Implementing Multiple Sources of Evidence to Describe Wildlife-Road Interactions in the Chignecto Isthmus Region of Nova Scotia and New Brunswick, Canada

by

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Dedication Page

This thesis is dedicated to all of the wildlife that is impacted by roads around the world, especially the ones which I photographed and removed from the roadside in the Chignecto Isthmus, summer 2018.

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Abstract

Roads impact wildlife through direct vehicle-caused mortality as well as through indirect effects of habitat degradation and fragmentation. These effects are of particular concern in areas important to wildlife movements, such as locations of regional flows or priority linkages, and have the potential to impact the viability and persistence of wildlife populations. The Chignecto Isthmus region of Nova Scotia and New Brunswick has been identified as one such area and is used in this thesis as a case study to model the implementation of a regional-scale road ecology study that uses multiple lines of evidence for wildlife-road interactions. Systematic roadkill surveys and collected wildlife-vehicle collision reports were used to identify road mortality hotspots; trail camera images were employed to qualitatively describe which species were interacting with the road yet not displaying high roadkill rates. These data will help verify wildlife movement pathways and provide evidence-based recommendations for road-effect mitigation strategies.

List of Abbreviations Used

AADT	Annual Average Daily Traffic volume
GIS	Geographic Information System
GNSS	Global Navigation Satellite System
Hwy	Highway
NAD	North American Datum
NB	New Brunswick
NB ERD	New Brunswick Department of Energy and Resource Development
NCC	Nature Conservancy of Canada
NS	Nova Scotia
NS LAF	Nova Scotia Department of Lands and Forestry
RCMP	Royal Canadian Mounted Police
Rte	Route
SCI	Staying Connected Initiative
UCL	Upper Confidence Limit
UTM	Universal Transverse Mercator
Yr	Year

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Chapter 1: Introduction

1.1 Problem Statement

The impacts of roads on wildlife are widely known and documented (Forman & Alexander, 1998; Trombulak & Frissell, 2000; Forman et al., 2003; Beazley et al., 2004; Coffin, 2007; van der Ree et al., 2011; van der Ree et al., 2015; Torres et al., 2016; Tucker et al., 2018; Gunson & Schueler, 2019). Roads affect wildlife through direct impacts such as road-related mortality (roadkill) and indirect impacts on habitat quality, quantity and connectivity (Forman & Alexander, 1998; Coffin, 2007). Such effects can impact populations, as well as individuals of wildlife, affecting population viability and species persistence (Corlatti et al., 2009; van der Ree et al., 2011; Tucker et al., 2018). Roads can cause barriers or pinch-points to wildlife movement, affecting the ability of populations to move and adapt to changes over time, such as seasonal and life requisites, and in response to climate changes (Pelletier et al., 2014). Such effects are of particular concern in areas important to wildlife movements, such as areas of regional flows or priority linkages. One such location is the Chignecto Isthmus, joining Nova Scotia, Canada, to the rest of continental North America (MacDonald & Clowater, 2005; Trombulak et al., 2008). This location has been identified as a priority linkage area, which is increasingly being restricted by sea level rise and infrastructural developments including roads, with potentially significant negative implications for wildlife (MacDonald & Clowater, 2005, Reining et al., 2006; NEGECP, 2016).

Consequently, this thesis examines the role that roads play in impacting ecological connectivity throughout a regional-scale landscape via their direct impacts on wildlife in terms of causing both wildlife-vehicle collisions and a barrier effect. Findings and conclusions are intended to help inform decisions for mitigating vehicle-caused wildlife mortality while enhancing human safety and habitat connectivity to promote robust, genetically diverse populations of wildlife in New Brunswick and Nova Scotia, around the Chignecto Isthmus and the mainland areas to which it provides a linkage. If implemented, recommended mitigation measures should be monitored to verify their effectiveness, providing information and a potential model for similar applications in other regions (Clevenger, 2005; Corlatti, 2008; Slesar, 2017). The research will contribute to the much-needed work to restore and maintain ecological connectivity in the Chignecto Isthmus, and thus increase the adaptability and resiliency of wildlife in Nova Scotia and of the larger Northern Appalachian-Acadia ecoregion (NS DNR, 2007; NEGECP, 2016). More broadly, the work will help address a gap identified in the literature on road ecology (e.g. Thorne et al., 2009; van der Ree et al., 2011) by focusing on a broad regional landscape assessment of road effects on wildlife, thereby providing an example that may prove illustrative for application in similar study regions elsewhere.

1.2 Literature Review

1.2.1 Impacts of Transportation Infrastructure on Wildlife

As a source of anthropogenic disturbance, roads rival other human development for their impact on wildlife by contributing heavily to habitat fragmentation (Underhill & Angold, 2000). Transportation infrastructure is pervasive, and there are few points on the landscape that remain unreachable by road (Ibisch et al., 2016) – even protected areas often have rudimentary access roads or highways which allow visitors to pass through, negating some of the effects of protection (Kleinschroth & Healey, 2017; Saura et al., 2018). Furthermore, if natural areas are unprotected, then road construction often leads to more development as access to previously inaccessible areas increases (Garriga et al., 2012; Kleinschroth & Healey, 2017). Road construction has increased rapidly over the past century to such a degree that a quarter of all land in Europe is located within 500 m of a road, and there is no land outside of protected areas that is greater than 1,500 m from a road in many areas of the world (Torres et al., 2016). Roadless areas with a buffer of at least 5 km from the nearest road constitue only 57% of the Earth's land cover with that total roadless area fragmented into upwards of 50,000 discrete patches (Ibisch et al., 2016). Of those patches, many have severely reduced ecological value (Ibisch et al., 2016). Currently, there are over 21 million km of roads globally and road development is on track to add an additional 3-5 million km of roads by 2050, mainly in developing countries, further fragmenting previously undeveloped natural areas (Kleinschroth & Healey, 2017; Meijer et al., 2018).

Road ecology, as a discipline, is an area of study which recognizes and investigates the effects of transportation infrastructure on multiple facets of ecosystems (Forman & Alexander, 1998; Forman et al., 2003; Coffin, 2007; van der Ree et al., 2011; Gunson & Schueler, 2019). Both biotic and abiotic impacts, such as the spread of invasive plant species, or increased erosion and pollutant transport due to water runoff from the road surface are experienced by ecosystems worldwide (Forman & Alexander, 1998; Forman et al., 2003; Coffin, 2007). Although the suite of ecological impacts imparted by roads is myriad, one of the most direct actions felt by wildlife is the loss of habitat connectivity. As the interconnectedness of road networks and the convenience of land-based transportation increases, the connectedness of valuable ecosystems decreases. Roads are mainly a linear type of disturbance, in any one area usually no more than several dozen metres in width depending on the number of lanes and the presence or absence of a median, however their prevalence is a major contributor to habitat fragmentation and therefore a loss of connectivity for wildlife (Trombulak & Frissell, 2000; Lesbarrères & Fahrig, 2012). Beyond the road surface, considerable effects on habitat from vegetation clearance and pollution occur up to 5 m away, with effects on the ecosystem up to 100 m from the road even for species which tolerate edge habitat (Underhill & Angold, 2000). For the majority of birds and mammals, however, a buffer distance of only 100 m is not large enough. Both birds and mammals generally either display road avoidance or reduced population density in response to road infrastructure with the effects evident up to 1 km away for birds and up to 5 km away for mammals (Benítez-López et al., 2010). In many areas of the world, there is very little area left that is outside of the 5 km road-effect zone for mammals, and therefore nearly all populations are affected by transportation infrastructure (Torres et al., 2016). For many wildlife species, road density, causing habitat loss, fragmentation, and degradation, is a negative indicator of viability and population persistence (Underhill & Angold, 2000; Forman et al., 2003; Beazley et al., 2004; Litvaitis & Tash, 2008).

As the number of roads in a fixed area of land increases, the instances of direct mortality due to collisions with animals attempting to cross to reach key habitat features and the effects on animals in terms of avoidance behaviour increase (Forman & Alexander, 1998; Beazley et al., 2004; Litvaitis & Tash, 2008). Jaeger et al. (2005) identify four main areas which represent the most critical negative ecological effects of roads. First, road development decreases the total amount of habitat available and further decreases the quality of the remaining habitat by reducing patch size and increasing the ratio of edge length to area. Second, vehicles travelling on roads increase the likelihood of direct mortality through collisions, for animals that attempt to cross. Third, roads prevent access to resources such as food and water, whether the animal is killed or avoids crossing. Fourth, roads subdivide larger populations into smaller subpopulations that may be more vulnerable to predators or reduced genetic diversity and therefore inbreeding, over time (Jaeger et al., 2005).

Where road development fragments habitat, it increases the proportion of habitat that is located near an edge, which has negative effects on the overall amount of available habitat for species which prefer the interior (Reed et al., 1996; Torres et al., 2016). Edge effects for habitat specialists can be particularly challenging as the conditions near the edge (e.g. noise, availability of shelter, vegetation types) are often vastly different from the interior, and some species may experience reduced density of populations in locations proximal to roads due to noise and reduction of habitat quality (Reijnen et al., 1997). Habitat generalists are more likely to tolerate this range of conditions and therefore survive in smaller patches (Andrén, 1994; Keinath et al., 2016). Wide-ranging wildlife with high mobility, however, or those with low reproductive rates, whether habitat specialists or generalists, are always more susceptible to negative road effects (Singleton et al., 2004; Rytwinski & Fahrig, 2012). Therefore, both the size and quality of remaining habitat patches as well as their connectedness to other patches are major factors related to the viability of wildlife populations (Harrison & Bruna, 1999; Singleton et al., 2004).

Roads pose a threat, and therefore a barrier, to animals that are both willing and unwilling to cross when encountering the road surface (Trombulak & Frissell, 2000; Coffin, 2007; Lesbarrères & Fahrig, 2012). Those which cross are vulnerable to injury or death through vehicle collisions. Factors which contribute to when and where animals are hit by vehicles include traffic volume, traffic speed, road width, the microclimate along the road corridor and the physical substrate of the road, the presence or absence of fencing, steepness of the embankments, availability of potential crossing structures (e.g. culverts, bridges, or tightly closed canopy for arboreal species), and position of the road in relation to good habitat resources, adjacent populations and regular migration pathways (Trombulak & Frissell, 2000; Fudge et al., 2007; Seo et al., 2015). Wildlife road mortality due to vehicle collisions, often called 'roadkill', is a major visible symptom of a loss of habitat connectivity for wildlife with negative influences on population persistence (Trombulak & Frissell, 2000).

1.2.2 Road-Effect Mitigation

As established above, roads have serious impacts on wildlife population persistence due to road mortality from vehicle collisions, and their roles as barriers and deterrents to animal movement (Forman & Alexander, 1998; Forman, et al., 2003; Jaeger et al., 2005; Coffin, 2007; Glista et al., 2009; Lesbarrères & Fahrig, 2012; Simpson, et al., 2016; Magioli et al., 2019). Many species experience high roadkill rates, especially if they have an increased likelihood of 1) entering the roadway because they do not avoid traffic or road-related threats, and 2) performing a behavioural response to traffic which puts them at greater risk of collision, such as freezing in place in response to the threat of a moving vehicle (Jacobson et al., 2016). Roadkill can severely limit the population numbers of these species, especially if they have life history characteristics that make them more susceptible to population decline with the added pressure of road mortality (e.g. low reproductive rate, lack of natural predators that would otherwise limit their populations) (Fahrig & Rytwinski, 2009;

Rytwinski & Fahrig, 2012). Road mortality has the potential to depress populations in these instances.

For other species, while roadkill is not a limiting factor to population persistence, because they rarely get hit on roads, the barrier effect as a deterrent is what causes the biggest issues. Species which are highly affected by the deterrent effect that roads create are those which avoid roads, even at low traffic volumes, and those which have low roadkill rates at high traffic volumes because they recognize the threat of moving vehicles and avoid entering the roadway (Jacobson et al., 2016). Additionally, these species which experience population-level effects generally have large home ranges, undergo seasonal migrations, or have experienced a recent barrier between habitat resources, such as a road built through a wetland (Rytwinski & Fahrig, 2012).

From a conservation perspective, roads are a source of mortality and a barrier, the effects of which should be mitigated through planning and implementation of strategies which address both human behaviour and animals' responses to roads (Rytwinski, et al., 2016). From a human health and safety perspective, strategies which keep wildlife from entering the roadway, as well as those which encourage motorists to change their driving habits, are often a major priority for funding and promotion. Conservation goals then have the potential to piggyback on health and safety goals to solicit and strengthen public support for their implementation.

There exist several low-cost strategies that address motorist behaviour to mitigate wildlife-vehicle collisions. While ultimately excluding wildlife from roads completely is the most effective option to eliminate roadkill altogether, it is not always practical, especially in residential areas where fencing becomes ineffective due to frequent gaps (Glista et al., 2009). Sometimes, it is more practical to increase awareness of the risks to human safety that collisions with wildlife pose and to mitigate vehicle speed, so that motorists can avoid collisions more easily and safely. Making motorists aware of the potential for wildlife crossing in a specific area, based on roadkill collision data, and reducing speed limits with increased speed limit enforcement are two strategies that directly target drivers' actions and should be implemented in tandem as a low-cost roadkill mitigation strategy (Glista et al., 2009).

Planning for both roadkill mitigation and barrier reduction are two complementary, yet at times opposing, actions. Transportation planners and conservation specialists would be well served to work together to consider multiple factors that impact the design and location of mitigation structures to protect humans and wildlife and allow for safe passage of both. These factors include understanding which species need to be targeted for mitigation and the specific ways in which they are impacted by roads, characteristics of the roadway, such as traffic volume or the potential to safely implement crossing structures, and the contiguous landscape, such as suitability of the surrounding habitat. Thus, when planning road-effect mitigation strategies, whether for a single roadway, or for an entire regional road network, one of the first considerations should be to determine which species are most in need of mitigation (Rytwinski & Fahrig, 2012).

Some animals, such as some species of small mammals, birds, herpetofauna and invertebrates, are frequently hit on roads. However, if they are small enough to not be a safety hazard and have population numbers stable enough to endure road mortality pressure, although sad, they are less likely to warrant focus for conservation or safety mitigation efforts. Because these are often generalist species which thrive around human-occupied spaces (e.g. raccoons, crows, squirrels), it would be nearly impossible to keep them off of roads completely. Others, such as most invertebrates, are "non-responders" to roads and do not recognize vehicles as threats (Jacobson et al., 2016), and therefore are also difficult to exclude from roads. Many of these species, though, may have the potential to secondarily experience positive effects of mitigation strategies designed with other focal species in mind, especially in cases that involve changing motorist behaviour, which, although less effective than removing wildlife from roads, may benefit a broad suite of wildlife when drivers become more vigilant (Magnus et al., 2004).

The considerations surrounding the decision as to which road-affected species to prioritize in road mitigation planning generally fall under two main categories: 1) species of conservation concern, and 2) species which cause human safety concerns (Litvaitis & Tash, 2008). The former are those species which experience negative population effects, including mortality rates greater than reproductive rates, due to collisions with vehicles or the barrier effect, and which may or may not be already listed as at risk (e.g. vulnerable, threatened or endangered) (Litvaitis & Tash, 2008). The latter are those species which are large enough to cause damage to vehicles, human injury, and/or loss of life when involved in collisions, including accidents which occur from motorists attempting to avoid collisions. These two categories are not necessarily mutually exclusive, as many large mammals experience population depression due to increased mortality, inability to access resources or decreased genetic flow (Singleton et al., 2004). Those species of conservation concern, however, which are impacted by roads, but which do not in turn impact human safety as severely as others, are often not in the public perception as ones to consider when planning road mitigation. Nonetheless, for conservation purposes, road mitigation for such species may be warranted.

Roadkill and road barrier mitigation strategies are not all equally effective and have different ranges of effectiveness for different species based on their size, life history requirements and past population pressures (Bager & Fontoura, 2013; Jacobson et al., 2016). For instance, Bager and Fontoura (2013) found that, although a wildlife protection system which included a series of underpasses, fences, and stock guards to block the beginnings and ends of the fences was successful in reducing mortality of the main species of mammal to which it was targeted, it had no effect on the roadkill rates of any other species. It was assumed that the system would also benefit a variety of other species in the ecosystem and reduce their roadkill rates, but this was not the case as some species were able to climb the fences, while others were able to pass through gaps or use vegetation growing around the fence to pass over or around the barrier (Bager & Fontoura, 2013).

