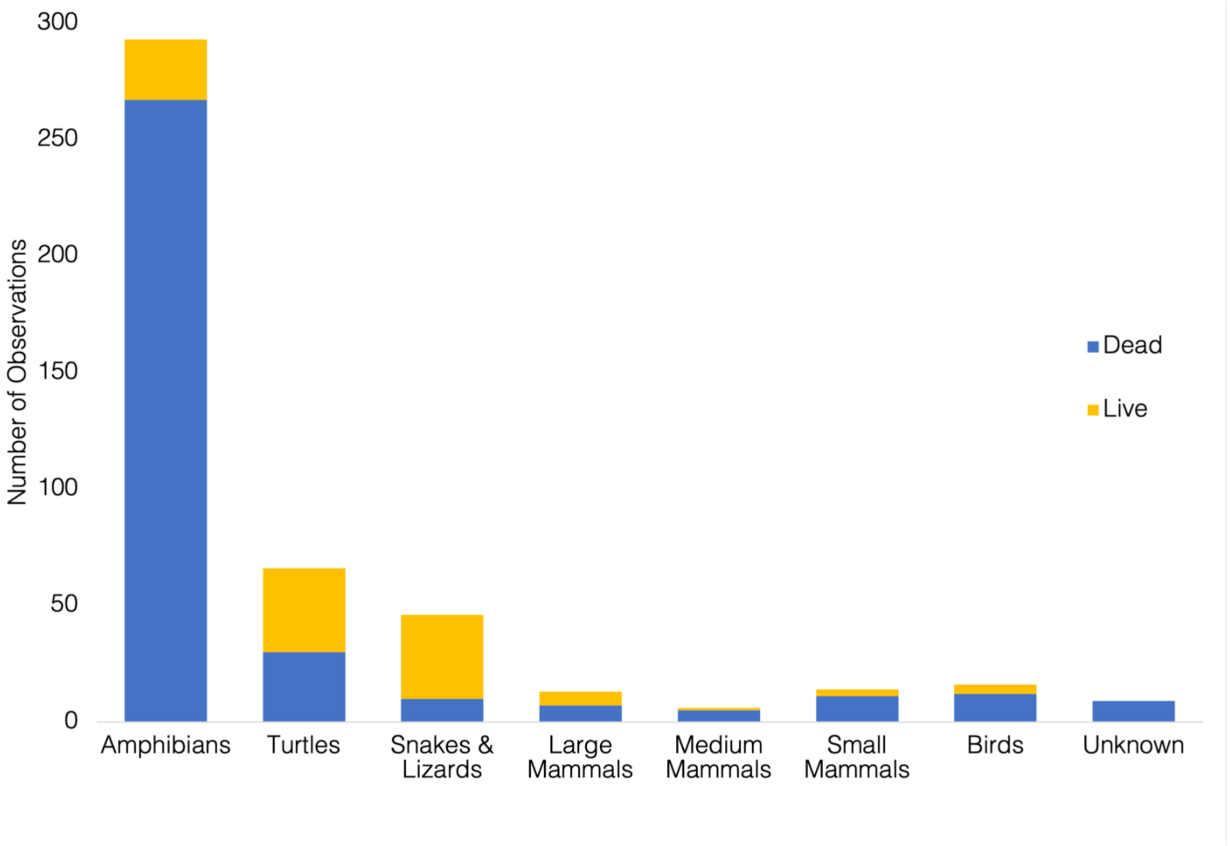

Figure 1.3. Total observations of live and dead wildlife from various taxa documented during weekly walking railway surveys at Shawanaga First Nation (SFN) and Magnetawan First Nation (MFN). One section of railway measuring 3.6 km in length was surveyed in each community by two observers. Counts of observed wildlife are pooled between survey sites and across three years (2019 – 2021).

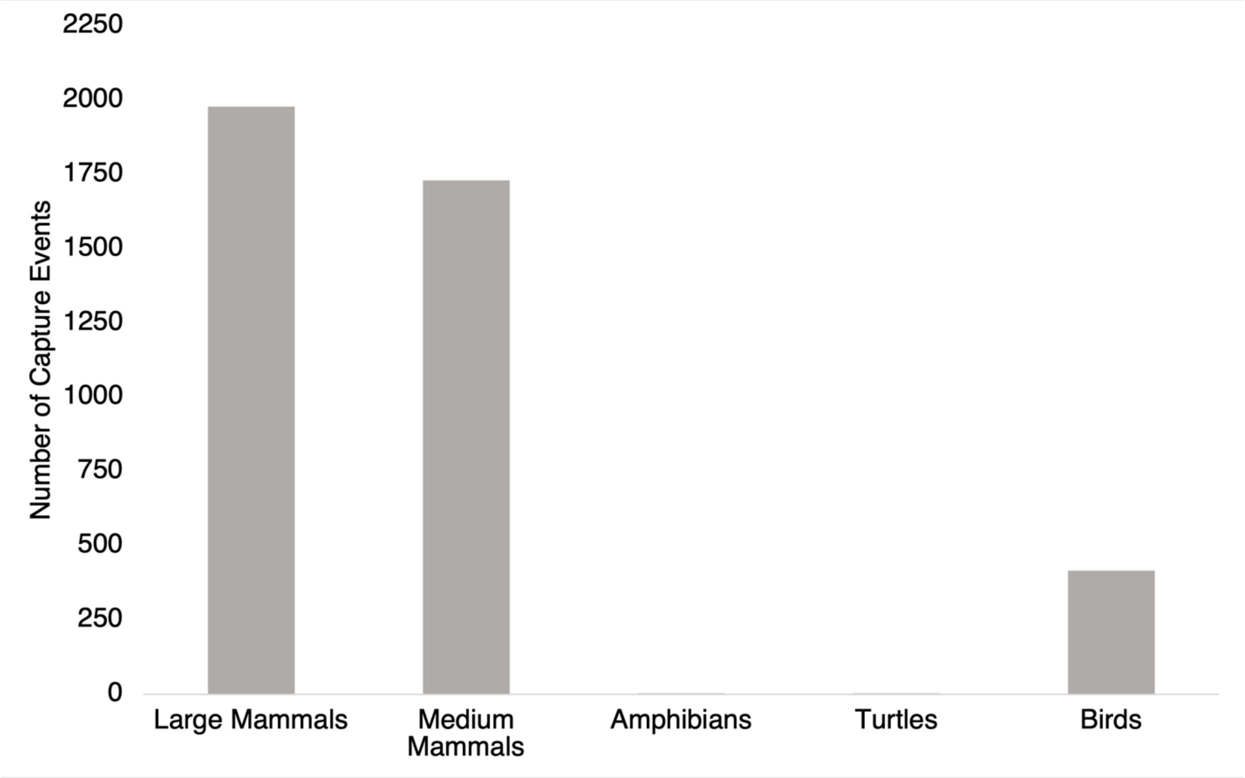

Figure 1.4. Number of capture events of wildlife-railway interactions for various taxa documented by trail cameras (*n* = 14) installed along the railway at Shawanaga First Nation (SFN) and Magnetawan First Nation (MFN), at ~500 m intervals.

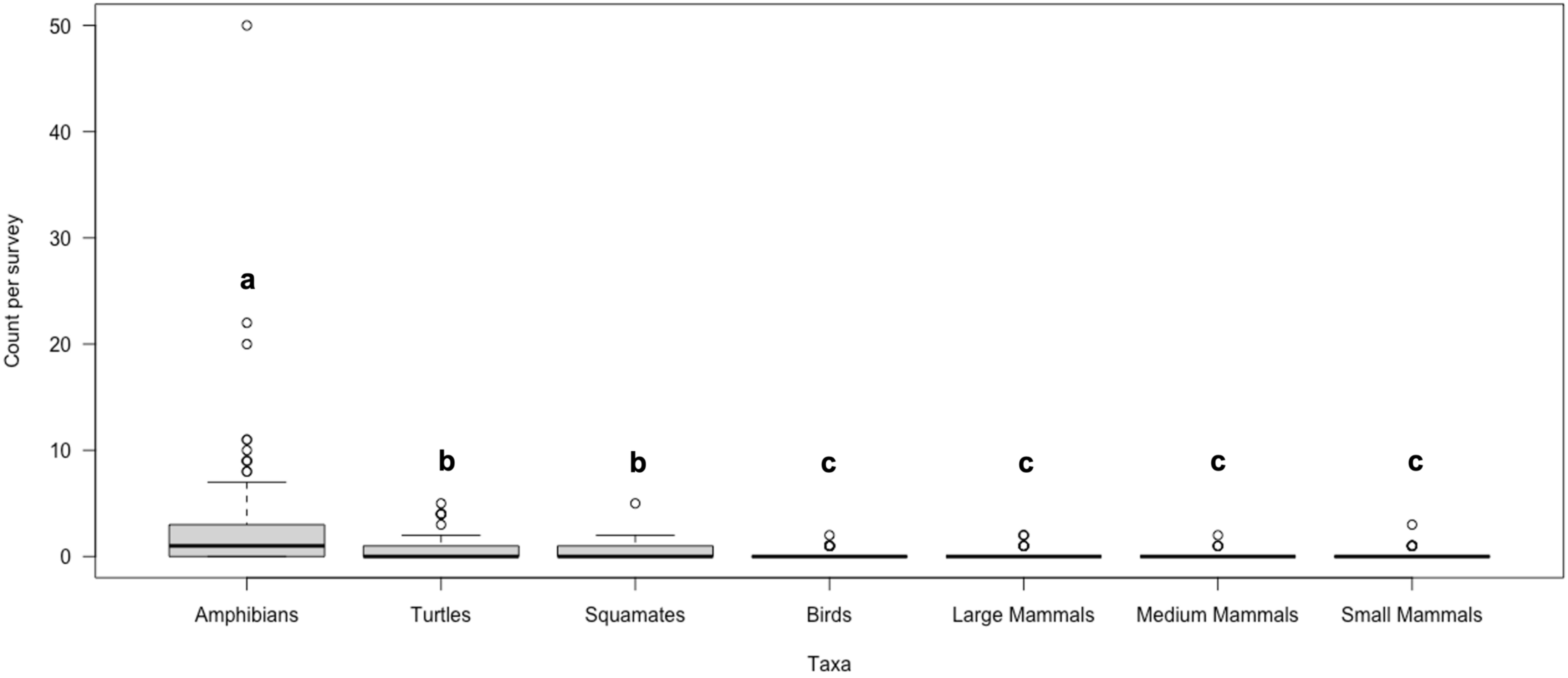

Figure 1.5. Boxplots showing taxonomic group differences between counts of live and dead animals per railway survey at both Shawanaga First Nation (SFN) and Magnetawan First Nation (MFN) in 2019, 2020, and 2021 combined. Group differences were assessed using a Kruskal-Wallis test, followed by a Dunn post-hoc test. Bold lines in plots represent the median count per survey for each taxon while circles represent outliers, or surveys with extreme count values. Differences between groups, indicated by unique letters above boxplots, were considered significant when $p \leq 0.05$.

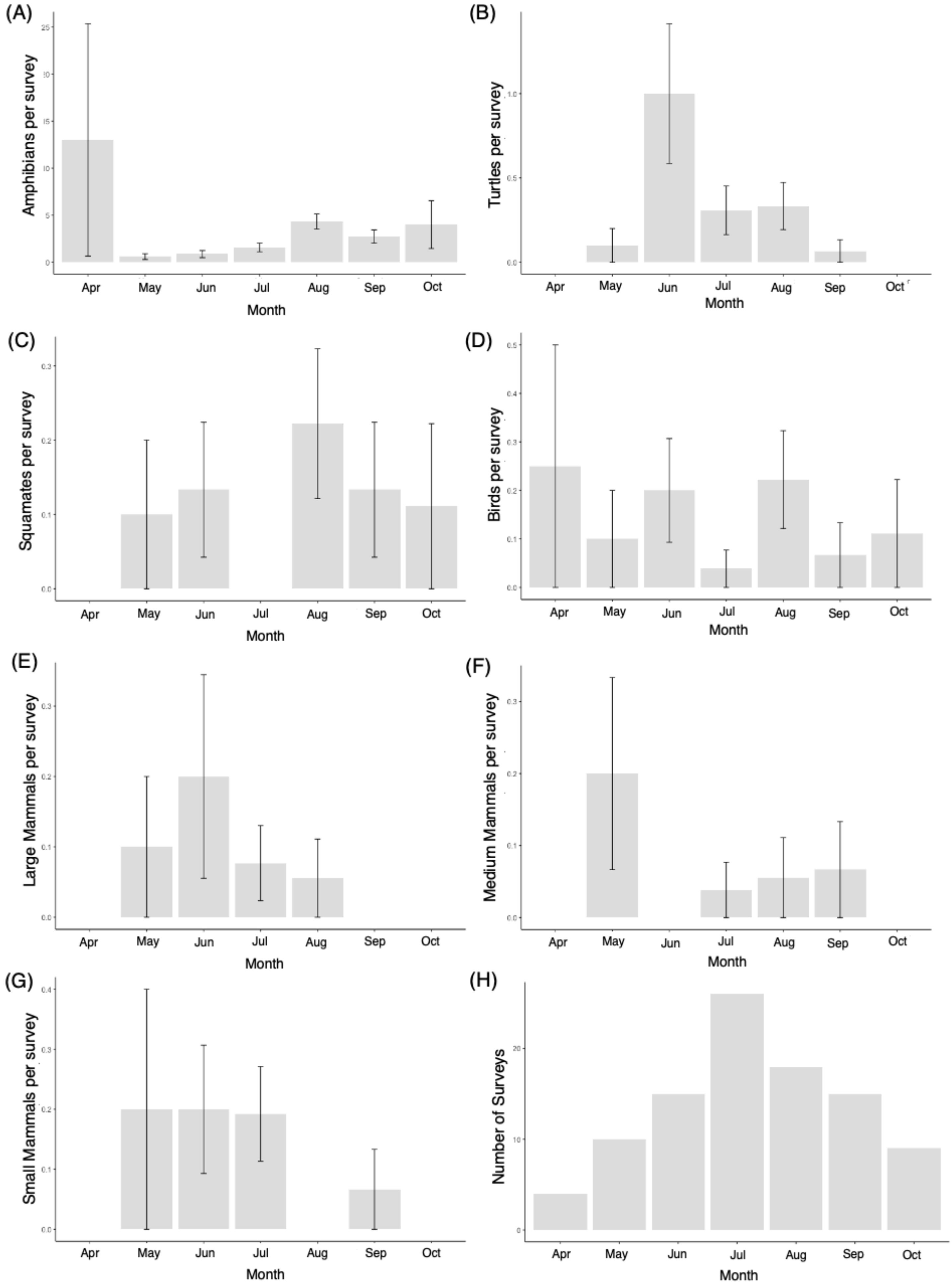

Figure 1.6. Mean number (± SE) of (A) amphibian, (B) turtle, (C) squamate, (D) bird, (E) large mammal, (F) medium mammal, and (G) small mammal mortalities per railway survey for each month from April to October at Shawanaga First Nation (SFN) and Magnetawan First Nation (MFN) conducted in 2019, 2020, and 2021. The cumulative number of surveys completed each month across all three years are presented in panel (H).