A variety of roadkill mitigation strategies exist, some targeting motorist behaviour, such as warning signs and reduced speed limits in known problem areas, others targeting wildlife responses to roads, such as fences and barriers to keep animals from entering the roadway (Magnus et al., 2004; Glista et al., 2009; Rytwinski et al., 2016). Unfortunately, although popular and relatively inexpensive, focusing on driver behaviour alone has not been shown to significantly reduce roadkill rates, and strategies to modify wildlife behaviour without physically blocking entry to the roadway, such as wildlife reflectors designed to deter animals from crossing, also do not have evidence for their effectiveness (Rytwinski, et al., 2016). The most effective strategy for reducing wildlife-vehicle collisions is one that removes the chance of wildlife appearing on the road altogether, which is a barrier structure such as a wildlife fence (Jaeger & Fahrig, 2004; Rytwinski et al., 2016). Depending on the species targeted, fences may take the form of plastic sheeting for amphibians, fine mesh for small mammals, or structures tall enough to keep ungulates from jumping into the roadway (Eco-Kare International, 2015). Planning for the target species is essential as, for example, amphibian fencing will not keep deer off of the highway and fencing with a large mesh size will not block a salamander migration. Beyond the type of fencing, other considerations are length of fencing, as fences which are not long enough result in roadkill hotspots shifting to the ends of the fences, rather than being reduced, as well as the inclusion of escape structures, such as jump-outs and one-way gates for animals that find their way onto the road (Clevenger et al., 2001b; Jaeger & Fahrig, 2004; Huijser et al., 2016; Rytwinski et al., 2016).

If mitigation planning aims at reducing roadkill, alone, then the general public may be pleased with the reduced roadkill events, especially with larger mammals. However, the road thus becomes a heightened barrier to wildlife and increases habitat fragmentation (Jaeger & Fahrig, 2004; Olsson et al., 2008). Good road-effect mitigation considers not only the reduction in roadkill as a measure of success, but also an increase in permeability of the road network for safe wildlife movement (Clevenger, 2005). This may sound contradictory, however there are options for wildlife to safely traverse the roadway without travelling directly on the road surface. Wildlife crossing structures, sometimes called “eco-passages”, are any structures that allow animals to safely move under or over the road to maintain horizontal ecological flow across the landscape (Clevenger et al., 2001a), and when properly implemented can contribute to reducing risk of a collision (Beazley et al., 2004). Crossing structures can take a variety of forms; underpasses range in sizes from small pipe or box culverts to larger passageways that promote movement for a wide array of species, while overpasses are generally larger, allowing for a continuation of the natural landscape from one side of the road to the other, but also may take the form of narrow rope bridges spanning tens of metres above the road to allow arboreal species safe crossing opportunities (Bissonette et al., 2008; Glista et al., 2009). Although the focus of this thesis is mainly on terrestrial species and their interactions with roads, aquatic connectivity is maintained across roads with the installation of bridges spanning rivers or allowing for flow across otherwise less permeable causeways, or through smaller culverts with flowing water allowing for drainage but also connectivity between wetlands fragmented by roads (Trombulak & Frissell, 2000; Januchowski-Hartley et al., 2013). Similar to goals in the terrestrial realm, aquatic connectivity opportunities should be systematically documented, and regional planning implemented to improve connectivity across landscapes that span political borders (Januchowski-Hartley et al., 2013).

Fencing without crossing structures reduces roadkill but increases the barrier effect of roads, while implementing crossing structures alone does not guarantee they will be used by wildlife if the roadway is still accessible and more convenient for crossing. Successful road effect mitigation must implement wildlife crossing structures along with properly installed and maintained fences to guide animals to the passageways (Rytwinski, et al., 2016).

One of the most common ways to begin to assess the impacts of a road on local populations of wildlife and to understand where problem areas exist is to analyze roadkill rates and locate hotspots for wildlife road mortality (Litvaitis &

Tash, 2008). Often, from these data, planners will determine priorities for sites at which to place fences and/or wildlife crossing structures. While not a misguided approach, it is not a complete one. Roadkill rates by themselves are not the only determining factor to inform decisions as to which roads should receive mitigation, or where that mitigation should be located along the road (Litvaitis & Tash, 2008; Roger & Ramp, 2009; Bager & da Rosa, 2010). Utilizing roadkill hotspots alone to determine placement of wildilfe crossing structures misses several major considerations, namely: 1) species whose populations have been depressed due to high rates of road mortality, 2) species which avoid roads and therefore are not frequently present in the roadkill record, and 3) habitat value of the surrouding landscape (Litvaitis & Tash, 2008; Bager & da Rosa, 2010; Eberhardt et al., 2013). Also, collection of roadkill data is highly dependent on the permanence of the carcass along the roadside, as individuals that may be experiencing high roadkill rates could go undetected due to the quick removal by scavengers or other environmental variables (Antworth et al., 2005; Santos et al., 2011; Ratton et al., 2014).

Accordingly, a robust, comprehensive approach to determing the best course of action to mitigate road-effects in terms of direct wildlife mortality and barriers to ecological flow will consider multiple sources of data and lines of evidence, which together can be examined to determine both the most critical species to target and highest priority locations to address (Vanlaar et al., 2012). Such a robust approach might take into account computer modelling of ecological flow and resistance to movement by natural and artificial barriers across the landscape, as well as habitat suitability modelling around roads to detrmine ideal locations to place crossing structures to mimic the continuation of natural habitat. This approach might also take into account relative population sizes and needs of individual species for habitat requirements and genetic exchange between populations or it could investigate historical population data to detect trends related to road construction or improvement and population increases or declines. Specific data related to wildlife-road interactions could be collected through wildlife-collision reports by motorists, systematic as well as opportunistic roadkill surveys, trail cameras, snow and sand track identification of species near roads, radio collaring and aerial surveys to determine actual wildlife movement, and also local knowledge from residents in the area about wildlife presence and movement, especially from hunters, trappers, landowners and other outdoorspeople.

1.3 Goal and Objectives

The goal of this thesis is to implement multiple sources of data related to wildlife-road interactions as evidence for wildlife movement paths through a regional scale landscape in the Chignecto Isthmus and as a case study to model a broad, regional-scale road ecology assessment. The accomplishment of this goal will promote evidence-based development of strategies to preserve and enhance wildlife pathways for increased ecological resilience in the region and provide an illustrative broad-scale road ecology method for potential application in similar regions elsewhere. This goal will be achieved through the following objectives.

- Examine and describe the availability and utility of multiple lines of evidence for wildlife interaction with roads, including analyses of:
    - Roadkill survey data from roads in the study area of the Chignecto Isthmus for hotspots corresponding to aggregations of significant wildlife road mortality;
    - Wildlife collision reports in the region from government agencies; and,
    - Trail camera images to describe wildlife presence near roads.
- Use wildlife-road interactions as a line of evidence for predicting where wildlife move across the landscape by:
    - Comparing the results of the roadkill hotspot analysis with a computer-modelled wildlife movement corridor produced for a suite of focal species across the Chignecto Isthmus region.
- Describe the usefulness of non-statistically significant observations that demonstrate where wildlife interact with roads to help strengthen the choice of future survey locations as well as road-effect mitigation structures.

1.4 Methodological Approach

This study employs a mixed methods approach to gathering both primary and secondary data. The initial focus was on gleaning data on wildlife-vehicle collisions directly from the source – carcasses left as evidence at the side of the road. Thus, the main source of data is one field season's worth of roadkill carcass surveys across 12 roads in the Chignecto Isthmus region. As a supplement, and to investigate what information can be learned from secondary reports of collisions collected by government agencies or law enforcement, wildlife road mortality reports from natural resource departments in Nova Scotia and New Brunswick were analyzed for their usefulness in providing information on the numbers and locations of wildlife mortalities on roads over an extended time period.

A third source of evidence is from observations of wildlife interactions with roads gathered through motion-triggered trail cameras. These still images are used to provide evidence of species which will approach and cross roads, with the aim of determining those which interact with roads on a regular basis. The camera images were analyzed for species richness at each location and for the usefulness of placing cameras near the roadside for collecting information on crossing and avoidance behaviour.

The three sources of data that are used in this thesis provide examples of different approaches to gathering information on the impact of roads on wildlife within a given region. Together, they show similarities and differences in their generated results; accordingly, they may be used to complement each other, and/or to provide greater support for results that are consistent across sources. These data sources are not exhaustive. A broad-scale study with the aim of improving habitat connectivity and ecological flow throughout a region should strive to integrate as many lines of evidence as possible. Increased confidence provided through multiple lines of inquiry should serve to support transportation planners in integrating evidence-based road-effect mitigation strategies into existing and future road designs.

1.5 Thesis Structure

The thesis is arranged as a series of five chapters, three of which describe the different methods of data collection, analyses and results, providing evidence for how wildlife are interacting with roads. Chapter two is intended as a stand-alone paper in preparation for submission to an academic journal. It introduces the specific geographic context of this study and discusses a novel application of roadkill data to ground-truth a modelled wildlife movement corridor across a regional-scale landscape. Since it will be a standalone piece, this chapter has its own introduction, methods, results and discussion sections, and therefore some repetition of content provided in other chapters is unavoidable.

Chapters three and four focus on the use of two additional sources of data to provide supplementary evidence of wildlife-road interactions, respectively: collision reports from provincial databases; and, motion triggered trail cameras. These chapters each contain a short literature review to orient the reader on the collection and use of these types of data sources, an overview of how these secondary data were treated and analyzed, and a discussion of the trends evident therein.

The final chapter provides a synthesis discussion and conclusion, drawing upon the three methods of inquiry. As such, it integrates the major sources of data with a discussion of the patterns within and similarities between the different lines of evidence that emerge upon comparisons. It also provides a brief look into another potential source of evidence for wildlife-road interactions and recommends further data collection and analyses related to describing road effects across a large regional landscape scale. Although the findings are preliminary, representing the first spatial analysis of road-related mortality in the region, potential measures for road-effect mitigation to increase connectivity across roads and decrease the occurrence of wildlife road mortality are discussed specific to the Chignecto Isthmus region.

Chapter 2: Implementation of Roadkill Survey Data across a Large Regional-Scale Landscape to Ground-Truth a Modelled Wildlife Movement Corridor at Locations where it Intersects Roads

2.1 Introduction

Connected habitat is critical to wildlife dispersal, migration, and other life-requisites such as finding mates, reaching diverse food sources, and undertaking home-range shifts in response to climate change (Noss, 1991; Bennett, 2003; Singleton et al., 2004; Tucker et al., 2018). Isolated patches of habitat are generally ineffective for maintaining population viability for many species, with implications for reduced genetic dispersal; interconnected habitat is essential to maintain important ecological processes and flow (Diamond, 1975; Singleton et al., 2004; Garriga et al., 2012; Saura et al., 2018). Identifying opportunities to conserve or restore habitat connectivity involves understanding where wildlife can move and disperse if necessary, and what barriers to movement are present. Barriers can result in bottlenecks or pinch-points to wildlife movement across the landscape, and connectivity modelling can show where they are likely to occur (Pelletier et al., 2014; Nussey & Noseworthy, 2018; Tucker et al., 2018). These restrictions occur where there is insufficient habitat, generally from human development, and are most often associated with roads. Areas where pinch-points intersect roads are likely to experience higher than expected incidences of wildlife-vehicle collisions for species that opportunistically attempt to cross roads (Forman & Alexander, 1998; Fahrig, 2003; Coffin, 2007; Fudge et al., 2007; Woolmer et al., 2008).

Empirical data to determine exactly where and how wildlife move, such as consistent observations using tracking, camera traps, or radio collar surveys, are not always available or feasible to collect due to time or financial constraints, as well as the limitations posed by working with wild animals and their reactions to humans (Silveira et al., 2003; Graves & Wang, 2012; Meek et al., 2014). One method to determine where wildlife are likely to move across the landscape is to model habitat requirements for focal species, then to determine the pathway of least resistance between start and end points (Singleton et al., 2004; Graves & Wang, 2012; Nussey & Noseworthy, 2018). Such models, however, require ground-truth validation. One way to do this is to collect and analyze wildlife road mortality (also known as roadkill) data to verify crossing areas and/or pinch-points using systematic carcass surveys (Gerow et al., 2010). Intersections between wildlife movement pathways and roads result in higher rates of animal mortality due to wildlife-vehicle collisions, barriers to animal movement due to aversion to traffic noise or sudden gap in tree cover, and other negative effects (Forman & Alexander, 1998; Lodé, 2000; Trombulak & Frissell, 2000; Coffin, 2007; Fudge et al., 2007). Roadkill has been shown to be related to the degree of connectivity in the surrounding landscape; roads which pass through otherwise more connected habitat tend to experience elevated levels of wildlife-vehicle collisions (Garriga et al., 2012; Kang et al., 2016).

The detection of roadkill hotspots requires systematic, standardized reporting methods, however data on wildlife road mortality are sparse and often collected unsystematically through motorist collision reports to law enforcement or by road maintenance crews untrained in species identification or the collection of GNSS data (Fudge et al., 2007; Huijser et al., 2007). The reliability of these data varies, and records may be missing key information such as an accurate location or taxonomic identification (Gunson et al., 2003). Eliciting the public for opportunistic observations allows for a broader understanding of the road mortality events that are occurring outside of the larger species that would often be reported, but it also requires coordinated efforts to promote data collection initiatives (Shilling & Waetjen, 2015). One method to improve the reliability of the data collection is to choose specific roads of interest, such as those which disrupt corridor connectivity or where key habitat patches are located on both sides and plan scheduled systematic surveys targeted to the species most likely to rely on connected habitat (Quintero-Ángel et al., 2012; Santos et al., 2015). This method of data collection can allow for the detection of road mortality hotspots to better inform conservation and transportation planners on where key pinch-points for wildlife crossing are located.

Despite a recognized need for broad, landscape-scale understandings of wildlife movements and interactions with roads so that mitigation measures can be integrated into road design, most road ecological studies continue to focus on fine-scale, local studies (Thorne et al., 2009; van der Ree et al., 2011). Roadkill carcass surveys are rarely conducted across large study areas, and typically focus on discrete road sections and/or on particular species or suites of species (Bager & da Rosa, 2010; Gerow et al., 2010). This study outlines a method for collecting roadkill data on a large-regional scale and demonstrates how these data have the potential to be used to ground-truth a modelled wildlife movement pathway by identifying the presence or absence of aggregations of wildlife mortality at road locations that do and do not intersect with the modelled pathway.

2.1.1 Chignecto Isthmus Study Area

The Chignecto Isthmus region connects the peninsular eastern Canadian province of Nova Scotia with the rest of North America, via New Brunswick. The isthmus is narrow, only 20-23 km in width in some places, low-lying, with a high degree of human impact, making both the infrastructure and remaining natural habitat vulnerable to climate change related events such as storm surges and sea level rise (MacDonald & Clowater, 2005; Woolmer et al., 2008; Mazerolle et al., 2016). As a result, it is increasingly difficult for wildlife, especially wide-ranging species, to find sufficient, un-impacted habitat. Without movement through this corridor, some wildlife in Nova Scotia and southern New Brunswick would be isolated from continental populations, with negative implications for viability and persistence (Snaith & Beazley, 2002; Fahrig, 2003; Beazley et al., 2004; Woolmer et al., 2008).

In 2016, the Nature Conservancy of Canada (NCC) produced a wildlife habitat connectivity model for the Chignecto Isthmus region. Modelled outputs delineated a high-probability wildlife movement pathway of approximately 3-7 km in width, running northwest-southeast across the New Brunswick-Nova Scotia border (Nussey & Noseworthy, 2018) (Fig. 1).