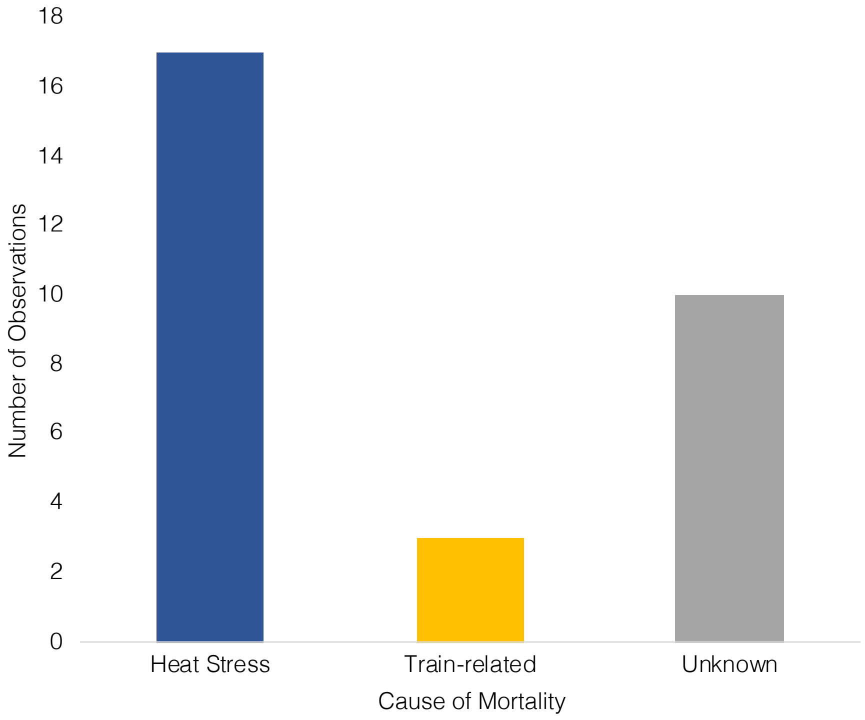

Figure 1.7. Number of turtle mortalities putatively caused by heat stress, train collisions, and unknown causes during weekly walking surveys of railways at Shawanaga First Nation (SFN) and Magnetawan First Nation (MFN) from 2019 – 2021.

Figure 1.8. Examples of turtles that putatively died of heat stress, documented during railway surveys at Shawanaga First Nation (SFN) and Magnetawan First Nation (MFN) in 2019, 2020, and 2021. (A) Female Midland Painted Turtle (*Chrysemys picta marginata*), (B) male Blanding's Turtle (*Emydoidea blandingii*), (C) juvenile Snapping Turtle (*Chelydra serpentina*), (D) male Midland Painted Turtle found stuck in creosote tar.

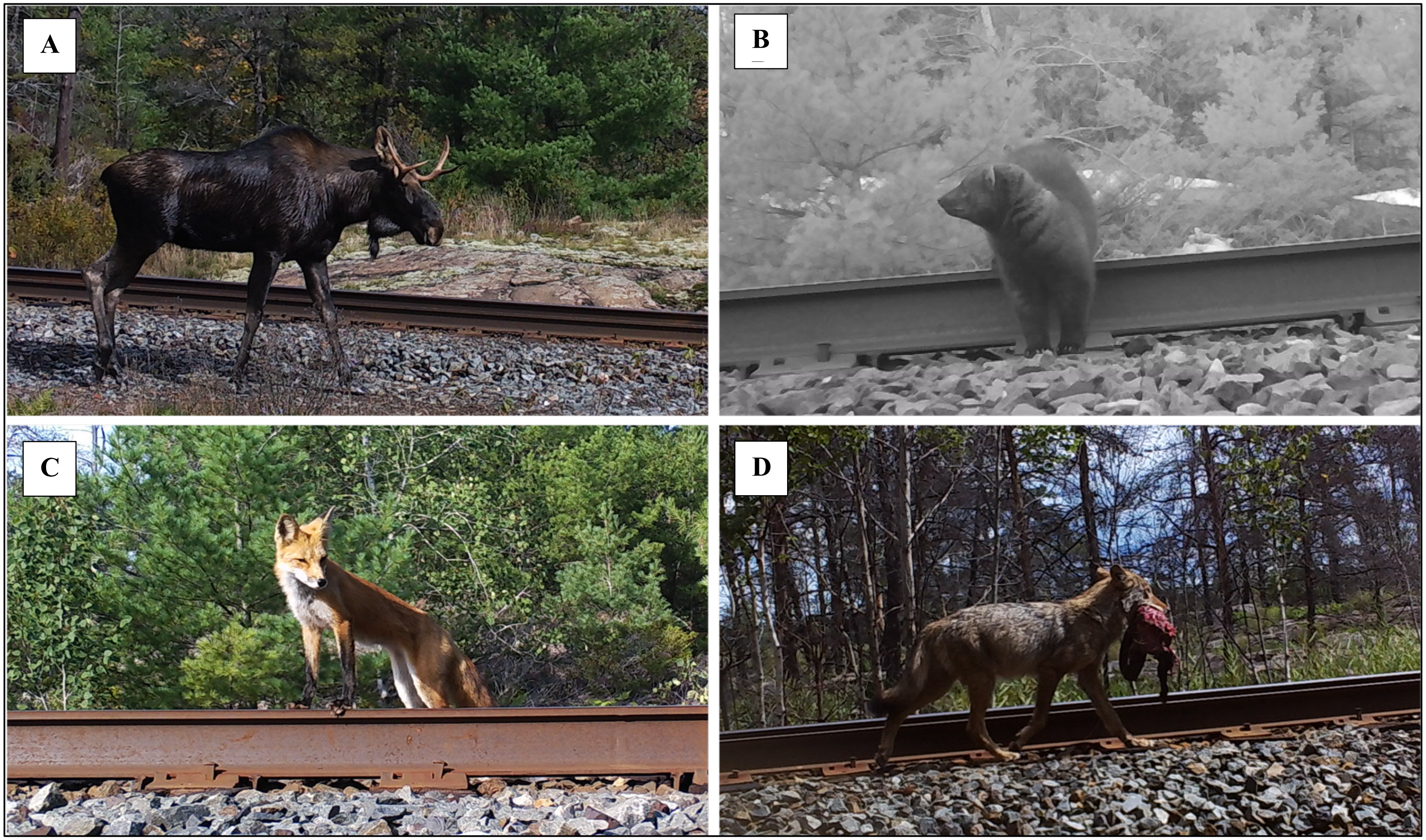

Figure 1.9. Examples of wildlife caught by camera traps at Shawanaga First Nation (SFN) and Magnetawan First Nation (MFN). (A) Male moose (*mooz; Alces alces*), (B) fisher (*ojiig; Martes pennanti*), (C) red fox (*waagosh; Vulpes vulpes*), (D) wolf (*ma'iingan;* Canid *spp.*) carrying beaver (*amik; Castor canadensis*) carcass.

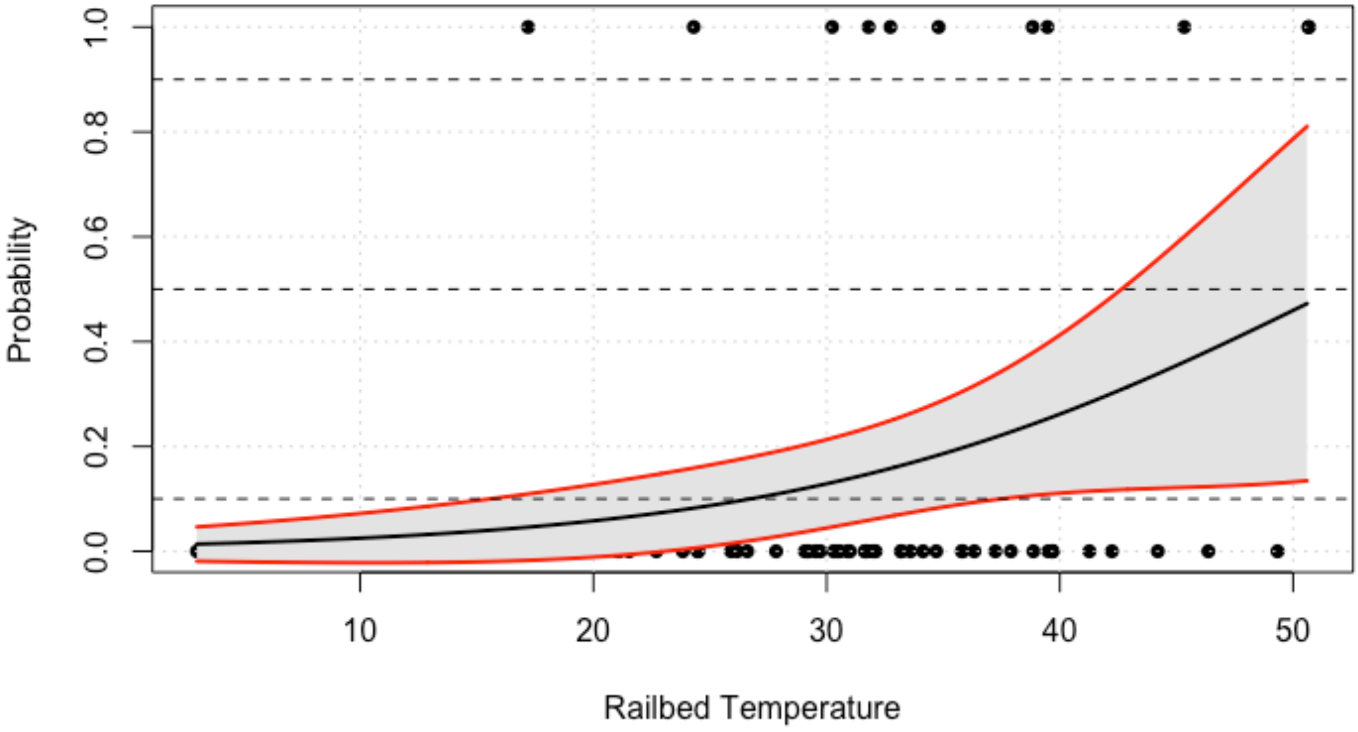

Figure 1.10. Logistic regression showing the relationship between railbed temperature (°C) and the probability of observing a turtle mortality from railway surveys at Shawanaga First Nation (SFN) and Magnetawan First Nation (MFN) in 2020 and 2021.

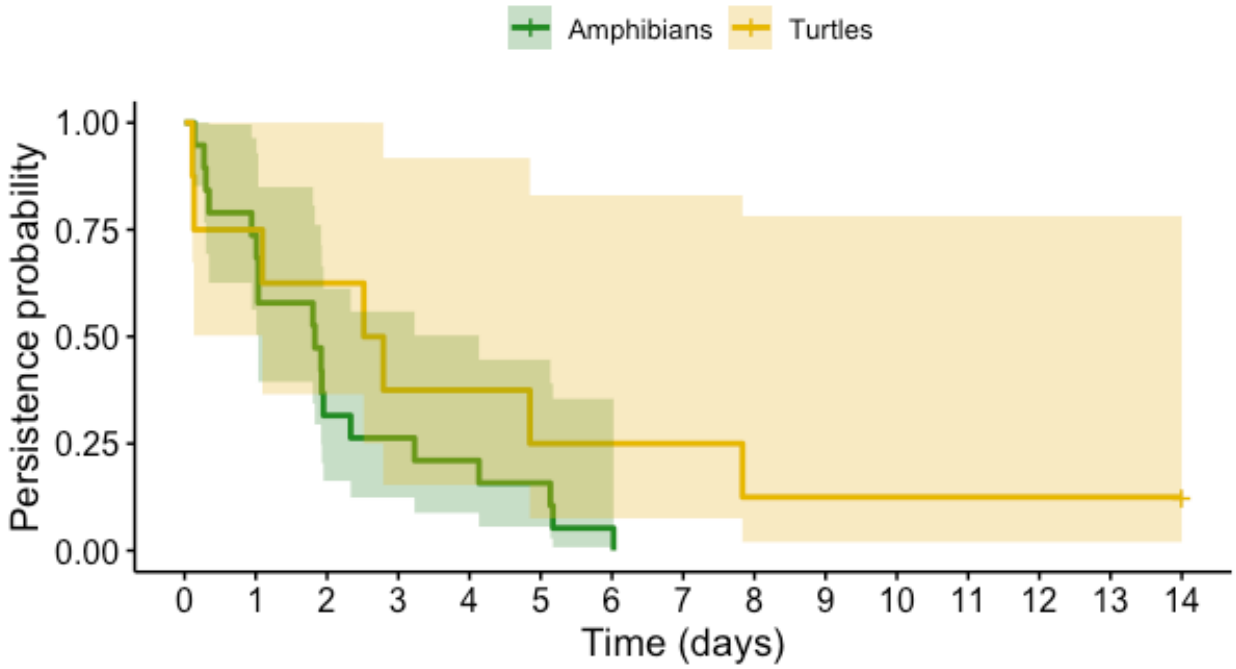

Figure 1.11. Probability of persistence of A) amphibian (*n* = 19) and B) turtle carcasses (*n* = 8) on a railway before removal by a scavenger or decomposition. Amphibian species used in trials included Green Frogs (*Lithobates clamitans*), Northern Leopard Frogs (*Lithobates pipiens*), American Bull Frogs (*Lithobates catesbeianus*), and Gray Tree Frogs (*Hyla versicolor*). Turtle species used in trials included Midland Painted Turtles (*Chrysemys picta marginata*), Blanding's Turtles (*Emydoidea blandingii*), and Snapping Turtles (*Chelydra serpentina*). Survival curves display Kaplan-Meier estimates and corresponding 95% confidence intervals (shading).