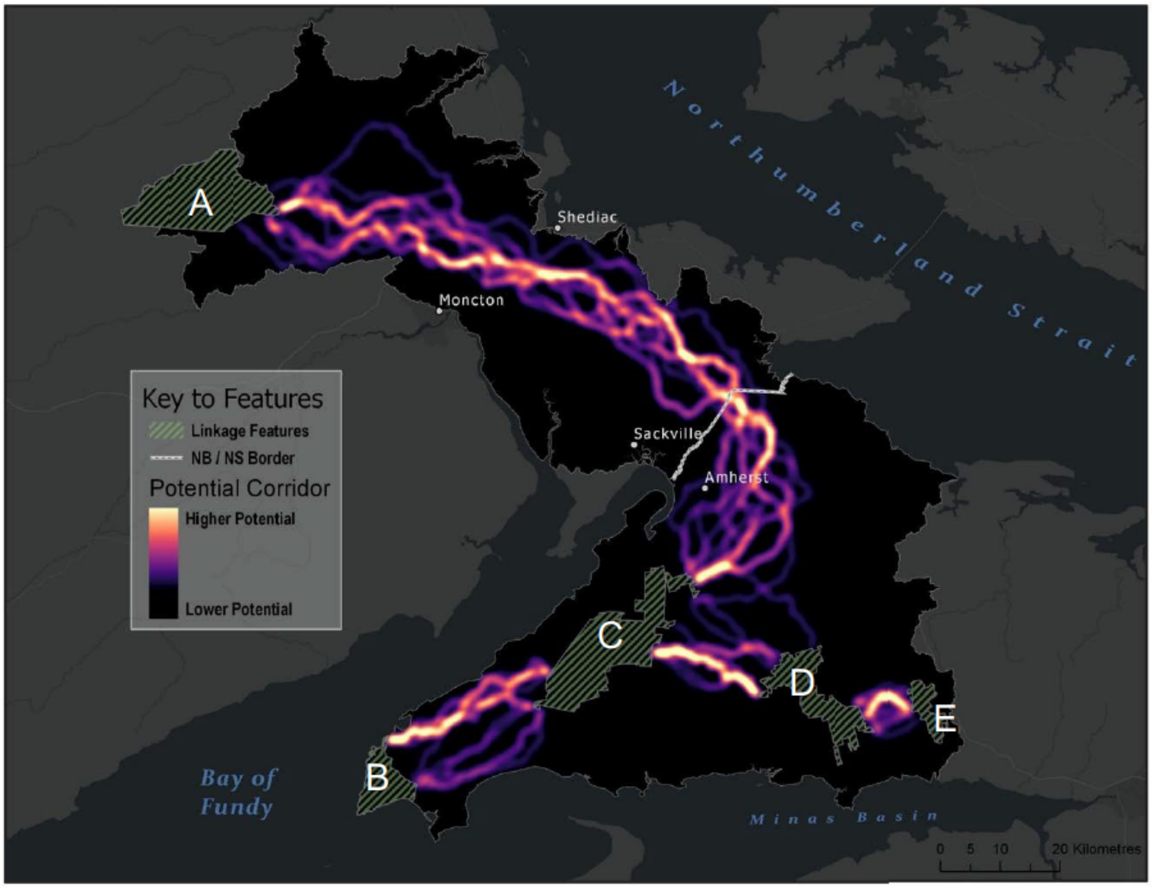

Figure 1. Model of potential corridors across the study area showing a low to high range of probability for wildlife movement. The four protected areas are shown as A) Canaan Bog, B) Cape Chignecto, C) Kelley River, D) Economy River, and E) Portapique. Adapted with permission from "A wildlife connectivity analysis for the Chignecto Isthmus Region" (Nussey & Noseworthy, 2018).

To define this corridor, NCC determined the most likely movement pathways for 12 representative vertebrate (mammal and bird) species[1], representing a variety of medium- to wide-ranging animals with both habitat generalists and specialists included. The 'least-cost paths' were determined by assigning habitat suitability scores to land cover between an area of protected

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[1] Focal species used for Chignecto Isthmus wildlife connectivity analysis were: moose (*Alces alces* americana), black bear (*Ursus americanus*), red fox (*Vulpes vulpes*), bobcat (*Lynx rufus*), snowshoe hare (*Lepus americanus*), fisher (*Martes pennanti*), northern flying squirrel (*Glaucomys sabrinus*), northern goshawk (*Accipiter gentilis*), pileated woodpecker (*Dryocopus pileatus*), brown creeper (*Certhia americana*), boreal chickadee (*Poecile hudsonicus*), and blackburnian warbler (*Setophaga fusca*) (Nussey & Noseworthy, 2018).

habitat in New Brunswick[2] and four protected areas in Nova Scotia[3], then calculating the paths of lowest resistance to movement between the protected areas. Through kernel density analyses, the resulting combined paths were used to predict a high-probability wildlife movement corridor, which represents a route that the selected wildlife are most likely to take that minimizes obstruction to ecological flow from perspectives of risk of mortality, lack of habitat resources, or physical barriers to movement (Nussey & Noseworthy, 2018). Several sections of the corridor represent pinch-points where wildlife may be in competition for space and resources and come into contact with roads (Fig. 2).

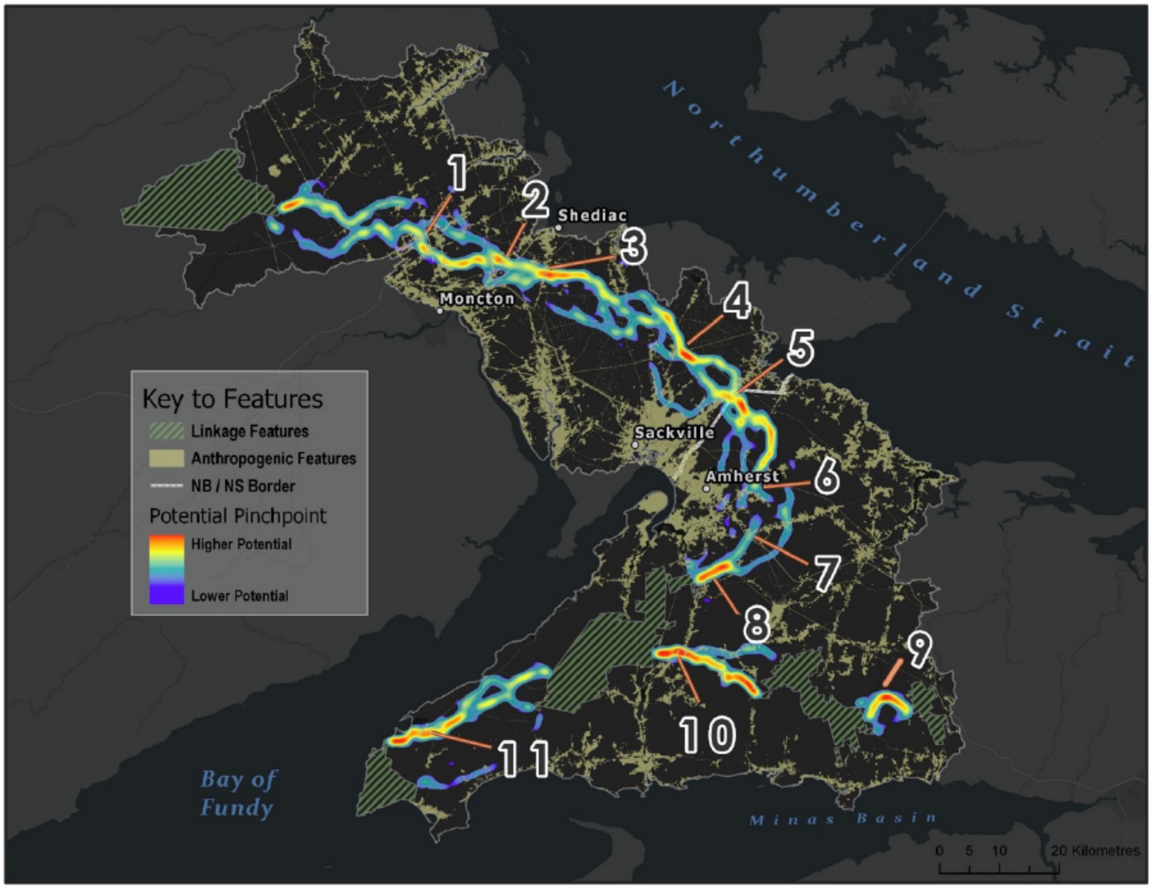

Figure 2. Potential pinch-points to ecological flow in the Chignecto Isthmus. With permission from "A wildlife connectivity analysis for the Chignecto Isthmus Region" (Nussey & Noseworthy, 2018).

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[2] Canaan Bog Protected Natural Area

[3] Cape Chignecto Provincial Park, Kelley River Wilderness Area, Economy River Wilderness Area, and Portapique Wilderness Area

The goal of this study is to verify corridor model results through field surveys such as roadkill analyses that compare data from within and outside of the modelled high-probability wildlife movement pathways. A key limitation to this type of corridor model is that the definition of start and end points is artificial and may not represent pathways of all wildlife. For instance, not all wildlife will move between the specified protected areas, dispersal is not necessarily linear, and wildlife may choose directions for travel that differ significantly from those chosen by the analyst for flow between protected areas. For this reason, it is expected that not all roadkill hotspots will necessarily fall within the modelled corridor, as there may be suitable habitat outside of the modelled corridor. Also, many local populations of animals do not travel large distances on a regular basis, contributing further to hotspots outside of the model. Thus, a key objective is to determine if significant spatial aggregations of wildlife mortality, also known as "hotspots", are associated with segments of roads that intersect the modelled wildlife corridor and can therefore be used to ground-truth or verify the potential for this corridor to serve as a high-probability pathway for wildlife movement. If this modelled corridor is actually used by wildlife for movement and dispersal through the Chignecto Isthmus, then this will be further evidence for deciding where to locate wildlife crossing structures or other safe-passage mitigations at key pinch-points along roads.

This study represents a pilot investigation into the state of wildlife-vehicle collisions in the Chignecto Isthmus region and indicates where more intensive studies should be conducted to target those areas where initial hotspot detection has occurred. Such broad, regional-scale road ecology analyses are rare, especially those which focus on systematic roadkill data collection. Accordingly, this study signifies a nascent foray into this territory, addressing a gap in the field. Because the study area is large and field work is time intensive, this single season of data collection and analysis represents preliminary data and results. Nonetheless, it is important (1) as a demonstration of a novel application of roadkill survey data for potential use in other regions with similar characteristics and challenges, and (2) for building a longer-term dataset for monitoring and decision making in the study area.

2.2 Methods

2.2.1 Study Area

The study area encompassed survey routes on 12 road sections totalling approximately 350 km in length over an area of 2,500 km^2, in the Chignecto Isthmus region of New Brunswick and Nova Scotia in eastern Canada (Fig. 3). The most northwestern study site is in New Brunswick, NB Rte 134, which connects the municipalities of Dieppe at the southwest end[4] with Shediac at the northeast end[5]. There are key points of restriction related to wildlife habitat connectivity between the towns of Dieppe and Shediac, which are less than 20 km apart. This pinch-point has the potential to also impact some wildlife movement into and out of Nova Scotia (Nussey & Noseworthy, 2018). The most southwestern study site is in Nova Scotia at approximately the intersection of NS Rtes 2 and 302 in Southampton[6]. Finally, the northeastern terminus of the study area is in Nova Scotia at approximately the intersection of NS Rtes 301 and 6 in Port Howe[7]. The roads were chosen as numbered routes (both highways and secondary roads) which intersect the NCC's (2016) modelled potential wildlife movement corridor between Canaan Bog Protected Natural Area in New Brunswick and Kelley River Wilderness Area in Nova Scotia (Fig. 3).

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[4] UTM Zone 20 T 368702.57 m E. 5109621.31 m N.
[5] UTM Zone 20 T 378013.13 m E. 5120444.55 m N.
[6] UTM Zone 20 T 402600.98 m E. 5049724.03 m N.
[7] UTM Zone 20 T 441540.79 m E. 5078032.39 m N.

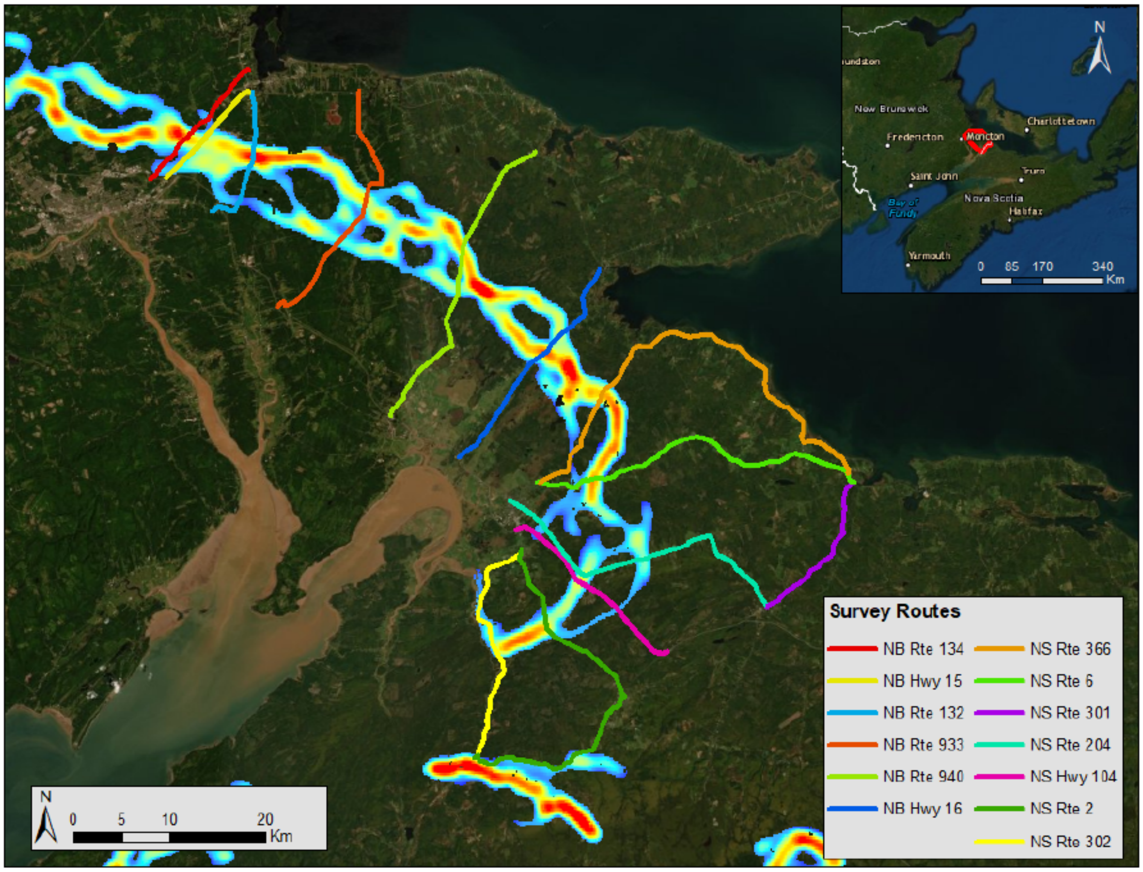

Figure 3. Chignecto Isthmus roadkill carcass survey routes intersecting the NCC's modelled wildlife movement corridor. The modelled corridor uses a cool – warm colour scale to indicate low – high probability of wildlife movement. The darkest red areas represent pinch-points to movement (Nussey & Noseworthy, 2018). The inset map shows the position of the Chignecto Isthmus as a terrestrial linkage between the peninsular province of Nova Scotia and the province of New Brunswick. Base maps courtesy of ESRI (ESRI, 2016).

2.2.2 Roadkill Surveys

Roadkill surveys were conducted over 15 weeks from May to August 2018 to collect quantitative observational data on wildlife road mortality events along the selected road sections. Vertebrate mortalities only were recorded, and domestic species and livestock (e.g. house cats, domestic rabbits, sheep) were excluded from data collection. All roadkill events were recorded regardless of state of decomposition or degradation. When unidentifiable to species, the taxon was recorded. The 12 roads chosen represented a range of size classes with speed limits of either 70-90 km/h, or 100-110 km/h (Table 1).

Table 1. Roads surveyed for roadkill carcasses in the Chignecto Isthmus region of New Brunswick and Nova Scotia from May to August 2018.

Province	**Route number**	**Speed limit range (km/h)**	**Number of lanes**	**AADT[8] (vehicles/day)**	**Length surveyed (km)**	**Survey frequency**	**Driving survey speed (km/h)**
NB	134	70-90	2	3,280	15.5	Twice weekly	50
NB	15	100-110	4	22,800	14.1	Twice weekly	70
NB	132	70-90	2	3,350	17.5	Weekly	50
NB	933	70-90	2	1,220	28.7	Weekly	50
NB	940	70-90	2	2,240	33.4	Weekly	50
NB	16	100-110	2	3,190	25.8	Weekly	60-70
NS	366	70-90	2	1,180	49.6	Weekly	50
NS	6	70-90	2	1,828	36.4	Twice Weekly	50
NS	301[9]	70-90	2	1,135	17.1	Weekly	50
NS	204	70-90	2	905	31.9	Weekly	50
NS	104	100-110	4	11,400	21.2	Twice Weekly	60-70
NS	2	70-90	2	1,172	40.2	Weekly	50
NS	302	70-90	2	1,665	25.1	Weekly	50

Four roads within the study area (i.e. NB Rte 134, NB Hwy 15, NS Rte 6, and NS Rte 104) were surveyed at a rate of twice weekly, while the remaining roads were surveyed weekly. These four roads of interest were selected for more frequent surveys due to their roles as important transportation corridors linking urban centres in the isthmus. NB Rte 134 (a secondary road) and NB Hwy 15 (a

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[8] Annual Average Daily Traffic

[9] NS Rte 301 did not intersect the modelled corridor but was surveyed weekly because the searchers used it as a connector between NS Rte 204 and NS Rte 6.

major highway) are both heavily travelled routes between Shediac and Moncton, by way of Dieppe. NS Hwy 104 and NS Rte 6 both connect with Amherst, an urban centre located at the border region in Nova Scotia, while Hwy 104 is the main highway leading out of Nova Scotia, and Rte 6 represents the secondary road in the Nova Scotia portion of the study area with the highest annual average daily traffic volume (AADT). Although it is suggested that sampling for roadkill should occur at one- or two-day intervals to account for low carcass persistence time of some species, which could lead to false-negative estimation of hotspots (Ratton et al., 2014; Santos et al., 2015), weekly surveys were chosen for the majority of roads due to the time and financial constraints of travelling large distances around the isthmus daily.

All roadkill surveys began at 6:00 am. Roadkill surveys are most effective when they detect mortalities that occur overnight, close to dawn, before scavengers can remove the carcass or the carcass becomes overly degraded by vehicle traffic (Collinson et al., 2014). Additionally, surveys performed shortly after sunrise will capture the mortality events that occur frequently overnight due to reduced motorist visibility and prevalence of nocturnal wildlife (Ratton et al., 2014). Depending on the length of the road and the number of roads surveyed on that day, surveys generally lasted 3-5 h. Thus, not every road segment was surveyed at the same time of day.

Each survey was conducted by car, travelling at speeds of 50-70 km/h (slower speeds for secondary roads with low traffic volumes and low speed limits, higher speeds for major highways with higher traffic volumes and higher speed limits). The maximum recommended speed at which reliable roadkill data can be obtained is 50 km/h, however it is also not recommended to drive more than 20 km/h slower than the speed limit for safety reasons (Collinson et al., 2014). Although searching by foot is more effective for detecting carcasses in the ditch or verge along the roadside, driving surveys at these speeds are as effective as walking surveys for detecting roadkill on the road surface or shoulder (Guinard et al., 2012), although some small individuals may still have been missed (Brockie et al., 2009). Thus, a compromise in survey driving speed was struck to maximize both visibility while searching and safety on the roads.

When an animal carcass was spotted (by the driver or the passenger), the car was stopped safely on the shoulder. The observers exited the vehicle, and collected photographs, geographic coordinates, and information on species identification, size, carcass position and condition, and on the surrounding roadside habitat. When it was safe to do so, the carcasses were removed from the road to 1) reduce the chance of being re-counted during a subsequent survey, 2) prevent further mortality of scavengers, and 3) allow nutrients to cycle back into the ecosystem through decomposition. Large carcasses (i.e. deer, bear) were reported to the appropriate department of transportation for removal. If an animal injured by a collision had been discovered alive, a nearby wildlife rehabilitation centre would have been called to help assess the situation.

Key sections (i.e. areas which overlapped with the model directly, and buffer sections on each side) were initially chosen as approximately 3-6 km stretches to be walked daily for fine-scale surveys. These sections comprised the sections of the modelled corridor which were predicted to encompass the highest degree of probability of movement and buffer sections of 2 km on either side. For 8 weeks, fine-scale walking surveys on short sections were conducted in conjunction with driving surveys designed to cover longer sections of each road, to provide for comparison between the road sections within and outside the modelled corridor. For the fine-scale walking surveys, the two observers started at opposite ends of the shorter sections when walking and walked towards each other (each walking against the direction of traffic for increased safety) to perform the searches on foot. As the main observer would remain in the car until reaching the drop-off point, each section of road was searched both in the car and on-foot. Through this process, it was determined that the fine-scale walking surveys were not returning noticeably different results from the surveys completed while driving at 50-70 km/h; any carcass that was detected during the walking survey was also detected while driving. Thus, the walking surveys were abandoned in favour of driving surveys after 8 weeks.

2.2.3 Spatial Analysis

Road network shapefiles were obtained from Service New Brunswick for the New Brunswick Road Network (Service New Brunswick, nd), and Open Data Nova Scotia, for the Nova Scotia Road Network (Open Data Nova Scotia, 2016). All data were projected to a common spatial reference, NAD 1983 UTM Zone 20N using ArcGIS Desktop V. 10.5 (ESRI, 2016). The spatial analysis to detect hotspots, defined as significant aggregations of mortality as compared to a random distribution of the given mortality events along the surveyed road (Coelho et al., 2014), was conducted using Siriema Road Mortality Software V. 2.0 (2014). A 2D analysis was chosen instead of a linear analysis, as the shape of the road was retained in this analysis instead of stretching the road into a straight line, which better represented the positioning of each road on the landscape (Coelho et al., 2008).

The scale at which significant aggregations of road mortality could be detected was determined by calculating the 2D Ripley K-Statistic for each road. This statistic is an important first step in the hotspot identification, as it allows for the determination of the size of the search radius around each road mortality event to be used to detect the presence or absence of hotspots. The Ripley K-Statistic also allows for the determination of whether there are any aggregations of mortality present at all. If there are no significant aggregations on a given road using the roadkill data collected, then a hotspot analysis can still be performed for visualization of the collected data, however the aggregations shown should not be used for mitigation decisions, as any location along the road will have the same impact for mitigation due to a lack of significant mortality hotspots (Coelho et al., 2014). Reasons for a lack of significance to the aggregations are related to insufficient sample sizes, associated with infrequent sampling but also possibly related to a lack of road mortality on a given road. Where L(r), which is the difference between the observed K value for a given radius based on the actual distribution of roadkill events and the expected or simulated value if all of the events were evenly distributed on the road, is above the upper 90% confidence limit (UCL), there are aggregations of mortality that are significant at this search radius (Coelho et al., 2014).

After running the 2D Ripley K-Statistic test for each road, with an initial radius of 300 m and a radius increase of 400 m at each step, it was determined that a radius of 1,000 m would be used as a moving window for the 2D Hotspot Identification tool, as several of the roads displayed significant aggregations at that scale. For comparison purposes, the same radius was used for each road for the hotspot identification, although it should be noted that not all aggregations of mortality visualized through this analysis were significant. Hotspots are defined as locations where $N_{events} - N_{simulated}$ is greater than the upper 90% confidence limit (Coelho et al., 2014). Raw data from the 2018 field surveys used for the Siriema hotspot analysis are found in Appendix A.

2.3 Results

A total of 577 vertebrate carcasses were recorded on roads in the study area during 15 weeks of surveys (Table 2). Over 50 individual species were observed from mammal, bird, amphibia and reptile taxa, with mammals being the most abundant, comprising over 60% of the observations. The most frequent species found during the surveys were North American porcupines (*Erethizon dorsatum*) and common raccoons (*Procyon lotor*). Both species often forage along disturbed edges of the roadside nocturnally. Together, they constitute nearly 40% of carcasses collected during surveys.

Table 2. Raw data of species (or bird families) collected during the roadkill carcass surveys.

Common name	**Scientific name**	**Count**	**% of Taxa**	**% of Total**
Mammals	**Class Mammalia**	**373**		**64.6**
North American porcupine	*Erethizon dorsatum*	120	32.2	20.8
Common raccoon	*Procyon lotor*	107	28.7	18.5
Striped skunk	*Mephitis mephitis*	29	7.8	5.0

Common name	**Scientific name**	**Count**	**% of Taxa**	**% of Total**
Snowshoe hare	*Lepus americanus*	23	6.2	4.0
American red squirrel	*Tamiasciurus hudsonicus*	21	5.6	3.6
Eastern chipmunk	*Tamias striatus*	14	3.8	2.4
Woodchuck	*Marmota monax*	9	2.4	1.6
White-tailed deer	*Odocoileus virginianus*	7	1.9	1.2
Red fox	*Vulpes vulpes*	6	1.6	1.0
Shrew species	*Sorex* spp.	5	1.3	0.9
Canadian beaver	*Castor canadensis*	4	1.1	0.7
Black bear	*Ursus americanus*	3	0.8	0.5
Muskrat	*Ondatra zibethicus*	3	0.8	0.5
Mouse species	Family Muridae	3	0.8	0.5
Eastern grey squirrel	*Sciurus carolinensis*	2	0.5	0.3
Eastern coyote	*Canis latrans*	1	0.3	0.2
American mink	*Mustela vison*	1	0.3	0.2
Ermine	*Mustela erminea*	1	0.3	0.2
Unknown (due to degradation of carcass)		14	3.8	2.4
Birds (by family)	**Class Aves**	**132**		**22.9**
Crows, jays, and magpies (American crow, common raven, blue jay)	Family Corvidae (*Corvus brachyrhynchos, Corvus corax, Cyanocitta cristata)*	34	25.8	5.9
New world warblers (northern parula, common yellowthroat, American redstart, yellow-rumped warbler, magnolia warbler, ovenbird)	Family Parulidae (*Setophaga americana, Geothlypis trichas, Setophaga ruticilla, Setophaga coronata, Setophaga magnolia, Seiurus aurocapilla*)	15	11.4	2.6
Starlings (European starling)	Family Sturnidae (*Sturnus vulgaris*)	11	8.3	1.9
Woodpeckers (northern flicker, pileated woodpecker)	Family Picidae (*Colaptes auratus, Dryocopus pileatus*)	9	6.8	1.6

Common name	**Scientific name**	**Count**	**% of Taxa**	**% of Total**
Thrushes and allies (hermit thrush, American robin)	Family Turdidae (*Catharus guttatus, Turdus migratorius*)	9	6.8	1.6
Troupials and allies (common grackle)	Family Icteridae (*Quiscalus quiscula*)	8	6.1	1.4
Waxwings (cedar waxwing)	Family Bombycillidae (*Bombycilla cedrorum*)	4	3.0	0.7
Swallows (barn swallow, tree swallow)	Family Hirundinidae (*Hirundo rustica, Tachycineta bicolor*)	4	3.0	0.7
New world sparrows (savannah sparrow, song sparrow, white-throated sparrow)	Family Passerellidae (*Passerculus sandwichensis, Melospiza melodia, Zonotrichia albicollis*)	4	3.0	0.7
Vireos (blue-headed vireo, red-eyed vireo)	Family Vireonidae (*Vireo solitarius, Vireo olivaceus*)	4	3.0	0.7
Ducks, geese, and waterfowl (common eider, Canada goose)	Family Anatidae (*Somateria mollissima, Branta canadensis*)	3	2.3	0.5
Pheasants, grouse, and allies (ring-necked pheasant, ruffed grouse)	Family Phasianidae (*Phasianus colchicus, Bonasa umbellus*)	3	2.3	0.5
Falcons (American kestrel, merlin)	Family Falconidae (*Falco sparverius, Falco columbarius*)	2	1.5	0.3
Tits, chickadees, and titmice (black-capped chickadee)	Family Paridae (*Poecile atricapillus*)	2	1.5	0.3
Tyrant flycatchers (alder flycatcher, least flycatcher)	Family Tyrannidae (*Empidonax alnorum, Empidonax minimus*)	2	1.5	0.3
Finches (American goldfinch)	Family Fringillidae (*Spinus tristis*)	1	0.8	0.2
Owls (great horned owl)	Family Strigidae (*Bubo virginianus*)	1	0.8	0.2
Unknown (due to degradation of carcass)		16	12.1	2.8
Amphibians	**Class Amphibia**	**70**		**12.1**
Green frog	*Lithobates clamitans*	52	74.3	9.0
Northern leopard frog	*Lithobates pipiens*	6	8.6	1.0
Red-spotted newt	*Notophthalmus viridescens*	6	8.6	1.0
Pickerel frog	*Lithobates palustris*	3	4.3	0.5

Common name	Scientific name	Count	% of Taxa	% of Total
Wood frog	*Lithobates sylvaticus*	1	1.4	0.2
Unknown (due to degradation of carcass)		2	2.9	0.3
Reptiles	**Class Reptilia**	**2**		**0.3**
Common garter snake	*Thamnophis sirtalis*	1	50	0.2
Red-bellied snake	*Storeria occipitomaculatus*	1	50	0.2

Only four (i.e., black bear, red fox, snowshoe hare, and pileated woodpecker) of the 12 focal species selected for the NCC's corridor model were observed as roadkill during the field season (Fig. 4). Three mortality instances of black bear (*Ursus americanus*), a wide-ranging habitat generalist, were observed, all on NS Hwy 104. Red fox (*Vulpes vulpes*) was observed as roadkill six times, mainly on secondary roads in Nova Scotia, with one instance on NB Hwy 15. Snowshoe hare (*Lepus americanus*), a habitat generalist and important prey species, was the fourth most common mammal roadkill observation, with 23 instances of mortality distributed across most of the surveyed roads. One instance of pileated woodpecker (*Dryocopus pileatus*), a habitat specialist and keystone species, mortality was recorded on NB Hwy 15, while other woodpeckers with less confident identifications (listed as unknown) were found on secondary roads in New Brunswick.

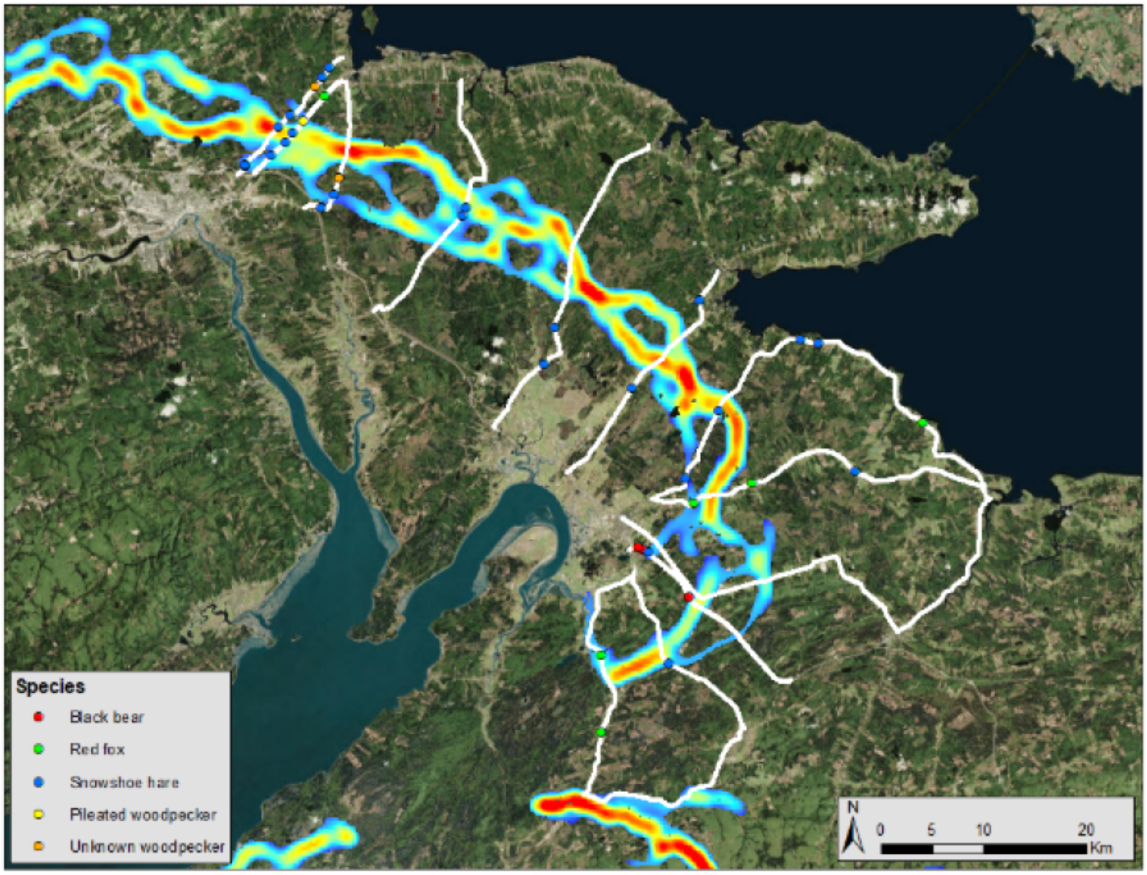

Figure 4. Locations of the roadkill events recorded for the four species included in the NCC's modelled connectivity analysis. Base map courtesy of ESRI (ESRI, 2016).

As the results of the Ripley K-Statistic analysis show, most roads will show significant aggregations of mortality at large search radii, while a smaller selection will display aggregations at lower search radii (e.g. 1 km or less) (Table 3). The smaller search radius of 1 km selected for hotspot detection returned more meaningful results for targeting the location of hotspots along each road. For NB Rte 940 and NS Rte 302, it was found that no scale would detect any significant aggregations of road mortality, therefore the hotspots detected for these roads are not significant. NB Rte 132, NS 301, and NS Rte 302 showed significant aggregations, but at scales larger than 8 km, so results for these hotspots with a search radius of 1 km are also not significant. Significant mortality aggregations were found on all other roads where the cluster of road mortality was higher than expected for a simulated random distribution of the mortality events along each road. At least one hotspot was detected for each of these roads, with a maximum of three hotspots. The size of hotspots varied from less than a kilometre to several kilometres in length.

Table 3. Results of road mortality aggregation detections using Siriema Road Mortality software. Where L(r)[10] is high (greater than the Upper 90% Confidence Limit), a smaller search radius around each roadkill event can be used to detect aggregations of mortality.