Chapter 2: The Influence of Landscape Variables on Turtle and Anuran Railway Interactions

Abstract

The impacts of railways on wildlife are poorly understood, particularly for less charismatic and more vulnerable taxa like reptiles and amphibians. Although some studies have examined wildlife-railway use and mortality rates, few have investigated how wildlife interact with railways spatially. Our aim was to improve understanding of turtle and anuran railway interactions by determining whether hotspots exist on railways, then investigating how adjacent habitat and landscape features influence where mortalities and live observations occur along the tracks. This study was initiated in partnership with two First Nations, Magnetawan First Nation and Shawanaga First Nation, and was developed based on community concerns for train-killed wildlife, particularly species at risk. We conducted weekly surveys along two 3.6 km sections of railway and documented all observations of live and dead wildlife. For hotspot and spatial analyses, we focused on turtle (*n* = 63) and anuran (*n* = 292) observations, as these groups had the highest railway mortality rates, already face global population declines, and First Nation community members highlighted concern about turtle railway mortalities. Hotspot analyses identified significant clustering of turtle and anuran railway interactions on both railway sections. Locations of turtle interactions were predicted by the presence of gaps under the rails, potentially leading to railway entrapment, and proximity to wetlands and rock barrens, while anuran interactions were influenced by proximity to habitats with diverse land cover, but were negatively influenced by proximity to wetlands. Understanding where to target mitigation structures is important for effective wildlife conservation, as these efforts are often costly, time consuming, and need to be taxon specific to be most effective. Our study provides valuable insights that may be used to target mitigation at identified hotspots and identifies habitat predictors that could be important for targeting turtle and anuran railway mitigation strategies on a broader scale.

Key words: Indigenous knowledge, railway ecology, hotspot, critical habitat, turtles, frogs

1.0 Introduction

While the impacts of roads on wildlife populations and the measures we can take to help mitigate those effects have received increased attention in recent years (Andrews et al., 2015; Teixeira et al., 2020; van der Grift et al., 2013), the impacts of railways on wildlife remain poorly understood (Barrientos et al., 2019; Borda-de-Água et al., 2017; Popp and Boyle, 2017). We do know that railways impact many species (Dasgupta and Ghosh, 2015; Heske, 2015; Popp and Boyle, 2017), in some cases causing population declines more significant that the effects seen on roads (Dorsey et al., 2015; Waller and Servheen, 2005), but our understanding is still limited, particularly for understudied taxa like herpetofauna. Turtles (*mkinaak;* [Anishinaabemowin]) and frogs (*omagakii*) are both taxonomic groups that are some of the most severely impacted by road mortality (Cunnington et al., 2014; Lesbarrères et al., 2014), and some research suggests they may be particularly susceptible to railway impacts as well (Heske, 2015; Kornilev et al., 2006; Rautsaw et al., 2018). While a few railway ecology studies have focused on understanding the magnitude of wildlife mortalities and how temporal variables affect wildlife-railway interactions (Dornas et al., 2019; Heske, 2015), few studies have investigated the influence of spatial variables like habitat area, landscape features, and railway features on wildlife-railway interactions. Those studies that have, primarily focus on large mammals (Gilhooly et al., 2019; St. Clair et al., 2020) but do not consider less charismatic fauna.

With railway infrastructure predicted to expand in the near future (Dulac, 2013), research to further understand how railways impact wildlife is important, but it is critical that studies be designed to gather data that can be used to develop and test effective mitigation measures to reduce the negative impacts associated with railways (Borda-de-Água et al., 2019; Popp et al., 2018). Mortality hotspots on railways have been identified for several species including elk, tortoises, and toads (Dornas et al., 2019; Iosif, 2012; Popp et al., 2018). However, as with railway ecology in general, these studies are rare and more work is needed to identify hotspots of wildlife-railway interactions, especially for understudied taxa (Popp & Boyle, 2017), and for taxa that already face threats and population declines.

The objective of our study was to use wildlife location data collected during weekly walking surveys to identify interaction hotspots for turtles and anurans, the taxa that were identified as being the most susceptible to railway impacts in our study area (Chapter 1). Our second objective was to assess which habitat, landscape, and railway features were predictors of observed railway interactions. We hypothesized that railway interactions for turtles and anurans would occur along the railway in relationship to critical habitat features associated with their respective annual cycle of activity. We predicted that railway interactions would not be evenly distributed along the railway but would be aggregated based on those habitat and landscape features. Our ultimate goal is to use the information obtained in this study to identify and suggest locations for potential mitigation measures that can be implemented to reduce wildlife-railway mortalities in both First Nation communities in the future, while also identifying broad scale habitat and landscape predictors for turtle and anuran railway interactions to inform our understanding of railway ecology in general.

2.0 Methods

2.1 Study Area

Shawanaga First Nation (SFN) and Magnetawan First Nation (MFN) are two Anishinaabe communities located approximately 30 km apart on the eastern coast of Georgian Bay, Ontario, Canada (Figure 2.1). Both study sites are located within the Great Lakes-St. Lawrence Forest region and consist of a variety of terrain and habitat types including a mix of forests, wetlands, and rock barrens typical of the Georgian Bay coast (Morningstar et al., 2021a, 2021b). Both communities are bisected by a single-track railway line that runs from Parry Sound to Sudbury in an approximately north – south direction, in parallel to nearby Ontario Highway 69 and Ontario Highway 529. The railway that runs through both First Nations is active and is operated by Canadian Pacific Railway (CPR) but also used by Canadian National Railway (CNR). Train traffic on the railway typically travels northbound, using an adjacent rail line outside of the study area to return south. The survey areas at both study sites consisted of a 3.6 km section of the railway bisecting each community (Figure 2.1). The study site at SFN extends 3.6 km northwest from Shawanaga Road North, while the study site at MFN extends 3.6 km south from Ontario Highway 529.

2.2 Data Collection

Wildlife-railway interaction data were recorded during weekly walking surveys of the railway in both communities from 2019 – 2021. Surveys were conducted during the late spring, summer, and early fall to adequately capture reptile and amphibian observations, as community members emphasized turtle observations and mortalities during these seasons in the preliminary study planning (Chapter 1). Surveys were conducted in all weather conditions, but survey frequency varied among years occurring from May – August in 2019 (n = 23), June – October in 2020 (n = 29), and April to October in 2021 (n = 45). Surveys were typically conducted by 2 -3 observers at each site over the course of the three field seasons. Whenever possible we started surveys at the same time and on the same day each week; however, survey frequency did vary over the course of the study, as the rail line is still actively used (Table 2.1). During surveys two observers walked on opposite sides of the railway tracks and recorded observations of live or deceased wildlife found anywhere within the centre rail or right-of-way (Figure 2.1).

Live and dead turtles and anurans encountered during surveys were identified to the most specific taxonomic level and referenced with a GPS unit (Garmin GPSMAP 62s) to record the location of the observation (accuracy ± 3 m). The identified species, time of observation, relative location on the railway (centre tracks, east or west side of right-of-way), suspected cause of mortality (e.g. train collision, heat stress), and behaviour of live individuals (e.g. attempting to cross tracks, basking etc.) were also recorded. Turtles are inventoried as part of on-going conservation programs implemented by both SFN and MFN, thus, when turtles were encountered, individuals were sexed, measured, photographed, and marked with a unique notch code (Cagle, 1939). Live turtles encountered during surveys were released in wetlands in the direction they were moving prior to processing; if direction of travel was not obvious, they were released in the next closest suitable habitat.

2.3 Hotspot Identification

We focused our spatial analyses on turtles and anurans as individuals from these taxonomic groups were found most often during railway surveys, both already face global declines (Bolochio et al., 2020; Lovich et al., 2018; Stanford et al., 2020), and community members from SFN and MFN expressed particular concern for turtle mortalities during Indigenous knowledge (IK) sharing interviews (Chapter 1).

The locations of live and dead turtles and anurans were used to investigate whether wildlife-railway interactions clustered spatially using the Getis-OrdGi* statistic in ArcGIS pro 2.8.7 (ESRI, Redlands, CA). We chose to include observations of both live and dead individuals in our analysis and hereafter refer to them as “railway interactions” since both events represent a spatial interaction with the railway. Observations of turtle and anuran species were pooled into their respective taxon and across all three years of study for analysis. To conduct hotspot analysis on the railway, we subdivided each 3.6 km surveyed section into equal length segments measuring 50 and 100 m ($n = 72$ and $n = 36$ segments, respectively) and performed analysis at both spatial scales. Using segment lengths of 50 and 100 m allowed us to compare hotspots at feasible scales for implementing mitigation measures while still meeting the assumption of the Getis-OrdGi* statistic of including > 30 features (i.e., railway segments) for effective analysis (ESRI, 2021; Garrah et al., 2015). Prior to beginning analyses, we snapped all wildlife observation points to the railway using the "near" function in ArcGIS pro 2.8.7 to ensure that counts were accurately represented for each segment. Getis-OrdGi* statistics compare the spatial clustering of observed points to a that of a random distribution (Galinskaitė et al., 2022; Getis and Ord, 1992). The analysis produces a Gi *z*-score for each railway segment after comparing the sum of observed points in each segment to those of its nearest neighbours (Getis and Ord, 1992). Railway segments were considered significant hotspots when Gi *z*-scores were ≥ 1.65 and were considered significant coldspots when Gi *z*-scores were ≤ -1.65 (ESRI, 2021; Getis and Ord, 1992).

2.4 Influence of Landscape Variables

We used generalized linear models (GLM) to examine which habitat, landscape, and railway features were the best predictors of turtle and anuran railway interactions using 50 m railway segments as the unit of scale for response and predictor variables (Canal et al., 2019; Zuur et al., 2009). We tested the effect of 6 fixed effect variables: railway gaps (count of gaps between railway ties and under the rail that may allow turtles access to the center of the railbed in each segment), adjacent wetland area (m^2), forest area (m^2), rock barren area (m^2), site (SFN, MFN), and land cover complexity (count of different ecological land classification (ELC) polygons adjacent to railway segments), on a count of turtle observations documented in each segment as our response variable. Modelling for anuran interactions used the same suite of predictor variables; however, we omitted railway gaps, as all anuran species within our study area can likely traverse the parallel rails, unlike turtles (Rautsaw et al., 2018). Land cover area adjacent to railway segments was extracted from ELC layers interpreted from aerial imagery (Morningstar et al., 2021a, 2021b) by generating 200 m buffers around each segment, creating 50 x 200 m rectangular polygons on either side of each railway segment (Figure 2.2). We then measured the area of each ELC layer within those rectangular buffers using ArcGIS pro 2.8.7. We grouped similar ELC polygons into the broader land cover classes described above (wetland, forest, and rock barren; Appendix E) because we had small sample sizes for modelling and broad taxonomic groups and including more general land cover classes should make our results more broadly applicable to future mitigation work. Railway gaps were identified and referenced with a handheld GPS unit (Garmin GPSMAP 62s) in 2021 to record the locations of gaps (accuracy ± 3 m) for modelling. We used ArcGIS pro 2.8.7 to count and summarize the number of railway gaps that occurred within each previously demarcated 50 m railway segment.

2.5 Model Selection

We assessed the suitability of all predictor variables for modelling by testing for collinearity between predictors using Spearman tests. We initially planned to include the presence of causeways (railway segments with wetland on either side) as a predictor, but found it was correlated with wetland area ($r = 0.62$), therefore we omitted the presence of causeways and continued analyses with wetland area under the assumption that wetlands would have greater biological significance for anurans and turtles as both groups depend on wetlands as critical habitat. No other predictors were highly correlated, so we used all other variables in respective model selection. Our count data per segment for both turtle and anuran interactions were zero-inflated and over dispersed, therefore we attempted modelling with alternative distributions and checked model fit. A Poisson distribution was used to model turtle railway interactions, and a negative binomial distribution was used to model anuran railway interactions (Zuur et al., 2009). We tested model fit by building our most complex model for each taxonomic group, then examined residuals and diagnostic plots. Because we had small sample sizes, we used Akaike's Information Criterion correction (AICc) selection to identify the most parsimonious model using backwards step selection where the least significant predictor variables were hierarchically removed from the full complex model until only significant predictors were left in the top candidate model (Burnham and Anderson, 2002). Models with the lowest AICc score were retained as the best models to explain variance in spatial railway interactions for turtles and anurans.

All statistical analyses were conducted in the R environment 4.0.4 (R Core Team, 2021). GLMs were fit using the stats and MASS package (Venables and Ripley, 2002). Model diagnostics were completed using the DHARMa package (Hartig, 2018).

3.0 Results

3.1 Turtle and Anuran Railway Interactions

A total of 292 anuran railway interactions, comprised of 6 species of frogs (Green Frogs *[omagakii; Lithobates clamitans]*, Spring Peepers [*Pseudacris crucifer]*, Northern Leopard Frogs *[gidagimakakii; Lithobates pipiens]*, Wood Frogs *[Lithobates sylvaticus]*, and American Bull Frogs *[Lithobates catesbeianus]*) and 1 species of toad (American Toad *[Anaxyrus americanus]*) were documented during surveys from 2019 – 2021 and used in spatial analyses. Although both live and dead individuals were considered as railway interactions, the majority of documented anurans were railway mortalities, making up 91 % of all anuran observations (Table 2.2).

We recorded 63 turtle railway interactions within our study area over the course of surveys from 2019 – 2021 (Table 2.2) In total, we documented individuals from 3 different turtle species interacting with the railway, including Blanding's Turtles (*Emydoidea blandingii*, endangered [SARA status]), Midland Painted Turtles (*miskwaadeswi; Chrysemys picta marginata,* special concern), and Snapping Turtles (*mikinaak; Chelydra serpentina,* special concern). Unlike anurans, just over half of the documented turtle railway interactions came from live individuals, making up 55 % of the turtle observations used in spatial analyses.

3.2 Hotspot Analysis

Both scales of analysis produced hot and coldspots (areas with significantly less clustering of interactions compared to neighbouring segments), but 100 m segments identified fewer hotspots than 50 m segments. While fewer segments were identified, the hotspots that were identified at 100 m were longer than those identified at a scale of 50 m. When we compared the distribution of clustering visually, both scales of analyses identified hotspots in the same general locations; however, 50 m segments gave finer scale differentiation of the levels of significance at each hotspot. As locations of hotspots were similar for railway segment lengths of 50 and 100 m, but the former gave better resolution while still being a practical scale for mitigation implementation, we proceeded with Getis-OrdGi* analysis and further spatial analyses at the scale of 50 m railway segments.

Hotspot analysis identified significant clusters of railway interactions for both turtles and anurans at both study sites at SFN and MFN; however, the locations of hotspots varied between taxa, apart from two adjacent segments at SFN that were significant hotspots for both turtles and anurans (Figure 2.3; Figure 2.4; Appendix D).

Although turtle railway interaction hotspots were present at both sites, the distribution of those hotspots differed visually between SFN and MFN. At SFN all significant turtle hotspots were concentrated towards the centre of the 3.6 km railway transect, with short distances (50 – 150 m) between them (Figure 2.3). Turtle hotspots at MFN were more evenly distributed along the length of the railway segment with clustering of interactions in the centre and at both ends of the surveyed railway (Figure 2.3). While long distances between interaction points existed at both study sites, the maximum distance between two adjacent points was longest at SFN, 775 m, compared to 330 m at MFN; however, no significant coldspots were detected for turtles at either site. Significant hotspots and the segments directly adjacent to them contained 44 % of all turtle railway interactions recorded at MFN, compared to 72 % of all turtle railway interactions at SFN. Hotspots for turtles at MFN covered 250 m (7 %) of the 3.6 km of railway surveyed. By comparison, hotspots for turtles at SFN covered 600 m (17 %) of the 3.6 km surveyed (Figure 2.3).

Both hotspots and coldspots were identified for anurans at SFN and MFN. The distribution of the hot and coldspots also differed between sites for anurans, with both clusters of hotspots at MFN being located on the north half of the railway segment, while hotspots at SFN were centered in the segment (Figure 2.4). In contrast, coldspots were located in the centre of the segment at MFN, but clustered at the north end of the segment at SFN (Figure 2.4). Outside of hot and coldspots, anuran railway interaction points were fairly evenly distributed, with a maximum distance between adjacent points being 165 m at SFN and 155 m at MFN. Interestingly, 22 % of anuran interactions were documented in significant hotspots and direct neighbouring segments at both MFN and SFN. Anuran interaction hot and coldspots covered 200 and 300 m, respectively at MFN, and covered 400 and 200 m, respectively at SFN.

3.3 Influence of Habitat and Landscape Variables

GLMs to predict the influence of habitat and landscape variables on turtle and anuran railway interactions were assessed using AICc model selection and produced preferred models for both taxonomic groups. The top model for turtle interactions per 50 m railway segment included the fixed effects of railway gaps, wetland area, and rock barren area, and explained 13 % of the variance (Table 2.4). Anuran railway interactions were best predicted by the fixed effects of habitat complexity and a negative relationship to wetland area; this model explained 11 % of the variance. Buffers around railway segments (200 m) at MFN were primarily comprised of wetland and forest, while land cover classes around buffers at SFN were on average more forested and had greater mean habitat complexity when compared to MFN (Table 4).

4.0 Discussion

The results of our hotspot analysis indicate that turtle and anuran interactions with railways cluster spatially and are not randomly distributed along these linear features. While there was some overlap in hotspots at SFN, the clustering of interactions tended to be different between the two tested taxa, suggesting that habitat and landscape variables influence where turtles and anurans interact with railways differently. Our modelling results indicate that turtle railway interactions were most influenced by the presence of gaps under the rails, and adjacent wetland and rock barren habitats surrounding railway segments. In comparison, anuran railway interactions varied in response to habitat complexity and wetland area in neighbouring habitat patches. The findings of our study are significant within the context of railway ecology research as they not only improve understanding of spatial interactions with railways for two globally threatened taxonomic groups, they provide valuable insight that could be used to reduce anuran and turtle railway mortality both locally at identified hotspots in each First Nation community, and on a broader landscape level scale based on identified habitat predictors.

4.1 Hotspots and Coldspots

We identified multiple significant hotspots of turtle railway interactions at both surveyed segments, supporting our prediction that turtle railway interaction locations would not be randomly distributed. Our results corroborate the non-random clustering of railway hotspots identified for Romanian Hermann's tortoises (*Testudo hermanni boettgeri*) by Iosif (2012), and similar patterns observed for freshwater turtles along roads (Boyle et al., 2017; Garrah et al., 2015; Glista et al., 2008; Langen et al., 2009). We also found support for our prediction about anuran railway interactions, as anuran observations were also non-randomly distributed along the railway. Similar studies have also identified clustering of toad observations along railways (Dornas et al., 2019) and anuran mortalities along roads (Boyle et al., 2017; Garrah et al., 2015; Glista et al., 2008; Langen et al., 2009; Matos et al., 2012). Although we found hotspots for both turtles and anurans, there was little overlap between significant segments for both taxa, emphasizing that different animals interact with railways differently, likely because of different habitat preferences and mobility. Only two adjacent 50 m hotspots overlapped for both turtles and anurans at SFN (Appendix D). This finding is not consistent with the results of two studies that investigated herpetofauna road mortality and found a high degree of overlap between the locations of amphibian and turtle mortality hotspots (Garrah et al., 2015; Langen et al., 2009). The lack of overlapping hotspots in our study might be explained by physical differences between roads and railways, like the presence of the rails themselves, which can be an obstacle to some wildlife like turtles who have limited mobility (Dorsey et al., 2015; Rautsaw et al., 2018). Some early road ecology research suggested that railways impact wildlife in ways similar to roads; however, recent studies have shown that railway impacts are often different or even more severe for certain taxa (Dorsey et al., 2015; Kornilev et al., 2006; Waller and Servheen, 2005). Differences in hotspot locations for turtles and anurans provide another example of how wildlife spatial interactions can vary when comparing railway impacts to those of roads.

While significant hotspots were identified on both surveyed segments, there were clear differences in the distribution of the hotspots at SFN and MFN; this was particularly evident for turtles, as significant segments were more evenly distributed along the railway at MFN, and more clustered in the center of the survey area at SFN (Figure 2.3). In the context of road ecology, differences in the location of hotspots are usually linked to the distribution of available suitable habitat for target species (Gomes et al., 2009; Gunson et al., 2009). Although our results suggest turtles and anurans may interact with railways differently than roads, site specific differences highlight the importance of evaluating the influence of habitat and landscape variables on railway interactions, an element of railway ecology that is still poorly understood.

4.2 Influence of Habitat and Landscape Variables

We observed significant relationships between spatial variables and railway interactions for both turtles and anurans. Anuran interactions were best predicted by habitat complexity and a negative relationship to wetland area adjacent to railway segments (Table 2.4). This result was unexpected, as other studies that have examined the influences of habitat location on anuran road mortalities found that one of the top predictors of hotspots was proximity to wetland areas (Garrah et al., 2015; Langen et al., 2009). One possible reason for the difference we observed in our study may stem from the diversity of anuran species and age classes we pooled for analysis.

All anurans require aquatic habitats for a portion of their life history, but among species there is a wide range of habitat specialization, movement ranges, and differences in juvenile dispersal (Patrick et al., 2012). The importance of habitat complexity in our models might reflect the diverse habitats used by different species at different life stages. For example, Wood Frogs are habitat specialists that breed in closed canopy vernal pools and are more likely to occupy terrestrial habitats, while Green Frogs are habitat generalists that breed in open aquatic environments, but are more likely to move long distances during juvenile dispersal (Gibbs et al., 2007; Patrick et al., 2012). Another possible explanation for habitat complexity being a significant term in our models might be the broadscale land cover classes we used for analysis. While our ELC layers captured large habitat patches, they did not consider small water bodies found within more dominant terrestrial habitat types that may be used for breeding or as temporary habitat for some species. In fact, during surveys, many anurans were observed using small rail-side pools in ditches (Vincent pers. observ.).

The spatial modelling results for turtles are much clearer, and follow the trends seen in similar studies. Turtle railway interactions were most influenced by the presence of gaps under rails, and proximity to wetlands and rock barrens. Because turtles have limited mobility, smaller species lack the ability to traverse the height of the rails (Dorsey et al., 2015; Kornilev et al., 2006; Rautsaw et al., 2018). When faced with a linear obstacle, turtles tend to walk along the feature until they find a route through or around the object, rather than attempt to cross over it (Peaden et al., 2017). During surveys we observed that most turtle mortalities were putatively caused by entrapment between the rails, leading to desiccation (Chapter 1). We suspect that turtles gained entry to the railbeds through gaps under the rails but became trapped when a corresponding gap on the other side was not present; the results of our GLM seemed to support this theory. This is similar to the effect of failures in road mitigation fencing on herpetofauna mortality, as documented by Baxter-Gilbert et al. (2015) who observed that gaps in fencing trapped individuals when there was not a corresponding gap on the opposite side of the road, increasing mortality risk. It should be noted that we identified and mapped the locations of railway gaps in 2021; however, the locations of these gaps are subject to change over time. During a site visit in 2022, we noticed that the railbed had been regraded since the end of the previous field season, essentially removing gaps from the length of the railway at MFN (Vincent pers. observ.). While this might reduce the chance of turtles gaining entry to the railbed, it also likely increases the chance that an individual will not find an escape route if they do become entrapped. Future research should focus on surveying and mapping rail gaps more extensively to see how railway maintenance impacts year-to-year turtle interactions as the frequency of gaps change. Wetland areas in 200 m buffers adjacent to railway segments were also a predictor of turtle railway interactions, a finding consistent with road ecology studies focused on the influence of spatial variables on herpetofauna (Garrah et al., 2015; Glista et al., 2008; Langen et al., 2012, 2009). The influence of rock barrens on turtle railway interactions also make sense ecologically, as rock barrens serve as critical nesting habitat in this region along the Georgian Bay coast (Markle et al., 2021).

4.3 Conservation Implications

Reptiles and amphibians are two of the most threatened taxonomic groups worldwide, facing population declines due to threats like habitat loss, road mortality, and the illegal pet collection trade (Böhm et al., 2013; Cox et al., 2022; IUCN, 2020; Lesbarrères et al., 2014). Herpetofauna in our study area face all of the threats listed above, including road mortality which has been previously investigated and is known to be high (Baxter-Gilbert et al., 2015). As we have documented, railway mortality also impacts turtles and anurans in the area, putting additional pressure on populations which are already in decline. This is especially the case for turtles, as all species that occur in the study area are currently listed as species at risk under the federal Species at Risk Act (SARA). Previous studies have shown that a mortality rate as low as 2 – 3 % can lead to long term population declines for some species of freshwater turtle (Congdon et al., 1993; Gibbs and Shriver, 2002).

Mitigation efforts to reduce road mortality have become increasingly common as the field of road ecology continues to develop and shed light on the damage caused by transportation infrastructure (Andrews et al., 2015; van der Grift et al., 2013). However, research also shows that mitigation must be well thought out, comprehensive, and targeted for specific taxa to be most effective (Baxter-Gilbert et al., 2015; Markle et al., 2017). While the hotspots and spatial predictors we identified can be used to target areas along the railway to install mitigation measures, more work must be done to determine what methods would be most effective. While developing and testing mitigation methods fall outside the scope of our current study, the potential for relatively simple and cost-effective measures seem plausible. It stands to reason that if turtles use natural gaps to gain entry to railbeds, they will also use gaps to escape, assuming they can find them. Trials to test whether turtles will use trenches dug between railway ties have been successful on decommissioned rail lines (Rautsaw et al., 2018); however, we recommend a method that uses a permanent culvert style underpass that will not be filled in during railbed maintenance. Railway culvert underpasses are open above to allow turtles that may be entrapped and walking the length of the railbed to fall in and escape. Railway underpasses have been used in Massachusetts on a decommissioned railway (Pelletier et al., 2005), and to mitigate turtle railway mortality in Japan (Matsuzawa, 2018); however, to our knowledge, no studies have assessed the success of these methods in the long term. We recommend that more effort be focused on understanding railway ecology at large, but particularly on developing and testing railway mitigation measures, ideally using a methodology that establishes a clear before-mitigation impact level to accurately assess whether measures are effective.

5.0 Conclusion

This project was initiated by our First Nation community partners based on their observations of wildlife-railway interactions and their concern about the impact train-related mortalities may be having on those vulnerable species. We were able to document wildlife railway interactions along the two 3.6 km study sites and use those data to investigate the spatial relationships between turtles, anurans, and railways because SFN and MFN knowledge holders initiated and informed our study (Chapter 1).

Like roads, railways also pose a threat to many species (Dorsey et al., 2015; Popp and Boyle, 2017). Here we have documented that reptiles and amphibians, specifically turtles and anurans, appear to be particularly vulnerable to railways due to their high frequency of rail interactions. Our results indicate that the railway interaction points for both turtles and anurans are not randomly distributed, but instead, are aggregated spatially as a function of adjacent habitat and landscape features. Unlike on roads (Langen et al., 2009), we found that turtle and anuran hotspots generally did not overlap, and that habitat predictors differed for each taxon, suggesting that future railway mitigation efforts must also be taxon specific. The findings of our study provide valuable insight that may be used to target mitigation on a local scale at identified hotspots, but also help to identify habitat predictors that could be important for targeting turtle and anuran railway mitigation strategies on a broader scale.