Province	**Route number**	**Length analyzed (km)**	**Scale of significant aggregations of mortality (km)** **L(r) > UCL**	**Road segment displaying hotspots[11] using 1 km radius[12]** **N_{events} - $N_{simulated}$ > UCL**
NB	134	15.5	1.1 – 13.5	Km 7.1 – 9.0*
NB	15	28.2 (east and westbound lanes)	0.3 – 12.7	Km 4.6 – 5.8* Km 7.5 – 9.5* Km 12.2 – 12.7*
NB	132	17.5	11.9 – 12.5	None detected at 1 km scale
NB	933	28.7	0.3 – 2.3 18.8 – 19.9	Km 13.7 – 14.2*
NB	940	33.4	No significant aggregations at any scale	Km 4.5 – 6.5 Km 24.0 – 24.5
NB	16	25.8	0.3 – 21.9	Km 10.3 – 11.1* Km 12.0 – 13.9* Km 15.5 – 17.8 *

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[10] The difference between the observed K value for a given radius based on the actual distribution of roadkill events and the expected or simulated value if all of the events were evenly distributed on the road.

[11] * Indicates result is significant at the 1 km radius scale.

[12] Assume kilometre zero is at the westernmost end of the road segment.

Province	**Route number**	**Length analyzed (km)**	**Scale of significant aggregations of mortality (km)**	**Road segment displaying hotspots[11] using 1 km radius[12]**
			$L(r) > UCL$	**$N_{events} - N_{simulated} > UCL$**
NS	366	49.6	0.3 – 30.0	Km 10.1 – 14.5* Km 30.5 – 30.8*
NS	6	36.4	0.3 – 15.1 18.5 – 21.8 23.9 – 28.7	Km 5.5 – 6.0* Km 24.5 – 26.8* Km 30.2 – 32.5*
NS	301	17.1	13.5 – 13.8	Km 2.6 – 3.4 Km 15.8 – 16.1
NS	204	31.9	0.3 – 3.5 5.6 – 9.9 23.2 – 24.8	Km 0 – 1.8* Km 5.5 – 7.6* Km 9.1 – 10.4*
NS	104	43.5 (east and westbound lanes)	0.3 – 14.5	Km 0.2 – 2.8* Km 6.5 – 10.2*
NS	2	40.2	8.3 – 10.4	Km 7.5 – 9.2 Km 12.0 – 14.2 Km 23.5 – 23.8 Km 37.1 – 37.5
NS	302	25.1	No significant aggregations at any scale	Km 13.7 – 16.0

When overlain on the NCC's modelled corridor, each of the roadkill hotspots can be compared to the position of the corridor as it passes through the Chignecto Isthmus, showing several locations where significant hotspots correspond with high probability pinch-points (Fig. 5). There are significant sections of road mortality that are roughly found along the NCC's modelled corridor on NB Rte 134, NB Hwy 15, NB Hwy 16, NS Rte 366, NS Rte 6, NS Rte 204, and NS Hwy 104. Close-up maps of each of these significant hotspots are located in Appendix B.

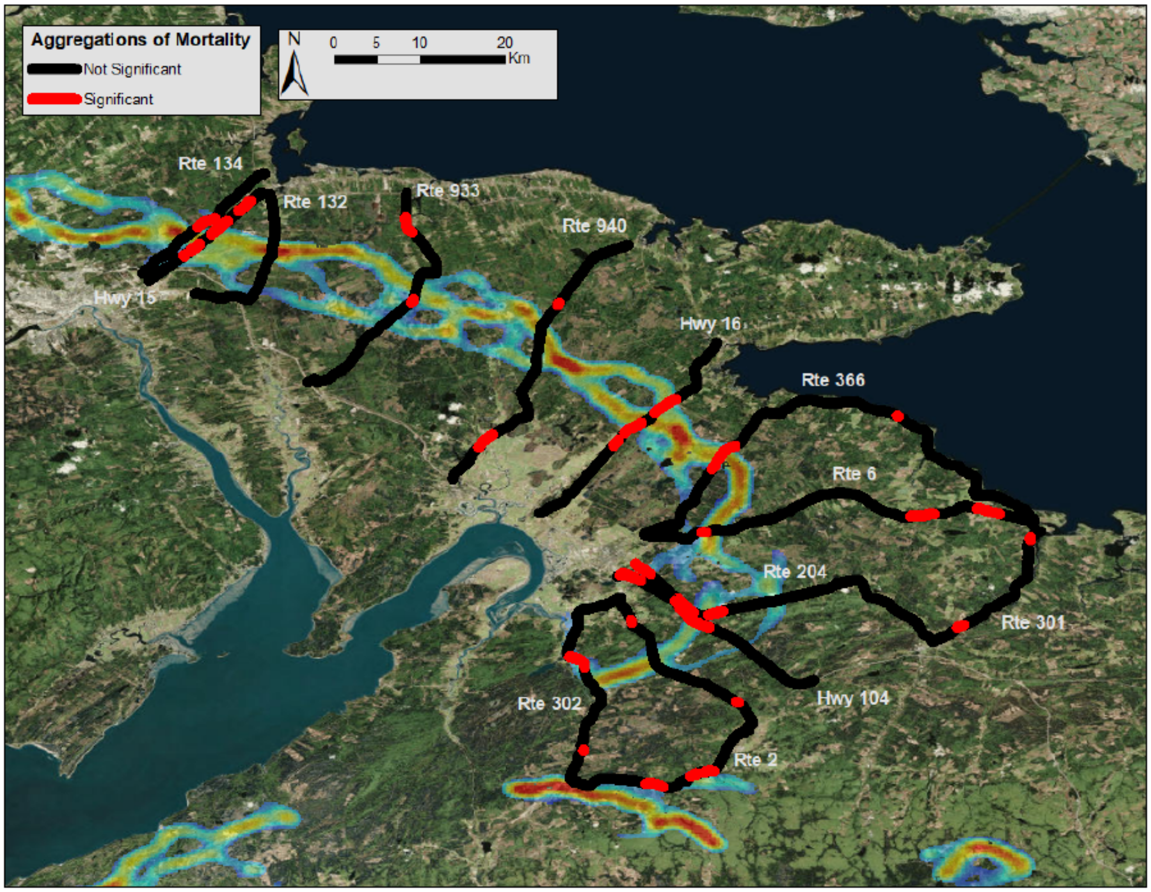

Figure 5. Results of Siriema 2D Hotspot Analysis showing significant aggregations of wildlife mortality in red along the Chignecto Isthmus survey routes, overlaid on the NCC's modelled wildlife movement corridor. Base map courtesy of ESRI (ESRI, 2016).

For comparison purposes, a second hotspot analysis was conducted with the same parameters, using a subset of the data with birds, amphibians, and reptiles removed. The mammalian roadkill represents approximately 64% of the data collected and as most mitigation decisions, such as large crossing structures, would be targeted to terrestrial mammals, it is logical to determine if the same patterns are seen. Overall, many of the same hotspots are seen as when the entire dataset was used to model the roadkill hotspots (Fig. 6).

However, hotspots are less concentrated, and show more diffuse patterns along each road.

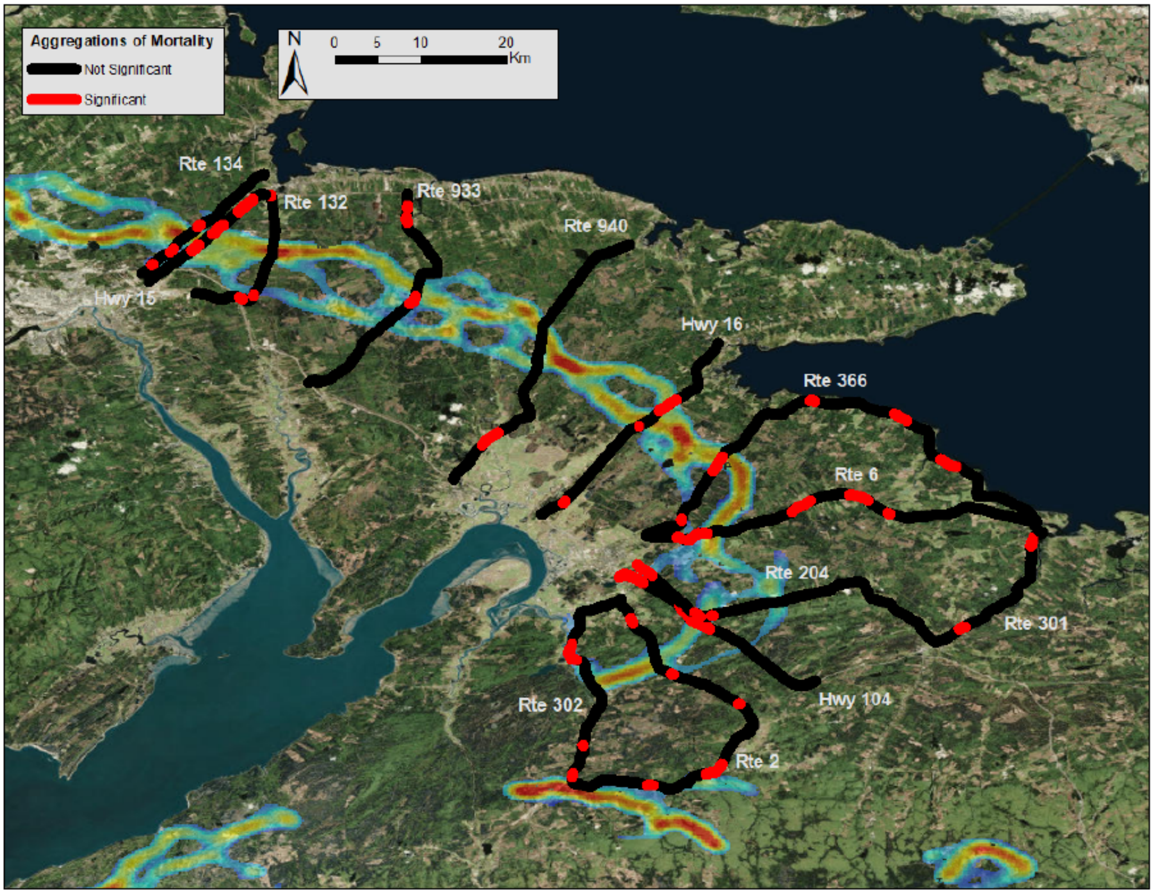

Figure 6. Results of Siriema 2D Hotspot Analysis for mammal roadkill only, showing significant aggregations of wildlife mortality in red along the Chignecto Isthmus survey routes, overlaid on the NCC's modelled wildlife movement corridor. Base map courtesy of ESRI (ESRI, 2016).

Raccoons are a generalist species which thrive near human disturbance, and therefore do not represent a good focal species upon which to base mitigation decisions for safe wildlife crossings. As raccoons made up nearly 30% of the mammals recorded and close to 20% of the entire dataset, it is possible that they skewed the results for locations of road morality hotspots. Although often a difficult sight for motorists, raccoons do not warrant road crossings on the basis of either human safety or wildlife conservation concerns. Once removed from the dataset, the 2D hotspot analysis was performed again and the results mapped (Fig. 7). NB Rtes 132 and 933 were not included in this analysis as there were no raccoon roadkill points recorded on either of these roads. NS Rte 301 was also not included on this map as the sample size after the removal of raccoons was too small (n=4) to conduct a meaningful analysis.

The aggregations of mortality for NB Rte 134 shifted northeast, away from Dieppe, and became more concentrated with the removal of the raccoons (Fig 7). For most of the other roads, only the size of the hotspot changed, while most of the general locations remained the same as with the mammal-only analysis.

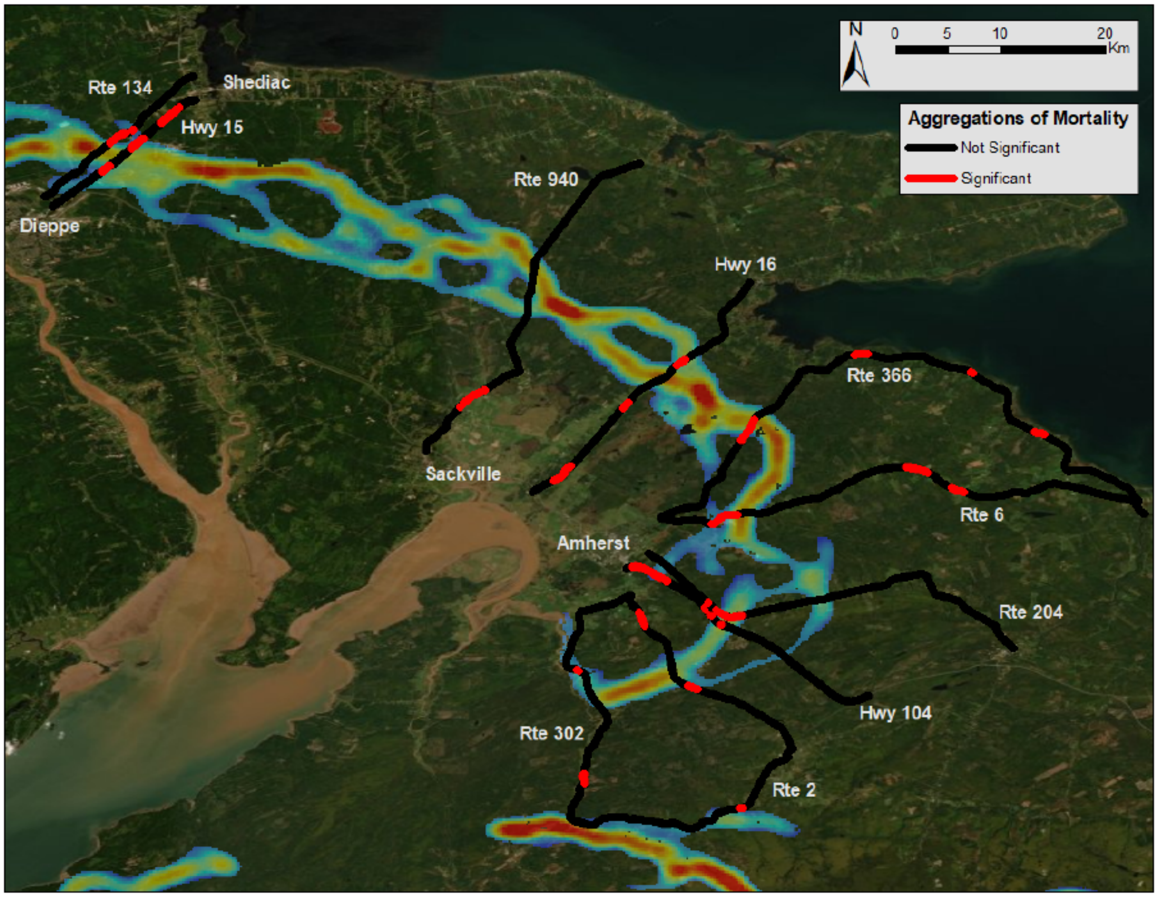

Figure 7. Results of Siriema 2D Hotspot Analysis for mammal roadkill only with raccoon mortality events removed, showing significant aggregations of wildlife mortality in red along the Chignecto Isthmus survey routes, overlaid on the NCC's modelled wildlife movement corridor. Base map courtesy of ESRI (ESRI, 2016)

Raccoons are not the only species which may skew the results in favour of presenting aggregations of mortality containing species of neither conservation nor human safety concern. Additionally, small-bodied mammals in the dataset are also not a safety concern and would require different mitigation measures than larger mammals, such as deer and bear. Small-bodied mammals in this study, defined as having a mass of <1 kg, were red squirrel (*Tamiascriurus hudsonicus*), grey squirrel (*Sciurus carolinensis*), Eastern chipmunk (*Tamias striatus*), mouse species (Family Muridae), and shrew species (*Sorex* spp.). With raccoon and smaller wildlife data removed, only six roads remained with a sample size large enough to warrant hotspot analyses (n≥10), however NB Hwy 15 and Hwy 16 were not shown on the map, as there were no small mammals removed from the dataset (Fig. 8).

The position of the aggregations which intersect the modelled corridor do not change dramatically with the removal of the small-bodied mammals, however some aggregations outside of the modelled corridor on NS Rte 366 disappear altogether (Fig. 8).

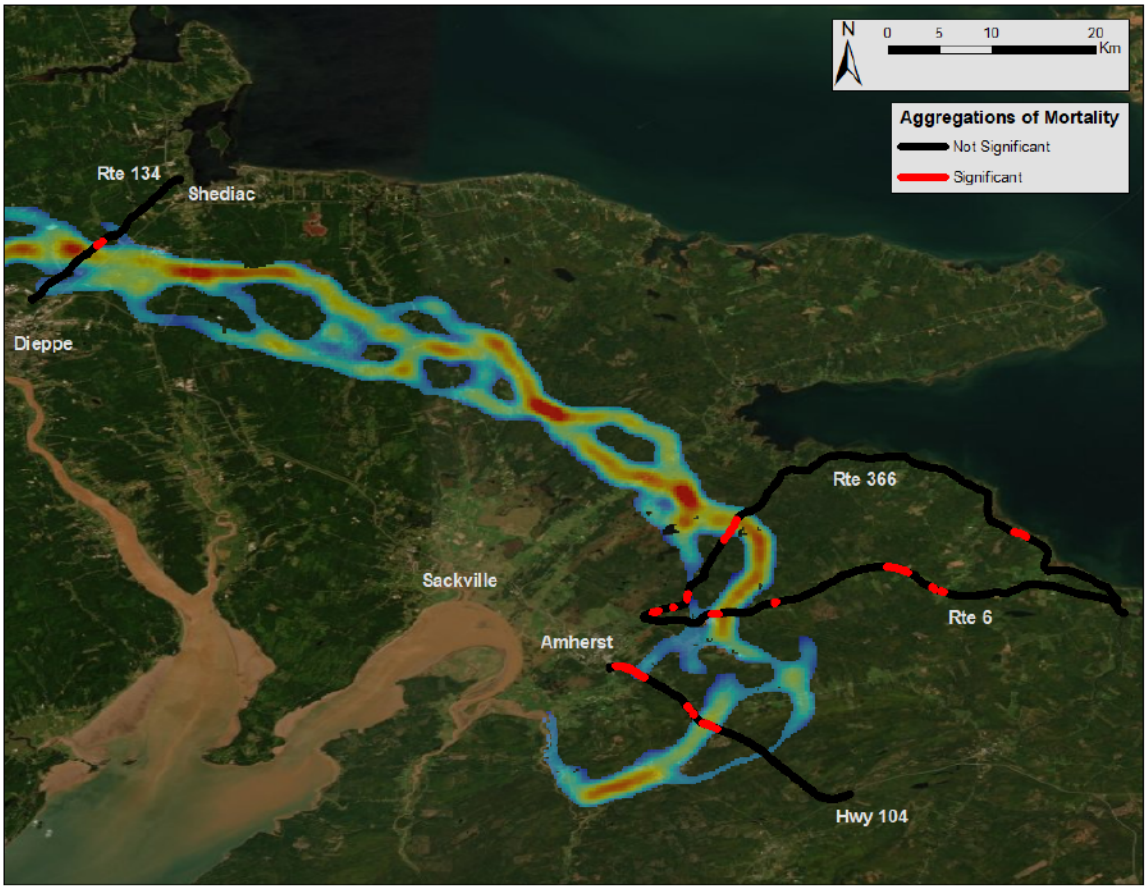

Figure 8. Results of Siriema 2D Hotspot Analysis for mammal roadkill only with raccoon mortality and small-bodied mammal mortality events removed, showing significant aggregations of wildlife mortality in red along the Chignecto Isthmus survey routes, overlaid on the NCC's modelled wildlife movement corridor. Base map courtesy of ESRI (ESRI, 2016).

Some roads were not shown in Fig. 8, as there were no further roadkill events to remove from the dataset. For management purposes, however, Fig. 9 displays a composite of hotspots for each road where only mammals were considered, and no raccoons or small mammals were included in the analysis. For the roads which showed statistically significant aggregations of mortality for the full dataset, there are aggregations using the smaller dataset that can be seen here (Fig. 9). NB Rte 134 shows a hotspot along the midsection of the road between Dieppe and Shediac to the northeast of a potential pinch-point for wildlife movement. NB Hwy 15 displays three aggregations, with two located within the modelled corridor. NS Hwy 16 also displays three aggregations, with one located within the modelled corridor. The main hotspot on NS Rte 366 is found to correspond directly with the model, while there are four smaller hotspots, three near Amherst, and one closer to the Northumberland Strait. NS Rte 6 also displays four aggregations with this dataset, with one hotspot corresponding to the wildlife movement model. NS Rte 204 has a larger hotspot that is directly located in the path of the model, and a smaller one adjacent. Finally, NS Hwy 104 displays an aggregation of mortality near Amherst, but also a hotspot directly at the corridor and one smaller one adjacent to the corridor within the buffer zone.

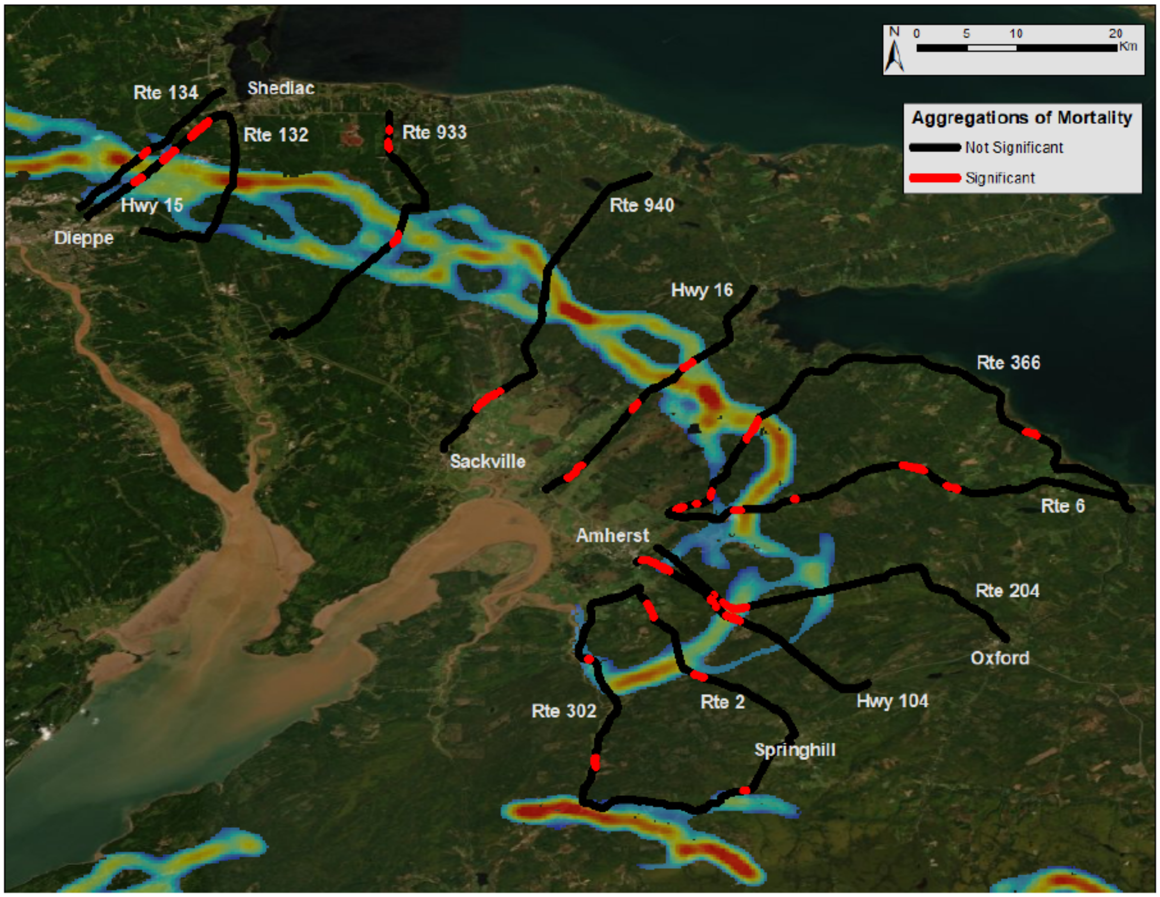

Figure 9. All roads shown with results of Siriema 2D Hotspot Analysis for mammal roadkill only with raccoon mortality and small-bodied mammal mortality events removed, showing significant aggregations of wildlife mortality in red along the Chignecto Isthmus survey routes, overlaid on the NCC's modelled wildlife movement corridor. Base map courtesy of ESRI (ESRI, 2016).

2.4 Discussion

In many road sections, hotspots found in roadkill data correspond with key pinch-points in the NCC's modelled wildlife movement corridor (Nussey & Noseworthy, 2018). There are significant aggregations of mortality within the visualized spread of the potential corridor model, which is a reasonable expectation as the model represents areas of important habitat for a diverse suite of species. The presence of additional significant hotspots on NS Rte 366 and NS Rte 6 outside of the modelled corridor does not negate the use of roadkill data to ground-truth wildlife movement, as the corridor is specifically designed to model movement between designated protected areas and for a subset of 12 species, rather than for the over 50 species identified in the roadkill survey. It is also likely that (1) wildlife movement becomes more diffuse outside of the narrowest section of the Chignecto Isthmus, and (2) the most suitable habitat patches for some wildlife species, including the NCC's modelled species, are not directly associated with the protected areas selected as start and end points for the connectivity analysis.

Further, NCC's modelled corridor was generated as the 'least cost path' for each species, combined through a kernel-density analysis to identify the narrowest pathway likely to accommodate the habitat needs of all 12 species. As such, it represents a relatively narrow, pseudo-optimized 'high probability movement pathway' for a subset of species, rather than a representation of current movement pathways for all wildlife species across the landscape (such as could be generated through other types of connectivity models, e.g. Circuitscape).

Nonetheless, the results suggest that as wildlife move across the landscape they are choosing areas within the modelled corridor, especially where movement outside of the modelled corridor is restricted, such as near areas of high human development. The landscape between Dieppe and Shediac is highly impacted by residential development and agriculture. Therefore, the presence of several individual aggregations on NB Rte 134 and NB Hwy 15 potentially speaks to the occurrence of wildlife seeking out any habitat that is available, or of wildlife using land, such as agricultural fields, for habitat differently than that of the focal species chosen for the connectivity analysis. For instance, a relatively wide-ranging species such as white-tailed deer (*Odocoileus virginianus*) may use open fields for refuge from biting insects as well as for forage (Fudge et al., 2007), and was not included as a focal species in the NCC's wildlife connectivity analysis.

The hotspot analysis for mammal-only road mortality displays similar patterns to the analysis using the entire dataset, with hotspots generally corresponding with the modelled corridor. The sample size is smaller, however, and the hotspots seem to be more diffuse, which is likely due to the smaller sample size. Although amphibians comprised only approximately 12% of the dataset, one of the major aggregations of mortality found outside of the model on NS Rte 6 using the full vertebrate dataset was directly due to the movement of amphibians across the road from one wetland feature to another over one night (i.e. recorded on a single survey day). This heightened mortality event (n>40 kills), the only such one observed during the field season, occurred after a heavy rainstorm which temporarily flooded low-lying roads in some areas of the isthmus. The presence of the excess water may have made the road surface less of a barrier, causing higher mortality in this area than usual, as water on the road surface may have served as a conduit for movement. Amphibian road mortality is often related to specific temporal (e.g. breeding season) or climatic (e.g. heavy rain) events (Langen et al., 2007). While this does not negate the need for mitigation for large, infrequent kills, it should be noted that this event may have skewed the overall results in favour of small-bodied wildlife and thus the consideration of only mammals in the analysis is a first step to understanding where wider-ranging wildlife are occurring in relationship to roads.

Once the generalists (i.e. raccoons) and small-bodied mammals (i.e. squirrels, chipmunks, mice, and shrews) were also removed from the dataset and the hotspot analysis was conducted again, there appeared a noticeable change in the location of the aggregations on NB Rte 134; it shifted away from the edges where more human impact is felt near Dieppe and Shediac and was concentrated closer to the modelled corridor. This shift is likely due to the removal of raccoons, which were not included in the NCC's original model, and which are usually more highly correlated with peri-urban areas than with more 'natural' areas.

Birds comprised less than 25% of the mortality events recorded. The main taxon of birds represented in the dataset, family Corvidae, contains crows (*Corvus brachyrhynchos*), which were frequently seen on the road surface, scavenging vehicle-killed carcasses of other animals. Birds that scavenge on the road are more likely to become roadkill, as are those that make use of habitats affected by humans, including corvids and starlings (*Sturnus vulgaris*) (Husby, 2016). The large proportion of warblers present (the second most represented bird family – Parulidae) is potentially due to the ability of species from this family to colonize diverse habitats, such as those which border roads (Collins et al.,1982), as there was also the highest number of individual species recorded in this group. The rural survey routes were surrounded mainly by mixed forest and fields, with wetlands also adjacent to sections of many roads, all providing good habitat for warblers.

The largest terrestrial mammal in the region, the moose (*Alces alces* americana), was conspicuously absent from the roadkill dataset. None were recorded during the daily roadkill surveys, despite this species' frequent involvement in collisions in New Brunswick that are financially costly and often cause human injury and mortality, as well as moose mortality. In contrast to the observed data, there was an average of one collision reported per week on the roads between Dieppe and Shediac during the spring of 2017 (Letterick, 2017). The large number of collisions that occurred in this area in the past has caused public concern as a road-safety issue. It is also of conservation concern in that, although moose are not endangered in New Brunswick, there are far fewer than 1,000 individuals left on mainland Nova Scotia (Timmermann & Rodgers, 2017) and recent estimates have placed population numbers as low as 100 individuals (T. Millette, Nova Scotia Department of Lands and Forestry, unpublished data as cited in McGregor, 2019). Even with small population numbers, road mortality has been an issue for mainland Nova Scotia moose in the past. The Cobequid Pass, a stretch of NS Hwy 104 which passes through the Cobequid Highlands, southeast of the study area, was in the past the site of frequent moose-vehicle collisions when population numbers were higher in Nova Scotia (T. Nette, Nova Scotia Department of Natural Resources, unpublished data, as cited in Beazley et al., 2006).

A potential explanation for the lack of moose representation in the roadkill survey dataset, is that moose collisions are nearly always reported to the authorities, and therefore these large animals are quickly removed from the road and not present to record during daily surveys. Although beyond the scope of this study, mapping moose-vehicle collision data from law enforcement reports would be an additional useful tool to visualize where they are present along the road corridor. Unfortunately, such data are not consistently reported and recorded across the study area and are often not accurately recorded in terms of geographic location, as will be discussed in Chapter 3. Nonetheless, a preliminary examination of moose-vehicle collision data shows 19 and 26 records of dead moose in Wildlife Management Zone 25, and part of Zone 19 in Westmorland County by the New Brunswick Department of Energy and Resource Development for 2017 and part of 2018 (up to August), respectively (Table 3.5). Comparable records from the Nova Department of Lands and Forestry for the same time period (2017 and 2018 for the entire year) reported no moose collisions (Table 3.4).

Although many of the focal species used in the creation of the modelled corridor were not present in the roadkill survey dataset, and vice versa, it is still useful to apply the roadkill data to this situation, as the habitat requirements for the focal species are broadly applicable to many of the species found in the survey and in the region. The representation of only four of the focal species from the connectivity analysis in the roadkill dataset is potentially related to their existing population sizes, as well as their behaviour in relation to roads. For example, if a species of conservation concern is already experiencing relatively low population numbers, individuals of that species are less likely to come in contact with the road and thus potentially experience a collision than if there are many individuals in the area.

In terms of species' behaviour towards roads, some, such as bobcat, display high road-avoidance behaviour and are negatively associated with high road density in an area (Donovan et al., 2011). Others may be more adept at avoiding traffic, choosing roads or times of day when traffic volume is low, and thus these species may be less prominent in the roadkill record (Litvaitis & Tash, 2008).

An important distinction is that the hotspot analysis presented here does not compare one road to another, rather it compares the likelihood of roadkill being uniformly distributed versus clustered along any given stretch of road.

Overall, systematic roadkill survey data can be useful to help verify modelled wildlife movement corridors where they intersect with roads. Roadkill hotspots at the points of intersection can be used to extrapolate movement patterns from one road to the next and lend further evidence to the need to both protect key habitat corridors across the landscape and to provide safe wildlife crossings where animals are likely to interact with roadways. This study uses preliminary data collected over one season and thus the results should be taken with the caveat that the sample size in terms of number of survey days should be increased. The collection and analysis of multiple seasons of field data will begin to form a more complete picture of where wide-ranging species are crossing roads and moving across the landscape. Nonetheless, the study represents a novel application of road ecology research at a larger spatial extent, addressing a noted gap in the literature and knowledge.

2.5 Conclusion

Systematic roadkill surveys can be a useful tool in describing the state of wildlife-road interactions within a region. For the data to be meaningful for road-effect mitigation planning, however, care should be taken to clearly define the objectives of the survey. While the focus of the surveys described in this study was to collect records of every instance of roadkill, time and energy could potentially be saved by collecting only records of wildlife that are of human health and safety and/or conservation concern. If mitigation was to only target large animals, driving surveys would be sufficient and could be conducted more quickly than those where stopping for each small individual was a priority. Alternatively, the surveys could be conducted simultaneously by several researchers to reduce the effort of surveying a large region by a single team. Surveys should be carefully planned out so that the number of medium-high traffic volume roads surveyed in the region is balanced with an increased number of survey days for each road (daily, rather than weekly surveys) and that there are multiple seasons collected for comparison over time.