References

Andrews, K.M., Nanjappa, P., Riley, S.P.D., 2015. Roads and ecological infrastructure: Concepts and applications for small animals. Johns Hopkins University Press, Baltimore, Maryland.

Barrientos, R., Ascensão, F., Beja, P., Pereira, H.M., Borda-de-Água, L., 2019. Railway ecology vs. road ecology: similarities and differences. Eur. J. Wildl. Res. https://doi.org/10.1007/s10344-018-1248-0

Baxter-Gilbert, J.H., Riley, J.L., Lesbarrères, D., Litzgus, J.D., 2015. Mitigating reptile road mortality: Fence failures compromise ecopassage effectiveness. PloS One 10, 1–15. https://doi.org/10.1371/journal.pone.0120537

Böhm, M., Collen, B., Baillie, J.E.M., 2013. The conservation status of the world's reptiles. Biol. Conserv. 157, 372–385. https://doi.org/10.1016/J.BIOCON.2012.07.015

Bolochio, B.E., Lescano, J.N., Maximiliano Cordier, J., Loyola, R., Nori, J., 2020. A functional perspective for global amphibian conservation. https://doi.org/10.1016/j.biocon.2020.108572

Borda-de-Água, L., Ascensão, F., Sapage, M., Barrientos, R., Pereira, H.M., 2019. On the identification of mortality hotspots in linear infrastructures. Basic Appl. Ecol. 34, 25–35. https://doi.org/10.1016/j.baae.2018.11.001

Borda-de-Água, L., Barrientos, R., Baja, P., Pereira, H., 2017. Railway Ecology, in: Borda-de-Água, L., Barrientos, R., Baja, P., Pereira, H. (Eds.), Railway Ecology. Springer, Cham, Switzerland, pp. 3–10.

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. Biodivers. Conserv. 26, 3445–3463. https://doi.org/10.1007/s10531-017-1414-9

Burnham, K.P., Anderson, D.R., 2002. Model selection and multimodel inference: A practical information-theoretic approach, Second. Ed. Springer Verlag, New York.

Cagle, F.R., 1939. A system of marking turtles for future identification. Copeia 1939, 170–173.

Canal, D., Camacho, C., Martín, B., de Lucas, M., Ferrer, M., 2019. Fine-scale determinants of vertebrate roadkills across a biodiversity hotspot in Southern Spain. Biodivers. Conserv. 28, 3239–3256. https://doi.org/10.1007/s10531-019-01817-5

Congdon, J.D., Dunham, A.E., Van, R.C., Sels, L., 1993. Delayed sexual maturity and demographics of Blanding's Turtles (*Emydoidea blandingii*): Implications for conservation and management of long-lived organisms. Conserv. Biol. 7, 826–833.

Cox, N., Young, B.E., Bowles, P., Fernandez, M., Marin, J., Rapacciuolo, G., Böhm, M., Brooks, T.M., Hedges, S.B., Hilton-Taylor, C., Hoffmann, M., Jenkins, R.K.B., Tognelli, M.F., Alexander, G.J., Allison, A., Ananjeva, N.B., Auliya, M., Avila, L.J., Chapple, D.G., Cisneros-Heredia, D.F., Cogger, H.G., Colli, G.R., de Silva, A., Eisemberg, C.C., Els, J., Fong G, A., Grant, T.D., Hitchmough, R.A., Iskandar, D.T., Kidera, N., Martins, M., Meiri, S., Mitchell, N.J., Molur, S., Nogueira, C. de C., Ortiz, J.C., Penner, J., Rhodin, A.G.J., Rivas, G.A., Rödel, M.O., Roll, U., Sanders, K.L., Santos-Barrera, G., Shea, G.M., Spawls, S., Stuart, B.L., Tolley, K.A., Trape, J.F., Vidal, M.A., Wagner, P., Wallace, B.P., Xie, Y., 2022. A global reptile assessment highlights shared conservation needs of tetrapods. Nat. 605, 285–290. https://doi.org/10.1038/s41586-022-04664-7

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

Dasgupta, S., Ghosh, A.K., 2015. Elephant–railway conflict in a biodiversity hotspot: determinants and perceptions of the conflict in northern West Bengal, India. Hum. Dimens. Wildl. 20, 81–94. https://doi.org/10.1080/10871209.2014.937017

Dornas, R.A.P., Teixeira, F.Z., Gonsioroski, G., Nóbrega, R.A.A., 2019. Strain by the train: Patterns of toad fatalities on a Brazilian Amazonian railroad. Sci. Total Environ. 660, 493–500. https://doi.org/10.1016/j.scitotenv.2018.12.371

Dorsey, B., Olsson, M., Rew, L.J., 2015. Ecological effects of railways on wildlife. Handb. Road Ecol. 219–227. https://doi.org/10.1002/9781118568170.ch26

Dulac, J., 2013. Global land transport infrastructure requirements: estimating road and railway infrastructure capacity and costs to 2050. Int. Energy Agency 1–54.

ESRI, 2021. How hot spot analysis (Getis-Ord Gi*) works—ArcGIS Pro | Documentation. Esri. URL https://pro.arcgis.com/en/pro-app/2.8/tool-reference/spatial-statistics/h-how-hot-spot-analysis-getis-ord-gi-spatial-stati.htm%0Ahttps://pro.arcgis.com/en/pro-app/latest/tool-reference/spatial-statistics/h-how-hot-spot-analysis-getis-ord-gi-spatial-stati.

Galinskaitė, L., Ulevičius, A., Valskys, V., Samas, A., Busher, P.E., Ignatavičius, G., 2022. The influence of landscape structure on wildlife and vehicle collisions: Geostatistical analysis on hot spot and habitat proximity relations. ISPRS Int. J. Geo-Information. 11 (1), 63. https://doi.org/10.3390/IJGI11010063

Garrah, E., Danby, R.K., Eberhardt, E., Cunnington, G.M., Mitchell, S., 2015. Hot spots and hot times: Wildlife road mortality in a regional conservation corridor. Environ. Manage. 56, 874–889. https://doi.org/10.1007/s00267-015-0566-1

Getis, A., Ord, J.K., 1992. The analysis of spatial association by use of distance statistics. Geogr. Anal. 24, 189–206. https://doi.org/10.1111/J.1538-4632.1992.TB00261.X

Gibbs, J.P., Breisch, A.R., Ducey, P.K., Johnson, G., 2007. The amphibians and reptiles of New York State: identification, natural history, and conservation. Oxford University Press.

Gibbs, J.P., Shriver, W.G., 2002. Estimating the effects of road mortality on turtle populations. Conserv. Biol. 16, 1647–1652.

Gilhooly, P.S., Nielsen, S.E., Whittington, J., St. Clair, C.C., 2019. Wildlife mortality on roads and railways following highway mitigation. Ecosphere 10. https://doi.org/10.1002/ECS2.2597

Glista, D.J., Devault, T.L., Dewoody, J.A., 2008. Vertebrate road mortality predominantly impacts amphibians. Herpetol. Conserv. Biol. 3, 77–87.

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

Gunson, K.E., Clevenger, A.P., Ford, A.T., Bissonette, J.A., Hardy, A., 2009. A comparison of data sets varying in spatial accuracy used to predict the occurrence of wildlife-vehicle collisions. Environ. Manage. 44, 268–277. https://doi.org/10.1007/S00267-009-9303-Y/TABLES/4

Hartig, F., 2018. DHARMa: residual diagnostics for hierarchical (Multi-Level/Mixed) regression models. R package version 0.2.0. https ://CRAN.R-project.org/ =DHARMa

Heske, E.J., 2015. Blood on the tracks: Track mortality and scavenging rate in urban nature preserves. Urban Nat. 1–12.

Iosif, R., 2012. Railroad-associated mortality hot spots for a population of Romanian Hermann's Tortoise (*Testudo hermanni boettgeri*): a gravity model for railroad-segment analysis. Procedia Environ. Sci. 14, 123–131. https://doi.org/10.1016/j.proenv.2012.03.012

IUCN, 2020. The IUCN red list of threatened species v.2020-1. URL https://www.iucnredlist.org

Kornilev, Y. V, Price, S.J., Dorcas, M.E., 2006. Between a rock and a hard place: Responses of Eastern Box Turtles (*Terrapene carolina*) when trapped between railroad tracks, Herpetol. Rev. 37(2), 145-148.

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. Biodivers. Conserv. 21, 3017–3034. https://doi.org/10.1007/S10531-012-0352-9/FIGURES/4

Langen, T.A., Ogden, K.M., Schwarting, L.L., 2009. Predicting hot spots of herpetofauna road mortality along highway networks. J. Wildl. Manag. 73. https://doi.org/10.2193/2008-017

Lesbarrères, D., Ashpole, S.L., Bishop, C.A., Blouin-Demers, G., Brooks, R.J., Echaubard, P., Govindarajulu, P., Green, D.M., Hecnar, S.J., Herman, T., Houlahan, J., Litzgus, J.D., Mazerolle, M.J., Paszkowski, C.A., Rutherford, P., Schock, D.M., Storey, K.B., Lougheed, S.C., 2014. Conservation of herpetofauna in northern landscapes: Threats and challenges from a Canadian perspective. Biol. Conserv. 170, 48–55. https://doi.org/10.1016/j.biocon.2013.12.030

Lovich, J.E., Ennen, J.R., Agha, M., Gibbons, J.W., 2018. Where have all the turtles gone, and why does it matter? Bioscience 68. https://doi.org/10.1093/biosci/biy095

Mark Peaden, J., Justin Nowakowski, A., Tuberville, T.D., Buhlmann, K.A., Todd, B.D., 2017. Effects of roads and roadside fencing on movements, space use, and carapace temperatures of a threatened tortoise. Biol. Conserv. 214, 13–22. https://doi.org/10.1016/J.BIOCON.2017.07.022

Markle, C.E., Gillingwater, S.D., Levick, R., Chow-Fraser, P., 2017. The true cost of partial fencing: Evaluating strategies to reduce reptile road mortality. Wildl. Soc. Bull. 41, 342–350. https://doi.org/10.1002/WSB.767

Markle, C.E., Sandler, N.A., Freeman, H.C.A., Waddington, J.M., 2021. Multi-scale assessment of rock barrens turtle nesting habitat: effects of moisture and temperature on hatch success. Ichthyol. Herpetol. 109, 507–521. https://doi.org/10.1643/H2020125

Matos, C., Sillero, N., Argana, E., 2012. Spatial analysis of amphibian road mortality levels in northern Portugal country roads. Amphibia-Reptilia 33, 469–483. https://doi.org/10.1163/15685381-00002850

Matsuzawa, Y., 2018. 38th annual symposium on sea turtle biology & conservation – “Beyond protection of the sea turtle.” Mar. Turt. Newsl. 154, 22–23.

Morningstar, D., Agnew, C., Catcher, L., Chung, K., 2021a. Summary report: Desktop ecological land classification for Magnetawan First Nation. Cambridge, Ontario.

Morningstar, D., Agnew, C., Chung, K., Catcher, L., 2021b. Summary report: Desktop ecological land classification for Shawanaga First Nation. Cambridge, Ontario.

Patrick, D.A., Gibbs, J.P., Popescu, V.D., 2012. Multi-scale habitat-resistance models for predicting road mortality hotspots for reptiles and amphibians. Herpetol. Conserv. Biol. 7(3), 407-426.

Pelletier, S.K., Carlson, L., Nein, D., Roy, R.D., 2005. Railroad crossing structures for spotted turtles: Massachusetts Bay Transportation Authority – Greenbush rail line wildlife crossing demonstration project.

Popp, J., Boyle, S., 2017. Railway ecology: Underrepresented in science? Basic Appl. Ecol. 19, 84–93. https://doi.org/10.1016/j.baae.2016.11.006

Popp, J., Hamr, J., Chan, C., Mallory, F.F., 2018. Elk (*Cervus elaphus*) railway mortality in Ontario. Can. J. Zool. 96, 1066–1070. https://doi.org/10.1139/cjz-2017-0255

R Core Team, 2021. R: A language and environment for statistical computing. https://www.r-project.org/

Rautsaw, R.M., Martin, S.A., Vincent, B.A., Lanctot, K., Rebecca Bolt, M., Seigel, R.A., Parkinson, C.L., 2018. Stopped dead in their tracks: The impact of railways on Gopher Tortoise (*Gopherus polyphemus*) movement and behavior. Copeia 106, 135–143. https://doi.org/10.1643/CE-17-635

St. Clair, C.C., Whittington, J., Forshner, A., Gangadharan, A., Laskin, D.N., 2020. Railway mortality for several mammal species increases with train speed, proximity to water, and track curvature. Sci. Rep. 10, 1–13. https://doi.org/10.1038/s41598-020-77321-6

Stanford, C.B., Iverson, J.B., Rhodin, A.G.J., Paul van Dijk, P., Mittermeier, R.A., Kuchling, G., Berry, K.H., Bertolero, A., Bjorndal, K.A., Blanck, T.E.G., Buhlmann, K.A., Burke, R.L., Congdon, J.D., Diagne, T., Edwards, T., Eisemberg, C.C., Ennen, J.R., Forero-Medina, G., Frankel, M., Fritz, U., Gallego-García, N., Georges, A., Gibbons, J.W., Gong, S., Goode, E. V., Shi, H.T., Hoang, H., Hofmeyr, M.D., Horne, B.D., Hudson, R., Juvik, J.O., Kiester, R.A., Koval, P., Le, M., Lindeman, P. V., Lovich, J.E., Luiselli, L., McCormack, T.E.M., Meyer, G.A., Páez, V.P., Platt, K., Platt, S.G., Pritchard, P.C.H., Quinn, H.R., Roosenburg, W.M., Seminoff, J.A., Shaffer, H.B., Spencer, R., Van Dyke, J.U., Vogt, R.C., Walde, A.D., 2020. Turtles and tortoises are in trouble. Curr. Biol. 30, R721–R735. https://doi.org/10.1016/J.CUB.2020.04.088

Teixeira, F.Z., Rytwinski, T., Fahrig, L., 2020. Inference in road ecology research: what we know versus what we think we know. Biol. Lett. 16. https://doi.org/10.1098/RSBL.2020.0140

van der Grift, E.A., van der Ree, R., Fahrig, L., Findlay, S., Houlahan, J., Jaeger, J.A.G., Klar, N., Madriñan, L.F., Olson, L., 2013. Evaluating the effectiveness of road mitigation measures. Biodivers. Conserv. 22, 425–448. https://doi.org/10.1007/s10531-012-0421-0

Venables, W.N., Ripley, B.D., 2002. Random and mixed effects, in: Modern applied statistics with S. Springer New York LLC, New York, pp. 271–300.

Waller, J., Servheen, C., 2005. Effects of transportation infrastructure on grizzly bears in northwestern Montana. J. Wildl. Manage. 69, 985–1000. https://doi.org/10.2193/0022-541x(2005)069[0985:eotiog]2.0.co;2

Zuur, A., Ieno, E., Walker, N., Saveliev, A., Smith, G., 2009. Mixed effects models and extensions in ecology with R. Springer Science+Business, New York.

Figures and Tables

Table 2.1. Survey start time range, date range, number of surveys, total distance travelled, and mean survey time for visual walking railway surveys at Shawanaga First Nation (SFN) and Magnetawan First Nation (MFN), ON, Canada over 3 years of study (2019 - 2021).

Site	Survey start time ranges (24h)			Dates			Number of surveys			Total distance surveyed (km)			Mean time per survey ± SE		
	2019	2020	2021	2019	2020	2021	2019	2020	2021	2019	2020	2021	2019	2020	2021
MFN	9:30-15:20	8:45-12:21	9:00-11:06	05/21-08/06	06/30-10/26	04/13-10/13	10	15	22	35	52.5	77	1h 41m ± 13m	1h 59m ± 8m	2h 9m ± 9m
SFN	9:30-14:20	8:12-13:23	10:35-13:02	06/17-08/08	06/29-10/26	04/12-10/12	13	14	23	45.5	49	80.5	1h 49m ± 6m	1h 24m ± 8m	2h ± 5m

*Adapted from chapter 1

Table 2.2. Counts of live and dead anurans and turtles used in spatial analyses, documented during weekly railway surveys at Shawanaga First Nation (SFN) and Magnetawan First Nation (MFN) from 2019 – 2021. Counts are pooled among sites and across all three years of surveys.

Taxon	Species name	Scientific name	Live	Dead
Amphibians	American Bull Frog	*Lithobates catesbeianus*	-	8
	American Toad	*Anaxyrus americanus*	18	11
	Gray Tree Frog	*Hyla versicolor*	-	14
	Green Frog	*Lithobates clamitans*	2	129
	Northern Leopard Frog	*Lithobates pipiens*	2	16
	Spring Peeper	*Pseudacris crucifer*	3	53
	Wood Frog	*Lithobates sylvaticus*	-	2
	Unknown anuran	-	-	34
Turtles	Blanding's Turtle*	*Emydoidea blandingii*	11	7
	Midland Painted Turtle*	*Chrysemys picta marginata*	17	12
	Snapping Turtle*	*Chelydra serpentina*	7	8
	Unknown Turtle	-	-	2

*Indicates species currently listed as Species At Risk under the federal Species at Risk Act (SARA). Adapted from chapter 1

Table 2.3. Descriptive statistics for land cover variables derived from ecological land classification (ELC) used in generalized linear models (GLMs) for turtle and anuran railway interactions at Magnetawan First Nation (MFN) and Shawanaga First Nation (SFN). Land cover class areas show means per 200 m buffer around 50 m railway segment ± SEM.

Land cover class	MFN	SFN
Wetland (m^2)	10348.51 ± 548.87	7302.85 ± 567.59
Forest (m^2)	470.93 ± 155.67	10284.89 ± 560.94
Rock Barrens (m^2)	8819.34 ± 507.65	2579.53 ± 464.86
Complexity	4.36 ± 0.14	6 ± 0.15

Table 2.4. Summary results of generalized linear modelling that tested the effect of six independent variables on turtle and anuran railway interactions measured in relation to railway segments (*n* = 144) at Magnetawan First Nation (MFN) and Shawanaga First Nation (SFN). Independent fixed effect variables included: count of gaps under rails (*Gaps*), surrounding wetland area (*Wetland*), rock barren area (*Rock Barrens*), forest area (*Forest*), habitat complexity (*Complexity*), and community (*Site*). Data used for modelling were collected during surveys at SFN and MFN from 2019 – 2021. Habitat area (m^2) surrounding railway segments was measured in 200 m buffers based on ecological land classification (ELC) polygons, interpreted from aerial imagery. Turtle and anuran interactions were defined as a count of live and dead observations within each railway segment across all three years of study. Bold font indicates significant predictors in top models.

Models	AICc	ΔAICc	Variance	Predictors and Confidence Intervals (CI)
Turtle Interactions ~ **Gaps** + **Wetland** + **Rock Barrens**	247.92	0	0.13	**Railway Gaps:** $1.907e^{-01}$ ($9.301e^{-02}$ – 0.270), **Wetland**: $7.533e^{-05}$ ($1.680e^{-05}$ – 0.0001), **Rock Barrens:** $5.629e^{-05}$ ($-1.980e^{-06}$ – 0.0001)
Turtle Interactions ~ **Gaps** + **Wetland** + **Rock Barrens** + Site	248.22	0.3		
Turtle Interactions ~ **Gaps** + **Wetland** + **Rock Barrens** + Complexity + Site	249.81	1.59		
Turtle Interactions ~ **Gaps +** **Wetland** + **Rock Barrens +** Forest + Complexity + Site	251.61	1.8		
Anuran Interactions ~ **Complexity** + **Wetland**	513.18	0	0.11	**Complexity**: $1.569e^{-01}$ ($6.024e^{-02}$ – $2.541e^{-01}$), **Wetland**: $-2.437e^{-05}$ ($-5.371e^{-05}$ – $4.467e^{-06}$)
Anuran Interactions ~ **Complexity** + **Wetland** + Site	513.57	0.39		
Anuran Interactions ~ **Complexity** + **Wetland** + Site + Forest	515.37	1.8		
Anuran Interactions ~ **Complexity** + **Wetland** + Site + Forest + Rock Barrens	517.31	1.94		

*Variance explained by each model was calculated: 1 – (Residual deviance/Null deviance)

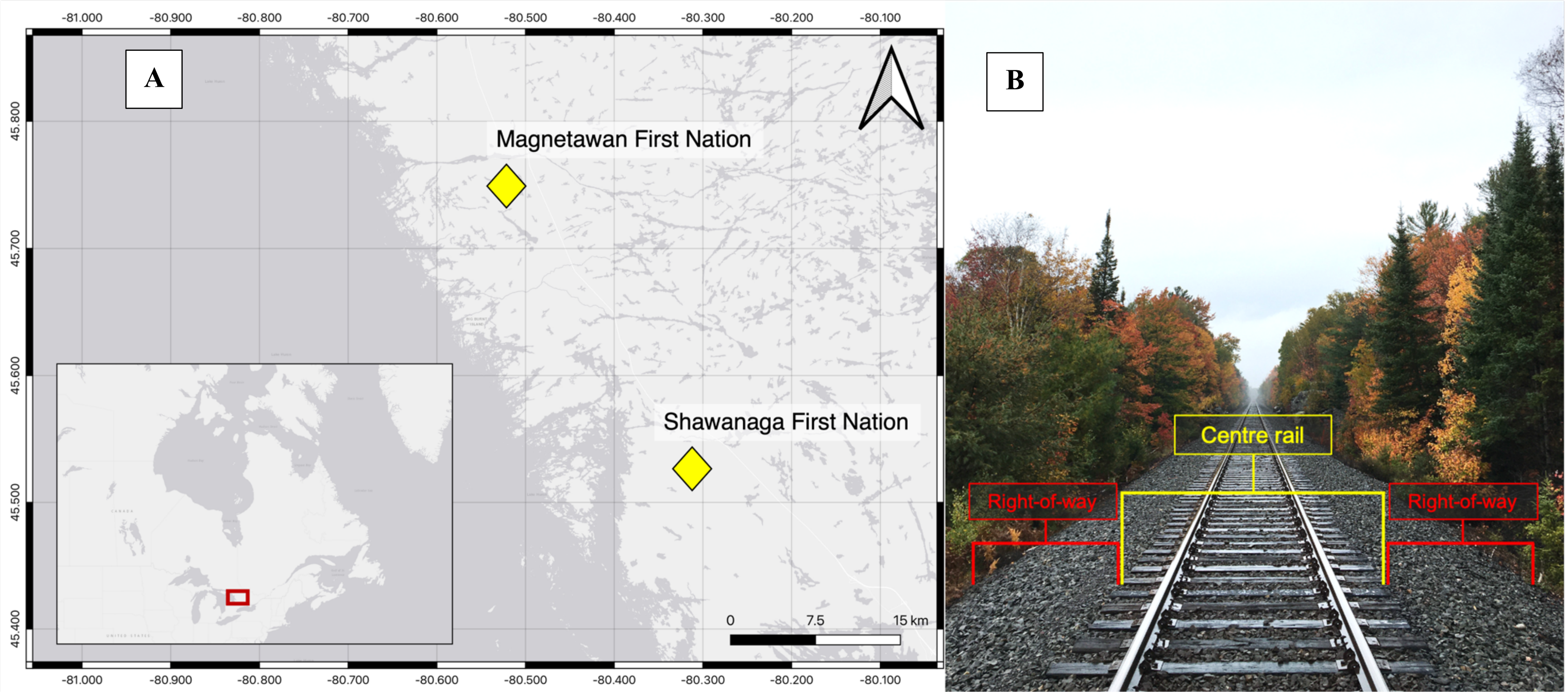

Figure 2.1. (A) Study area and associated study sites at Shawanaga First Nation (SFN) and Magnetawan First Nation (MFN), ON, Canada, where railway surveys were conducted during the field seasons of 2019 – 2021. Surveyed railway segments at each study site measured 3.6 km in length. (B) Example of the surveyed sections of single-track railway surveyed at each site including the centre rails and right-of-way. (Adapted from chapter 1)

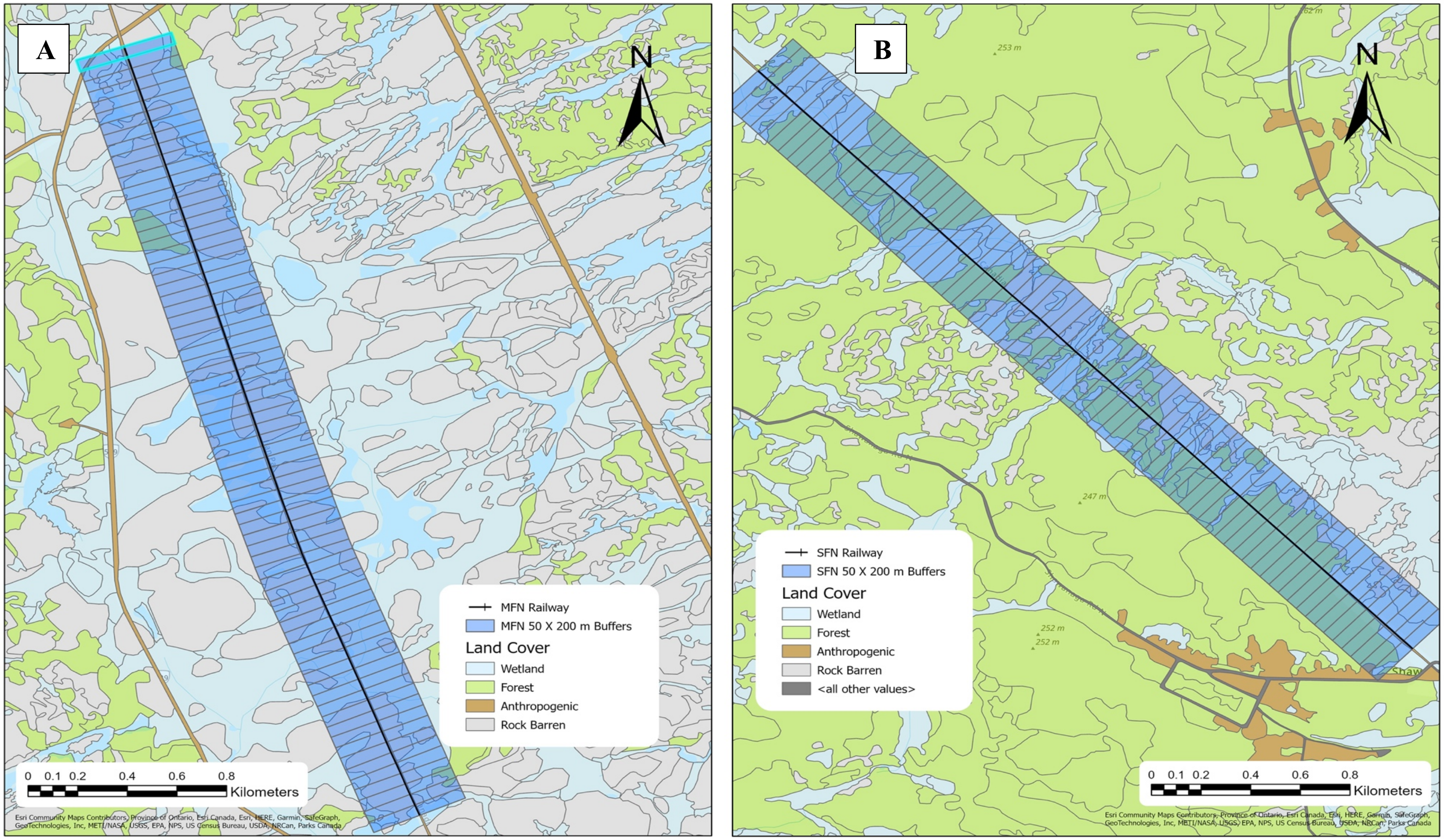

Figure 2.2. Layout of 200 m buffers used to measure the area of land cover classes in 50 x 200 m polygons on either side of the railway bisecting Magnetawan First Nation (A) and Shawanaga First Nation (B) along the eastern coast of Georgian Bay, Ontario. Buffers were defined based on 50 m railway segments and extended 200 m into adjacent railway habitat. Ecological land classification (ELC) polygons interpreted from aerial imagery (Morningstar et al., 2021a, 2021b) were used to define land cover classes