Nonetheless, these preliminary results may be used to describe locations within the NCC's modelled wildlife movement corridor that should be examined more carefully for potential road crossing opportunities and barriers. Although not all identified hotspots were statistically significant, they point to areas where further roadkill surveys, enhanced by snow or sand tracking, or trail camera studies should occur. They also represent locations where road-effect mitigation strategies, such as crossing structures dedicated to wide-ranging animals that require connectivity through the isthmus, could be situated (upon further confirmation of the data with repeated seasons and multiple lines of evidence) to maximize their use.

Further, this study represents a pilot contribution to a new body of road ecology literature at larger landscape and regional scales for which additional case studies and methods should be published moving forward to increase knowledge and improve methodologies. A road network has greater impacts than a single road alone, and while the individual impacts of each road may be large on local populations, assessing the effects at a larger scale will help to determine impacts on connectivity between populations across multiple landscapes and even borders.

Chapter 3: Using Reported Motorist Collision Data to Visualize Problem Areas for Large Animal Collisions

3.1 Introduction

Targeted, systematic roadkill surveys will provide the most complete dataset for a short-term study of roadkill encompassing a large variety of species. To capture a fuller picture of the wildlife-road mortality in a region, surveys should employ methods for collecting data across successive seasons and years (Brockie et al., 2009). The observers, whether on foot, by bicycle, or in a slow-moving car, will detect most carcasses present on the road during the survey, and should be able to confidently record the species and a precise location (Collinson et al., 2014). This type of survey, as described Chapter 2, and employed for one season as the primary method of data collection for this study, allows for a nearly complete description of which species are experiencing road mortality in the study area, including those carcasses difficult to detect by the casual observer, and which did not contribute to human injury or property damage. Even with consistent survey methods, it is nearly impossible to capture every instance of roadkill unless a road segment is surveyed daily, a challenging task for a regional-scale study, as carcass persistence times for most vertebrates can be quite short, depending on body size and environmental conditions (Santos et al., 2015; 2016).

A less systematic, more incidental collection of wildlife-vehicle collision data, whether reported by the motorist involved, or by someone who is concerned about the hazard to other motorists posed by the dead animal along the roadside, can still offer insights into where problem spots are occurring for both barriers to wildlife movement and dangerous wildlife-vehicle collisions involving large mammals. Roadkill surveys that are consistent and long-term can be expensive, therefore obtaining these data opportunistically through incident reports or through the solicitation of data from volunteers, can help to provide more timely information which can be obtained at a relatively low cost (Bíl et al., 2017; Périquet et al., 2018). Intensive roadkill surveys are not always feasible, therefore the availability of a centralized, constant data hub for collecting and maintaining collision data records for a region is important for monitoring long-term trends to identify species which are the most frequently involved in collisions, and to describe changes over time (Bíl et al., 2017).

Often, the most consistent form of wildlife road mortality data in a region can be obtained from provincial transportation or natural resource departments, which collect records from law enforcement, road maintenance personnel, insurance reports, and the concerned public (Hesse & Rea, 2016; K. George, personal communication, July 2019). These collision records may lack representation of small species which are not easily seen and reported and do not usually cause human injuries or property damage. While they may not produce an accurate picture of isolated events, such as short-term amphibian migrations across single roads, they do have the potential to give a longer-term picture of large-animal collisions in the region and tend to capture the majority of serious collisions (Périquet et al., 2018). These records also have the potential to produce a dataset that is completely different from that produced by citizen science records with little overlap found between volunteer observations and those collected by government departments (Shilling & Waetjen, 2015).

Although road maintenance personnel or the general public may not possess the taxonomic identification skills of a trained biologist, and often misidentify species when many similar species exist in the same area, large, common species are often identified correctly (Abra et al., 2018). This phenomenon is not generally an issue when the goal is to determine the impact of large mammals on driver safety, as most safety risks tend to involve easily identifiable species. In Nova Scotia and New Brunswick, the three largest mammal species are moose, deer, and bear, which are easily identifiable by any layperson. The maritime provinces of Canada have relatively low biodiversity, making the identification of most vertebrate species easier than in places, such as the tropics, with high biodiversity and much overlap in the appearance of different species (Abra et al., 2018). When the data are used to determine the impact on species of conservation concern, however, correct identifications are necessary. Incorrect identifications may lead to false positive detection of hotspots for more common species or false negatives for less common species that are easily confused with common ones (Abra et al, 2018).

It is not required by law to report all collisions with wildlife, so many of the smaller collisions go unreported. However, most bear and deer collisions and all moose collisions are estimated to be reported in Nova Scotia (Fudge et al., 2007). In Canada, wildlife-vehicle collision data may be collected by law enforcement; collisions with damage totalling over $1,000 CAD must be reported to the Royal Canadian Mounted Police, and officers will respond to collisions with wildlife resulting in significant property damage, human injury or loss of human life (Gunson et al., 2003; Hesse & Rea, 2016). Thus, law enforcement collision data generally only contains information on large species that cause human harm.

Wildlife-vehicle collision data compiled by government departments have the potential to lack consistency in reporting methods, which may lead to problems with using the data to inform mitigation decisions (Huijser et al., 2007). A major disadvantage is in the ability to map, and therefore accurately locate, collision hotspots due to the lack of GNSS coordinates recorded by most agencies. More commonly, the roadkill observations are recorded relative to highway mile or kilometre markers and therefore present reduced potential for accurately identifying aggregations of mortality (Huijser et al., 2007).

Despite issues with consistency, some advantages do exist to having these data collected, which can support conservation and human health and safety goals (Huijser et al., 2007). Having data collected and recorded in one place allows for comparisons over time, even when directed road ecology studies are not currently underway. These data provide a historical record of wildlife-vehicle collisions in the region and can highlight changes that have occurred in species composition over time (Huijser et al., 2007; Hesse & Rea, 2016). They are also useful for showing general patterns of wildlife movement, and aggregations of mortality on individual roads (Gunson et al., 2003). Finally, they can provide additional evidence as to which species are problematic in terms of their behaviour near roads and at certain times of the year (Gunson et al., 2003). It is well recognized by road ecologists that improvements should be made in the compilation of wildlife-vehicle collision databases to standardize and maintain provincial records so that these benefits are not overshadowed by reporting inconsistencies (Hesse, 2006; Shilling et al., 2015; Hesse & Rea, 2016).

In the Chignecto Isthmus, animal-vehicle collision data are collected and compiled by the Nova Scotia Department of Lands and Forestry (NS LAF) and the New Brunswick Department of Energy and Resource Development (NB ERD), the two corresponding natural resource departments for the provinces in the study area. In this chapter, the potential utitlity of using these data to complement systematic roadkill survey data to provide support for the implemenation of roadkill mitigation strategies is assessed.

3.2 Methods

Reported animal-vehicle collision data in the Chignecto Isthmus region for the years 2013-2018 were obtained from the NS LAF and the NB ERD. Discrepancies in how the data were recorded and reported made direct comparisons difficult; nearly all New Brunswick records were associated with GNSS coordinates, while many Nova Scotia records were lacking this information. The Nova Scotia report contained not only dead wildlife records, but also instances of sick, injured, and distressed wildlife, wildlife nuisance complaints, and general wildlife sightings. All of the records are associated with roads, and thus it is reasonable to assume that the mortalities were collision related. Once the records were filtered to include only dead wildlife, there were categories for (1) wildlife that were reported dead and (2) incidents that involved a vehicle. Both of these categories were included in the counts in Table 1, as it was possible that the person who reported the dead animal did not cause the collision, and therefore simply reported it as dead without specifying a cause. The New Brunswick dataset contained only records for three large mammals (American moose, white-tailed deer, and black bear) which died as a result of a collision with a motor vehicle. For consistency, these were the only species counted from the Nova Scotia dataset, although other larger species, such as coyote, bobcat, and birds of prey were also included in the records.

The locations were often vaguely described (e.g. some records were listed with the associated road, others with a general location description). Consequently, the records were sorted by county and/or wildlife management zone, rather than by individual roads. This caused the data to be less comparable with the targeted roadkill surveys as those surveys were conducted on 12 roads in the Chignecto Isthmus, and these datasets cover a larger area and more roads. The Nova Scotia dataset is for Cumberland County, which borders New Brunswick and encompasses the towns of Amherst, Oxford, Springhill, and Parrsboro. The New Brunswick dataset is for Wildlife Management Zone 25, and for the Rte 134 and Hwy 15 portion of Zone 19. These zonations cover part of Westmorland county, which borders Nova Scotia and encompasses the towns of Dieppe, Shediac, and Sackville.

A 2-D hotspot analysis was performed on the data using methodologies described in Chapter 2, employing Siriema Road Mortality Software V. 2.0 (2014). Only two roads from the study area (i.e. NB Hwy 15, and NB Hwy 16) which intersected the NCC's modelled wildlife movement corridor (Nussey & Noseworthy, 2018) presented enough records with GNSS coordinates for this analysis and were therefore included in the Siriema hotspot analysis.

3.3 Results

Over six years (2013-2018), a total of 301 dead wildlife records associated with roadways in Cumberland County were reported to the NS LAF for the three largest mammals in the province: moose, deer and bear (Table 4). The highest number of records collected was in 2014, and the lowest numbers were recorded in 2016 and 2017. White-tailed deer were the most frequently reported species, comprising over 80% of the dataset. Black bear were the second most abundantly represented species, at almost 15% of the records, and moose were sparsely represented which is not surprising given their at-risk status in the province, at almost 3%.

Table 4. Counts of large mammals (moose, deer, bear) recorded dead near roads by Nova Scotia Department of Lands and Forestry listed by year, from 2013-2018 in Cumberland County, Nova Scotia.

Year	American moose	White-tailed deer	Black bear	Year Total
2013	2	61	11	74
2014	0	71	8	79
2015	2	51	4	57
2016	4	18	1	23
2017	0	21	2	23
2018	0	27	18	45
Species Total	8	249	44	
% of Total	2.7	82.7	14.6	

For the same time frame (minus four months), a total of 683 records of large mammal roadkill were recorded in Wildlife Management Zone 25, and part of Zone 19 in Westmorland County by the New Brunswick Department of Energy and Resource Development (Table 5). Although the dataset for 2018 comprised only eight months instead of 12, the highest number of records was reported for this year. Similar to the Nova Scotia dataset, the lowest number of records was recorded in 2016. Again, white-tailed deer were the most prevalent in the New Brunswick dataset at almost 80%; the proportions of moose and bear were reversed compared to Nova Scotia, with moose comprising over 16% of the records and bear at 4%.

Table 5. Counts of large mammals (moose, deer, bear) recorded dead near roads by New Brunswick Department of Energy and Resource Development listed by year, from 2013-2018 in Wildlife Management Zone 25, and part of Zone 19 in Westmorland County.

Year	American moose	White-tailed deer	Black bear	Year Total
2013	23	95	9	127

Year	**American moose**	**White-tailed deer**	**Black bear**	**Year Total**
2014	12	103	4	119
2015	19	73	4	96
2016	13	73	4	90
2017	19	95	2	116
2018 (as of August)	26	105	4	135
Species Total	112	544	27	
% of Total	16.4	79.6	4.0	

Of the 683 records from the New Brunswick dataset, 37 were recorded along NB Hwy 15, and 69 along NB Hwy 16 (Table 6). Of these 106 records, 13 were moose for the 2013-2018 timeframe, with more moose casualties on NB Hwy 15 than on Hwy 16, although Hwy 16 displayed a higher total number of wildlife-vehicle collisions due to the higher number of deer collisions. Hwy 16 does display a higher degree of human use for residential and agricultural purposes, while Hwy 15 is heavily forested on both sides. This could explain the difference in distribution of deer and moose collisions between the two roads. Deer are generally more attracted to open fields while moose are more attracted to the close cover found in forested areas for temperature regulation.

Table 6. Species distribution of reported deer, moose and bear collisions on the segments of NB Hwy 15 and NB Hwy 16 located in the study area for 2013-2018.

	Road	
Species	NB Hwy 15	NB Hwy 16
Deer	24	66
Moose	11	2
Bear	2	1
Collision Totals by Road	37	69

NB Hwy 15, between Dieppe and Shediac, and Hwy 16, between Aulac and Port Elgin along the border with Nova Scotia both displayed aggregations of large mammal mortality corresponding with the NCC's modelled corridor (Fig. 10). The aggregation of mortality for Hwy 16 lined up with the modelled corridor well, lending further evidence for the effectiveness of this section for wildlife movement near the border region of New Brunswick with Nova Scotia. The aggregations of mortality on Hwy 15 are less concentrated towards the centre of the corridor, and it is unclear whether this spreading out of a potential hotspot is related to the lower sample size, or that there is forested habitat along both sides of Hwy 15 for much of the stretch between Dieppe and Shediac.

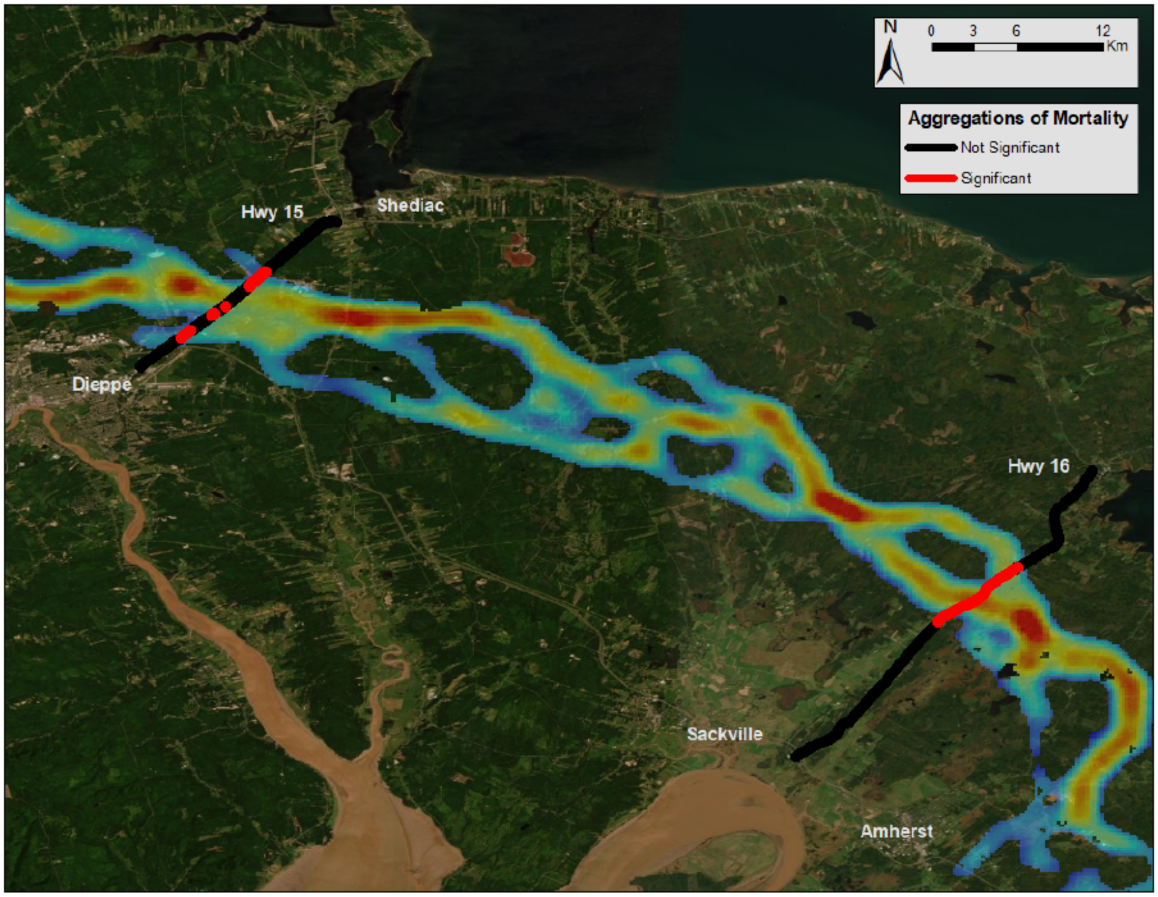

Figure 10. Hotspot analysis based on NB ERD collision data for two roads in New Brunswick which were also surveyed for roadkill during the 2018 field season. Hwy 15 between Dieppe and Shediac displays two main aggregations along the edges of the modelled corridor and Hwy 16 displays an aggregation of mortality that lines up directly with the modelled corridor. Base map courtesy of ESRI (2016).