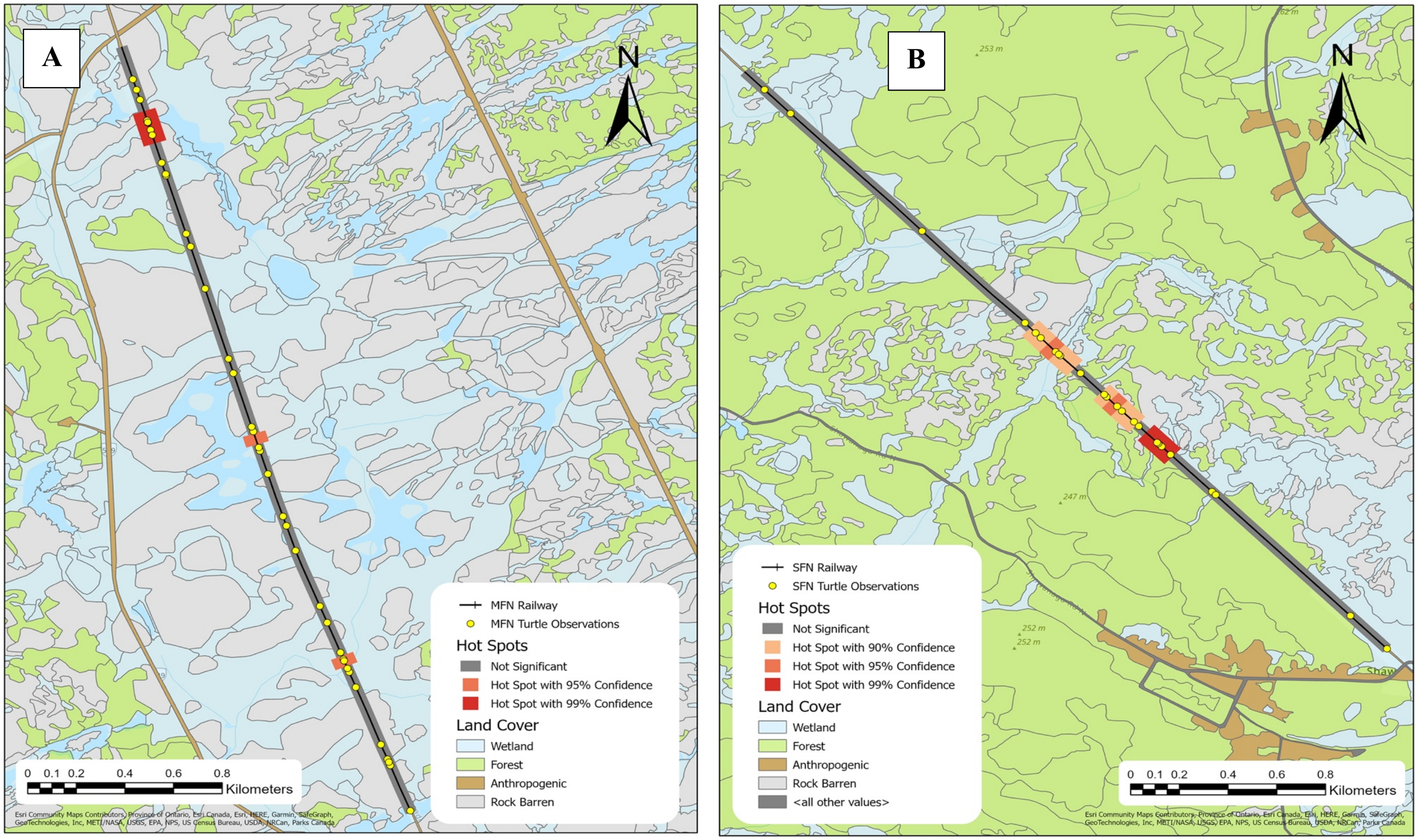

Figure 2.3. Hotspots of turtle railway interactions on the railway bisecting Magnetawan First Nation (A) and Shawanaga First Nation (B) along the eastern coast of Georgian Bay, Ontario. Railway interactions were defined as live or dead observations of turtles documented during weekly surveys from 2019 – 2021. Colour coding of hotspots is indicative of segment significance, represented by Gi *z*-scores assigned to each railway segment (50 m) based on Getis-OrdGi* analysis. Land cover classes were derived from ecological land classification (ELC) polygons interpreted from aerial imagery (Morningstar et al., 2021a, 2021b).

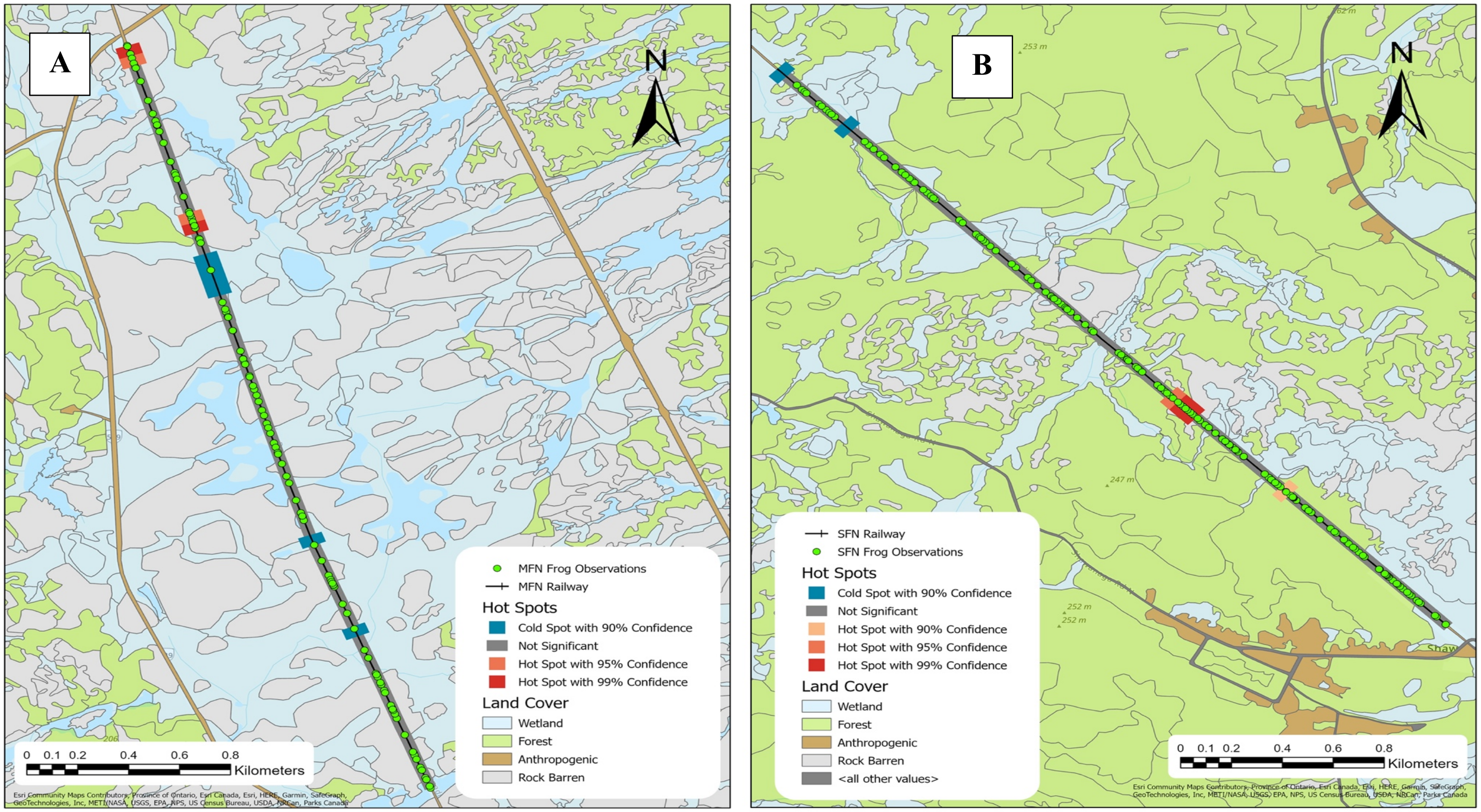

Figure 2.4. Hot and coldspots of anuran railway interactions on the railway bisecting Magnetawan First Nation (A) and Shawanaga First Nation (B) along the eastern coast of Georgian Bay, Ontario. Railway interactions were defined as live or dead observations of anurans and toads documented during weekly surveys from 2019 – 2021. Colour coding of hot and coldspots is indicative of segment significance, represented by Gi *z*-scores assigned to each railway segment (50 m) based on Getis-OrdGi* analysis. Land cover classes were derived from ecological land classification (ELC) polygons interpreted from aerial imagery (Morningstar et al., 2021a, 2021b).

Chapter 3: *Chrysemys picta marginata* (Midland Painted Turtle) Novel Railway Mortality

While surveying a 3.6-km section of railway at Shawanaga First Nation, Ontario, Canada, we observed a *Chrysemys picta marginata* mortality putatively caused by entrapment in creosote-tar leached from a railway tie. Here we report on this novel cause of mortality for a freshwater turtle. Wildlife-railway mortality data have been collected from 21 May 2019 to 13 October 2021, and are being used for a broader study investigating wildlife mortalities on railways. This study was initiated by Shawanaga First Nation and Magnetawan First Nation based on community concerns about impacts to wildlife caused by railways.

Railway-related mortality is known to occur for turtles, often caused by direct collisions with trains, or entrapment between the parallel rails of railbeds; subsequently leading to death caused by heat stress (Dorsey et al. 2015). A combination of small body size and a general lack of shell flexibility have been identified as likely causes of turtle railway entrapment, as these morphological traits restrict the ability of turtles to escape over the rails after entering the railbed (Kornilev et al. 2006).

While conducting weekly surveys, at 1635h on 17 June 2019, we encountered a dead adult male *C. picta marginata* (midline carapace length = 13.63 cm) in the center of the railway tracks (45.5228ºN, -80.2892W, WGS 84, 219 m elev.) resting on its plastron with three desiccated limbs extended from the leg pockets. The carcass was found directly on top of a railway tie surrounded by a pool of leached creosote-tar. We observed that the turtle was adhered directly to the tie by tar when we attempted to flip the carcass over, which required substantial force, to remove it from the tracks. Once fully overturned, much of the tar remained on the turtle, covering approximately two thirds of the plastron, primarily on the pectoral, abdominal, and femoral scutes (Figure 3.1).

The carcass showed no signs of physical trauma as would be expected from a direct collision with a train or hi-rail truck. We suspect the turtle likely entered the railbed through a gap between railway ties (areas where railway ballast has shifted, leaving openings under the rails), several of which exist along the survey route (pers. obs.; Figure 3.2.). The individual likely became trapped in the tar while walking down the length of the tracks after getting entrapped between the rails. At the time of observation, we measured the temperature of the air at 28.5 ºC, the railbed at 38.0 ºC, and the rail tie at 52.0 ºC using a probe thermometer (accuracy ± 1 ºC). Based on the high temperature of the railway tie in comparison to the ambient air temperature, it is likely that the turtle, once immobilized in tar, would have quickly succumbed to heat stress, as suggested for general turtle-railway entrapment (Kornilev et al. 2006).

To our knowledge, this is the first documented observation of turtle mortality caused by entrapment in railway-tar. Over the course of three years of weekly surveys, no other tar-entrapment mortalities were observed. However, two other *C. picta marginata* mortalities found in the center of the rails showed evidence of tar accumulation on their plastrons. A community member from Shawanaga First Nation also reported seeing turtles with tar on them after finding them trapped between the rails. This suggests that although this may be a rare occurrence, railway-tar entrapment might present a previously unreported threat to freshwater turtles.

All research was carried out under an approved Laurentian University Animal Care Committee protocol and was authorized by Laurentian University and Shawanaga First Nation. We would not have made this observation without the initiation of the broader study by both Shawanaga First Nation and Magnetawan First Nation, and the Indigenous Knowledge shared by

both communities. Financial support for this project was provided by the Natural Sciences and Engineering Research Council (NSERC), an Ontario Graduate Scholarship (OGS), the Laurentian University Advancing Indigenous Research Fund, and the Canada Research Chair Program.

References

Dorsey, B., Olsson, M., Rew, L.J., 2015. Ecological effects of railways on wildlife. Handb. Road Ecol. 219–227. https://doi.org/10.1002/9781118568170.ch26

Kornilev, Y. V, Price, S.J., Dorcas, M.E., 2006. Between a rock and a hard place: Responses of Eastern Box Turtles (*Terrapene carolina*) when trapped between railroad tracks, Herpetol. Rev. 37(2), 145-148.

Figures

Figure 3.1. Male *Chrysemys picta marginata* (Midland Painted Turtle) found entrapped in creosote-tar leached from a railway tie, that putatively died from heat stress, at Shawanaga First Nation, Ontario, Canada. Photo by Steven Kell.

Figure 3.2. Example of the pre-existing gaps between railway ties along the railway corridor at Shawanaga First Nation, Ontario, Canada. We suspect these gaps may allow turtles entry into the railway bed where they then become trapped.

Appendices

Appendix A

Appendix A. Examples of themes and associated example quotes identified from interviews with participants of the Indigenous knowledge study (chapter 1). All interview participants were community members from Magnetawan First Nation (*n* = 15) and Shawanaga First Nation (*n* = 17).

Themes	Example quotes
Community use	
Improved access to land and medicines	*They [railways] help, yeah to a certain degree, because a lot of the railroad goes right through the swamps, sometimes that's where the medicines are.* – Fay Rice, Magnetawan First Nation *Actually it [railway] helps because you can just walk and use the train tracks to get across the bushes easier.* – Jasper Janvier, Shawanaga First Nation
Improved access for fishing/hunting	*Mostly in the springtime [walking the railway], just to access towards the river […] to go harvest walleye.* – Community Member, Shawanaga First Nation
Contamination of medicines	*Even if there were medicines coming out of there, you can't use them because of the stuff that's coming off the railroad track or whatever put on it is contaminated.* – Carol Stevens, Magnetawan First Nation
Decreased access due to train traffic	*There's way more trains going by. When I was younger there would only be trains maybe twice or three times a day, but now it's something like 20 times a day […] I just don't like being out there on my bike. I don't usually go to those places anymore.* – Community Member, Shawanaga First Nation
Decreased hunting ability due to noise	*There are times they increase [access to land], They also can be dangerous. You always have to be careful when you're travelling on those railways […] it is hard to be connected [when] that loud sound goes by you and interferes with everything you were hoping to accomplish [hunting].* – Roger Jacklin, Magnetawan First Nation

Appendix A cont'd

Examples of themes and associated example quotes identified from interviews with participants of the Indigenous knowledge study (chapter 1). All interview participants were community members from Magnetawan First Nation (*n* = 15) and Shawanaga First Nation (*n* = 17).

Themes	Example quotes
Impact to Wildlife	
Railway mortality and habitat fragmentation	*They die within the tracks and there's lots of that going on, and I just think it has really fragmented all the area that they used to range naturally and they are a really big, really big problem for wildlife in any area with the railway lines go through there.* – Jerry Smith, Magnetawan First Nation *There are easy pathways for animals to use a railway and a lot of them get hit by a train. That's bottom line.* – Dawn Gagne, Magnetawan First Nation
Noise disturbance	*When they go through our communities I know they always have the horn blasting and sometimes you never know, the animals might be there, and then all of a sudden this big loud thing, it's probably disturbing them too, it's scaring them*. – Kimberly Blacksky, Shawanaga First Nation
Use as a movement corridor	*You can see the tracks as they're [wildlife] walking along. Because it's easier to walk on the sandy parts [of the railway] right. But [...] especially if you're crossing a big pond or something and you don't want to be bothered swimming across*. – Wanda Noganosh, Magnetawan First Nation
Wildlife Mortality	
Mammal mortality	*I've seen a few coyotes dead. I see deer killed on the train tracks and the moose animals.* – Community Member, Magnetawan First Nation
Herpetofauna mortality	*There was the snake, the hognose snake, that one died. Then there were all the turtles [deceased] [...] Turtles are the main ones [...] There was one turtle that was almost totally dried up. It had been hit by the train.* – Tim Ladouceur, *Shawanaga First Nation*
Turtle railway entrapment	*We find lots of turtles on the railway tracks. On hot days those turtles step over the tracks. They don't even make it across the track sometimes because they start boiling right on the track there. They die within the tracks.* – Jerry Smith, Magnetawan First Nation

Appendix B

Appendix B. Counts of live and dead wildlife documented during weekly walking railway surveys at Shawanaga First Nation (SFN) and Magnetawan First Nation (MFN). Total counts are pooled among sites and across three years of surveys (2019 – 2021).

Taxon	Species name	Scientific name	Live	Dead
Amphibians	American bull frog	*Lithobates catesbeianus*	-	8
	American toad	*Anaxyrus americanus*	18	11
	Gray tree frog	*Hyla versicolor*	-	14
	Green frog	*Lithobates clamitans*	2	129
	Northern leopard frog	*Lithobates pipiens*	2	16
	Spring peeper	*Pseudacris crucifer*	3	53
	Wood frog	*Lithobates sylvaticus*	-	2
	Eastern newt	*Notophthalmus viridescens*	1	-
	Unknown frog	-	-	34
Turtles	Blanding's Turtle*	*Emydoidea blandingii*	11	7
	Midland Painted Turtle*	*Chrysemys picta marginata*	17	12
	Snapping Turtle*	*Chelydra serpentina*	7	8
	Unknown Turtle	-	-	2
Squamates	Dekay's brownsnake	*Storeria dekayi*	1	-
	Eastern gartersnake	*Thamnophis sirtalis*	11	2
	Eastern hognosed snake*	*Heterodon platirhinos*	2	-
	Eastern massasauga*	*Sistrurus catenatus*	6	1
	Eastern milksnake	*Lampropeltis triangulum*	1	-
	Eastern ribbonsnake*	*Thamnophis sauritus*	1	-
	Northern watersnake	*Nerodia sipedon*	2	1
	Red-bellied Snake	*Storeria occipitomaculata*	1	3
	Ring-necked Snake	*Diadophis punctatus*	-	1
	Smooth greensnake	*Opheodrys vernalis*	3	1
	Five-lined skink*	*Plestiodon fasciatus*	8	-
	Unknown snake	-	-	1
Large Mammals	American black bear	*Ursus americanus*	3	1
	Moose	*Alces alces*	2	4
	White-tailed deer	*Odocoileus virginianus*	1	-
	Unknown large mammal	-	-	2
Medium Mammals	American mink	*Neovison vison*	-	1
	Beaver	*Castor canadensis*	-	1
	Muskrat	*Ondatra zibethicus*	-	1
	Porcupine	*Erethizon dorsatum*	1	-
	Red fox	*Vulpes vulpes*	-	2

Appendix B cont'd

Counts of live and dead wildlife documented during weekly walking railway surveys at Shawanaga First Nation (SFN) and Magnetawan First Nation (MFN). Total counts are pooled among sites and across three years of surveys (2019 – 2021).

Taxon	Species name	Scientific name	Live	Dead
Small Mammals	Least chipmunk	*Tamias minimus*	1	2
	Mouse sp.	*Peromyscus spp.*	-	2
	Red squirrel	*Tamiasciurus hudsonicus*	2	1
	Snowshoe hare	*Lepus americanus*	-	1
	Unknown small mammal	-	-	5
Birds	Barred owl	*Strix varia*	-	1
	Black-billed cuckoo	*Coccyzus erythropthalmus*	-	1
	Blue jay	*Cyanocitta cristata*	1	-
	Flycatcher sp.	*Tyrannidae spp.*	-	1
	Great blue heron	*Ardea herodias*	1	-
	Sandhill crane	*Grus canadensis*	-	1
	Turkey vulture	*Cathartes aura*	2	1
	Unknown bird	-	-	7
Unknown	Unknown (bone fragments)	-	-	9

* indicates a species listed as At Risk under SARA, the Canadian Federal Species At Risk Act

Appendix C

Appendix C. Number of capture events of species documented on the railway at Shawanaga First Nation (SFN) and Magnetawan First Nation (MFN), identified from trail camera photos taken from June 2020 – October 2021. Capture events were recorded passively by trail cameras (*n* = 14) installed along the railway at ~500 m intervals in both First Nation communities

Taxon	Species name	Scientific name	# Capture events
Large Mammals	Canid sp.	*Canid spp.*	1469
	American black bear	*Ursus americanus*	292
	White-tailed deer	*Odocoileus virginianus*	166
	Moose	*Alces alces*	44
	Domestic dog	*Canis familiaris*	7
Medium Mammals	Red fox	*Vulpes vulpes*	1477
	Raccoon	*Procyon lotor*	183
	American marten	*Martes americana*	12
	American mink	*Neovison vison*	6
	Porcupine	*Erethizon dorsatum*	4
	Fisher	*Pekania pennanti*	3
	Weasel spp.	*Mustella sp.*	3
	House cat	*Felis catus*	1
	Bobcat	*Lynx rufus*	1
	Muskrat	*Ondatra zibethicus*	1
	Northern river otter	*Lontra canadensis*	1
	Unknown medium mammal		38
Small Mammals	Red squirrel	*Tamiasciurus hudsonicus*	153
	Snowshoe hare	*Lepus americanus*	38
	Chipmunk	*Tamias sp.*	6

Appendix C cont’d

Number of capture events of species documented on the railway at Shawanaga First Nation (SFN) and Magnetawan First Nation (MFN), identified from trail camera photos taken from June 2020 – October 2021. Capture events were recorded passively by trail cameras ($n = 14$) installed along the railway at ~500 m intervals in both First Nation communities

Taxon	Species name	Scientific name	# Capture events
Birds	Corvid spp.	*Corvidae spp.*	241
	Sandhill crane	*Antigone canadensis*	48
	Unknown bird		38
	Turkey vulture	*Cathartes aura*	22
	Blue jay	*Cyanocitta cristata*	20
	Canada goose	*Branta canadensis*	9
	American robin	*Turdus migratorius*	8
	Ruffed grouse	*Bonasa umbellus*	4
	Sparrow spp.		4
	Common grackle	*Quiscalus quiscula*	3
	Northern flicker	*Colaptes auratus*	3
	American kestrel	*Falco sparverius*	2
	Great blue heron	*Ardea herodias*	2
	Mallard	*Anas platyrhynchos*	2
	Rock pigeon	*Columba livia*	2
	White-throated Sparrow	*Zonotrichia albicollis*	2
	Black-capped chickadee	*Poecile atricapillus*	1
	Flycatcher sp.	*Tyrannidae sp.*	1
	Red-winged blackbird	*Agelaius phoeniceus*	1
	Snow bunting	*Plectrophenax nivalis*	1
	Wild turkey	*Meleagris gallopavo*	1
Amphibians	Unknown frog	*Anura spp.*	4
Turtles	Blanding's turtle	*Emydoidea blandingii*	2
	Midland painted turtle	*Chrysemys picta marginata*	1
	Snapping turtle	*Chelydra serpentina*	1

Appendix D

Appendix D. Railway segments identified as hotspots and coldspots of turtle and anuran railway interactions (live and dead observations) recorded at Magnetawan First Nation (MFN) and Shawanaga First Nation (SFN) during weekly surveys from 2019 – 2021. Hotspots and associated Gi *z*-scores and Gi P-values were identified using Getis Ord Gi* analyses in ArcGIS pro (version 2.8.7). Hotspots are defined as segments with a Gi *z*-score ≥ 1.65 while coldspots are defined as segments with a Gi *z*-score ≤ -1.65.

Site	Taxon	Segment ID	Gi *z*-score	Gi *p*-value	Nearest neighbours	Gi bin
MFN	Turtle	16	2.31174272	0.02079187	3	2
MFN	Turtle	37	2.31174272	0.02079187	3	2
MFN	Turtle	65	2.98835034	0.00280488	3	3
MFN	Turtle	66	3.66495797	0.00024738	3	3
MFN	Turtle	67	2.98835034	0.00280488	3	3
MFN	Anuran	1	1.98426956	0.0472258	3	2
MFN	Anuran	17	-1.6789973	0.09315257	3	-1
MFN	Anuran	26	-1.6789973	0.09315257	3	-1
MFN	Anuran	50	-1.6789973	0.09315257	3	-1
MFN	Anuran	51	-1.6789973	0.09315257	3	-1
MFN	Anuran	52	-1.6789973	0.09315257	3	-1
MFN	Anuran	53	-1.6789973	0.09315257	3	-1
MFN	Anuran	56	2.90008628	0.0037306	3	3
MFN	Anuran	57	1.98426956	0.0472258	3	2
MFN	Anuran	72	2.72213647	0.00648614	2	3
SFN	Turtle	26	3.35778194	0.00078571	3	3
SFN	Turtle	27	3.35778194	0.00078571	3	3
SFN	Turtle	28	3.35778194	0.00078571	3	3
SFN	Turtle	*30	1.66121843	0.09666958	3	1
SFN	Turtle	*31	1.66121843	0.09666958	3	1
SFN	Turtle	32	2.50950019	0.01209022	3	2
SFN	Turtle	33	1.66121843	0.09666958	3	1
SFN	Turtle	37	1.66121843	0.09666958	3	1
SFN	Turtle	38	1.66121843	0.09666958	3	1
SFN	Turtle	39	2.50950019	0.01209022	3	2
SFN	Turtle	40	1.66121843	0.09666958	3	1
SFN	Turtle	41	1.66121843	0.09666958	3	1
SFN	Anuran	19	1.91003177	0.05612912	3	1
SFN	Anuran	29	3.67313801	0.00023959	3	3
SFN	Anuran	*30	3.37928697	0.00072674	3	3
SFN	Anuran	*31	2.49773385	0.012499	3	2
SFN	Anuran	66	-1.9100318	0.05612912	3	-1
SFN	Anuran	72	-1.7865632	0.07400811	2	-1

* Indicates railway segments that are hotspots for both turtles and anuran

Appendix E

Appendix E. Summary of ecological land classification (ELC) polygons and groups of land cover classes used in spatial analyses of turtle and anuran railway interactions and Magnetawan First Nation (MFN) and Shawanaga First Nation (SFN). ELC polygons were interpreted from aerial imagery by Morningstar et al. (2021a, 2021b).

Land Cover Class	ELC Code	ELC Polygon
Wetland	FEB	Fen or Bog
	BOD	Open Bog
	BOS	Shrub Bog
	BOT	Treed Bog
	FEO	Open Fen
	FES	Shrub Fen
	FET	Treed Fen
	MAM	Meadow Marsh
	MAS	Shallow Marsh
	SWC	Coniferous Swamp
	SWD	Deciduous Swamp
	SWM	Mixed Swamp
	SWT	Thicket Swamp
	OAO	Open Aquatic
Forest	FOC	Coniferous Forest
	FOD	Deciduous Forest
	FOD3	Dry Fresh Poplar
	FOM	Mixed Forest
Rock Barren	CLO	Open Cliff
	RBO	Open Rock Barren
	RBS	Shrub Rock Barren
	RBT	Treed Rock Barren