3.4 Discussion

The most useful reason for acquiring collision data from the natural resource departments is to display spatial trends for larger mammals experiencing road mortality, but which are often reported and subsequently cleared away before they could potentially be recorded in a roadkill survey. The initial impetus for this study was the concern over elevated numbers of moose-vehicle collisions on New Brunswick Hwy 15 (P. Noel, personal communication, January 2018). The single field season of data collected using roadkill surveys for this thesis did not, however, return any moose mortality records for either Nova Scotia or New Brunswick. The results from the collision dataset confirm that there are moose moving across roads in the Chignecto Isthmus region of New Brunswick, some of which are involved in collisions. The discrepancy between the much higher numbers of moose collisions in the New Brunswick portion of the study area compared to the Nova Scotia portion (112 reports over six years vs. eight reports) mirrors the stark contrast in population numbers on either side of the border and further reinforces the idea that roads in the New Brunswick portion of the isthmus serve as barriers to moose migration into Nova Scotia and/or from Nova Scotia to areas of New Brunswick and North America beyond these New Brunswick highways.

The positions of the modelled hotspots derived from provincial report data on Hwy 15 and Hwy 16 correspond with the NCC's modelled wildlife corridor and are consistent with the results obtained from the Siriema hotspot analysis of a full suite of vertebrate roadkill derived from weekly roadkill surveys (Fig. 2.5). This further suggests that the modelled corridor represents important habitat connectivity and a movement pathway for a wide variety of species, and thus may indicate appropriate locations for the installation of wildlife crossing structures.

The main challenge in using these data collected from different observers and departments for a hotspot analysis is the lack of consistent reporting. While, ultimately, the relevant data can be filtered out from a larger dataset (e.g. one that also contains live animal sightings and wildlife nuisance complaints), for comparison between provinces, the consistent reporting of (1) species with correct identifications, (2) accurate locations using GNSS coordinates, and (3) the correct route numbers are all critical components to allow the data to be used in a road ecology study. For the purposes of this study, the generally reported limitation associated with challenges in accurately identifying species was not considered to be a limiting factor, as the three largest mammals (moose, deer and bear) are not easily confused with other species in the region. The Nova Scotia dataset contained coordinates for some observations but not all. There was also a field for the general location, which was not as specific as needed to pinpoint the observation to a specific road (e.g. some locations were listed as just "Springhill" or "Malagash", or there was inconsistency between using the route number and the descriptive name of the roads). Therefore, the Nova Scotia dataset was challenging to use to tally numbers of roadkill events for specific roads and was not able to be used to map the events or conduct a hotspot analysis. The records in the New Brunswick dataset were more consistently associated with GNSS coordinates which allowed for the points to be mapped and a hotspot analysis for two key roads (i.e., Hwy 15, and Hwy 16) to be conducted. There were also separate fields in this dataset for the route number and the general location, which made it easier to tell generally which roads were experiencing collisions before entering the coordinates into mapping software. There were some errors in this information, however, as once the points were mapped it became evident that some of the records had been mislabeled with the wrong route number (e.g. labeled as Hwy 15 instead of Hwy 16, while the coordinates made it clear that the record was directly found Hwy 16). This made general counts of mortality events by road difficult to determine, and thus it was not possible to conduct road-specific analyses.

A key recommendation for any department charged with the task of collecting and compiling road mortality data is to keep a dedicated database for roadkill observations with fields for date, species, route number, general location, and GNSS coordinates. The maintenance of a central location combining law enforcement, transportation department, and natural resource department records, and all observations called in by the public to these various agencies would reduce redundancy and increase reliability of the data allowing for a better estimation of the true numbers of major wildlife-vehicle collisions (similar to the findings reported by Hesse & Rea, 2016). If it is difficult to solicit total compliance in reporting styles for observations from the public, then these data could potentially form a supplementary dataset for anecdotal evidence of wildlife-vehicle collisions. It is important to compile as complete a dataset as possible from the records available and to increase the reporting of wildlife road mortality so that conclusions and mitigation measures can be based on solid evidence of wildlife movement and risk of collision (Hesse & Rea, 2016).

3.5 Conclusion

Despite challenges in using existing wildlife road-mortality reports from the region, they remain an important source of data for supplementing or triangulating field data collected by other means. In this study, it is clear from motorist collision reports to government agencies that moose were killed along roads in New Brunswick in the same year (2018) as the roadside survey, even though no roadkill observations for moose were obtained from the roadside survey (Chapter 2). Some of the data collected by the NB ERD are sufficiently accurate, with associated geographic coordinates, to allow for hotspot analyses on specific roads for a multi-year time period. Records collected by the NS LAF were more varied in terms of accuracy and consistency, with the entries displaying a wide variety of information. While these reports undoubtedly represent the high variability in reports from the public on wildlife encounters, a database for dedicated wildlife-vehicle collision records with consistent records of geographic location would improve the utility of these data to road ecology studies in the region and across provincial borders.

Chapter 4: Using Camera Trap Images of Wildlife near Roads to Describe Behaviour in Response to Roads and Supplement Roadkill Survey Data

4.1 Introduction

Camera traps are frequently used by wildlife conservationists to gather ecological data and are a cost-effective way to assess the conservation status of many larger mammalian species (Silveira et al., 2003; Linkie et al., 2013; Meek et al., 2014; Gálvez et al., 2016). Because camera traps can be set, and then left, causing minimal human interference with wildlife, they are appropriate surveying tools to answer a wide variety of questions in terms of species abundance and richness, and patterns of movement (Silveira et al., 2003; Gálvez et al., 2016). Advantages to using camera trap surveys lie in the relative ease of identification of individual animals compared to other surveys, such as track identification, and an equal chance of capturing nocturnal and diurnal sightings, compared to walking or driving a road and recording live observations (Silveira et al, 2003). Although the start-up costs for purchasing and installing camera traps may be high, the return in terms of ease and abundance of data collection, and the low requirements for monitoring, make camera traps a popular choice in ecological studies (Silveira et al., 2003; Gálvez et al., 2016).

Within the Northern Appalachian-Acadian Ecoregion[13] within which the Chignecto Isthmus is situated, there are more than 300 cameras deployed currently or in the recent past, that are used for wildlife research, many providing data to address issues related to habitat fragmentation in the region (Rafferty et al., 2016). Camera traps are used in road ecology studies to monitor wildlife use of existing wildlife crossing structures, road crossing and avoidance behaviour in locations without crossing structures, wildlife activity in buffers around roads, and monitoring of road crossing locations pre- and post-installation of dedicated crossing structures (Rafferty et al., 2016).

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[13] Encompassing parts or all of Massachusetts, New Hampshire, Vermont, New York, Maine, Quebec, New Brunswick, Prince Edward Island, and Nova Scotia.

As part of a study to monitor mammal use of a wildlife underpass in Antigonish, Nova Scotia, along Hwy 104, 37 trail cameras were used to document presence of 15 species over 2 years (White, 2017). These trail camera data provided evidence of which species were utilizing the dedicated wildlife underpass to cross Hwy 104, and also which species were using the nearby culvert as well as an underpass not dedicated for wildlife use approximately 4 km to the west. This study provided support for the usefulness of trail cameras as a tool for monitoring wildlife movement across roads, however in a specific capacity, as the cameras were not pointed directly at the road but rather at the openings to the underpasses and culverts. The results of the study showed that medium-sized wildlife were likely to use the wildlife underpass, and to a lesser extent, the shared use underpass, as safe crossing structures underneath the roadway. It also provided recommendations for future camera trap studies to maximize the ability to capture a larger subset of wildlfie using the crossing structures.

To supplement the roadkill surveys and official wildlife-vehicle incident reports in the Chignecto Isthmus region, images from six camera traps, in place for 1-2 years on NB Rte 134 and Hwy 15, were obtained from the Nature Conservancy of Canada (NCC). Initially, these data were expected to give evidence of wildlife crossing roads successfully, demonstrating which species were less likely to view the road as a barrier, and therefore not likely to feature as prominently in the roadkill record. Additionally, it was hypothesized that animals which display road avoidance behaviour and decide to not enter the roadway would be detectable in the image records, in which case the road would be identified as serving as a barrier or deterrent to these species. Typically, it is difficult to determine an animal’s interaction with the road after it passes out of the camera frame, and thus there are often limitations to confidence in using camera trap images for confirming road crossing or avoidance behaviour. Nonetheless, the camera trap image dataset may provide qualitative evidence to supplement the results of the roadkill datasets. Inferences may be gleaned from the images about which species of wildlife approach the roads on which cameras are sited to distances of less than 500 m. To this end, this chapter presents the results of a quantitative assessment of the camera trap images and discusses ways that camera trap surveys may be better implemented for future determination of wildlife crossing locations on roads in the Chignecto Isthmus.

4.2 Methods

4.2.1 Image Processing

Image data from six camera traps deployed by NCC staff and in place for 1-2 years (June 2016-June 2018) on NB Rte 134 and Hwy 15 were obtained from NCC in July 2018. Approximately 20,000 images were recovered from memory cards from these cameras. Volunteers were recruited to sort these data, and images were discarded which did not show signs of wildlife (i.e. false positives triggered by moving vegetation, humans or other motion not produced by wildlife). Retained images were organized by date in folders which reflected when each camera was periodically checked. When images were deleted due to lack of wildlife, the individual folders were retained as evidence of 'absence' data. Images were assessed to identify species and number of individuals captured at each camera location. Results are reported as number of individuals of each species observed at each location, in each of the first and second years of camera deployment.

4.2.2 Camera Deployments

From June 2016 until June 2018, six Reconyx trail cameras were active at key locations of suitable habitat or potential crossing structures. NCC sited four cameras on NB Rte 134, and two cameras on NB Hwy 15 (Fig. 11). These locations were recommended to NCC in a report titled "Identifications of wildlife corridors between Moncton and Shediac" (Chiasson, 2016). They were identified as the best locations for cameras within the wildlife corridors between Moncton and Shediac, based on their potential as road crossing points (i.e. with woodlots, field edges, railway tracks, or culverts already in place). They are among 26 potential locations recommended across these two roads (Chiasson, 2016).

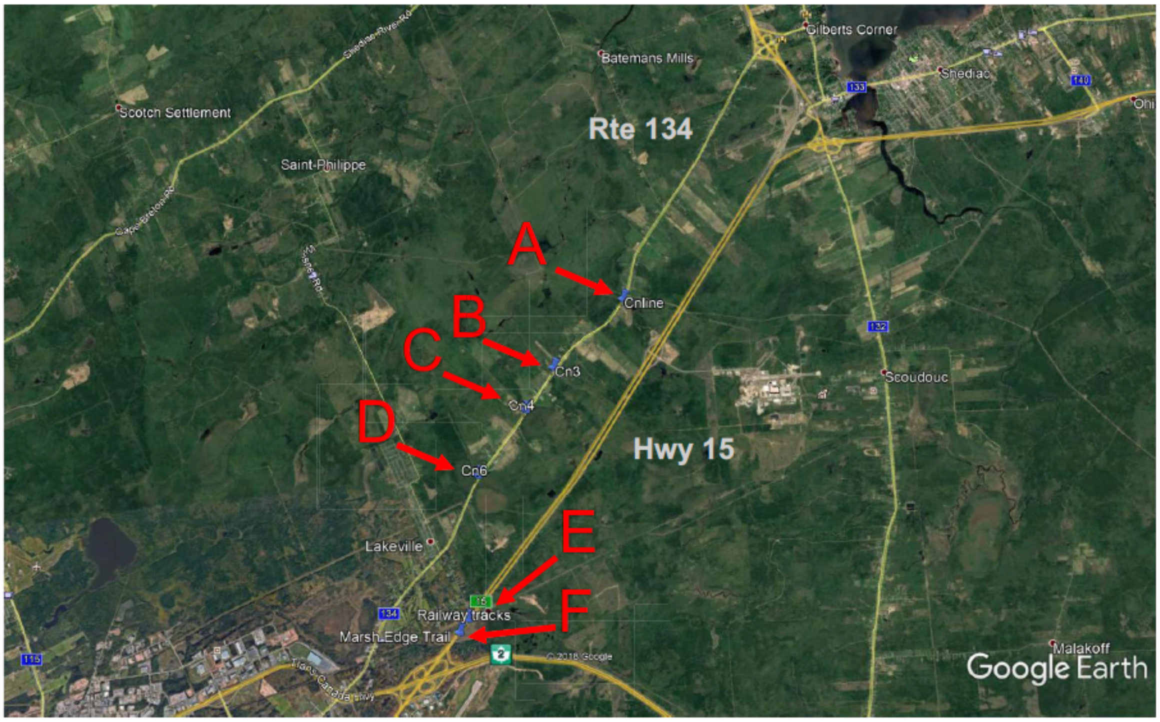

Figure 11. Locations of six NCC trail cams on NB Rte 134, A) CnLine, B) Cn3, C) Cn4, D) Cn6, and NB Hwy 15, E) Railway tracks, and F) Marsh Edge Trail. Base map courtesy of Google Earth.

NCC placed each camera in such a way that it faced a crossing location that intersected with the road. The cameras were monitored regularly and were checked approximately every three months. Three[14] of the cameras on NB Rte 134 were placed so that they faced clearings (Table 7). These locations were hypothesized to constitute less of a barrier to movement for terrestrial species and the lack of steep embankments or wetlands at these locations would also promote road crossing attempts by wildlife (Chiasson, 2016). A fourth location[15] on Rte 134 was chosen as an aquatic crossing, and the camera was positioned facing a culvert that passed under the road with running water, emptying into a marshy area on the other side (Table 7). This crossing location was expected to be used by amphibians and small mammals (Chiasson, 2016). The two camera locations on NB Hwy 15 were located in close proximity, near the junction with NB Hwy 2. The 'Marsh Edge Trail' camera faced a boggy area with tall grass,

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[14] Camera IDs: Cn3, Cn4, Cn6

[15] Camera ID: CnLine

and it was thought that instead of this location serving as a crossing point, that wildlife would follow the edge of the marsh to the nearest underpass to cross (Chiasson, 2016). The nearest underpass was a 44 m high railway crossing, where the 'Railway Tracks' camera was placed where larger wildlife could easily pass under the road (Chiasson, 2016). The railway tracks were not visible from the camera, however, and the camera faced an open field.

Table 7. Location of the NCC's trail cameras, based on recommendations given in a report on "Identifications of wildlife corridors between Moncton and Shediac" (Chiasson, 2016).

Camera ID	**Feature Type**	**Road**	**Crossing Description**[16]	**Camera Orientation Observations**
Cn3	Crossing Point	NB Rte 134	Crossing between 2 woodlots. Large mammal crossing.	Camera faces a clearing with trees approximately 10 m away.
Cn4	Crossing Point	NB Rte 134	Connects 2 woodlots, commercial property for sale. Deep ditches.	Camera faces an unpaved road.
Cn6	Connections to 2 woodlots	NB Rte 134	Track, forest edge, woodlot, graded road. Mammal crossing.	Camera faces a clearing with brush approximately 5 m away.
CnLine	Trail	NB Rte 134	Powerline trail. Possible corridor.	Camera faces a culvert running under the road with an aquatic crossing.
Marsh Edge Trail	Trail	NB Hwy 15	Instead of crossing road animals could follow the edge of the marsh and cross under the overpass.	Camera faces a boggy area with tall grass.
Railway Tracks	Railway Tracks	NB Hwy 15	2 railways create a wide corridor, 44 m high. One railway track is broken. Possible crossing with adjacent dirt road.	Camera faces a grassy field with an ATV track.

Four[17] of the cameras were operational for nearly two years, although the Marsh Edge Trail camera is missing data from July through October 2017,

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[16] Chiasson, 2016

[17] Camera IDs: Cn3, CnLine, Marsh Edge Trail, Railway Tracks

possibly due to a camera malfunction[18]. The remaining two cameras[19] collected data for only the first year due to theft and a camera malfunction. The vast majority of the more than 20,000 records were false positives due to triggers from vegetation moving with the wind; each time the camera was triggered, it took a burst of five images. All images except those with animals present in the frame were deleted. Images of domestic cats were retained by the volunteers but were not included in the analysis. Finally, there remained approximately 1,800 images showing instances of wildlife.

Due to the inability of determining whether wildlife crossed the road or circled back behind the camera, conclusive determinations of crossing or avoidance behaviour were not possible. Instead, numbers of individuals which were present in the camera's vicinity were counted as evidence of wildlife presence near roads. All animals that passed by the camera in the same direction were counted as individuals. If the same species passed in the opposite direction within 10 minutes, it was considered to be the same individual. This independence interval (i.e. the amount of time that passes for an observation to be considered independent of the previous observation) is on the lower range of what is seen in the literature (Meek et al., 2014). 10 minutes was chosen as an appropriate threshold, as it was determined to be a sufficient time for the animal to pass the camera, approach the road, then decide to return from in the opposite direction. Ultimately, if two or more individuals were spotted within the 10-minute independence interval, they occurred within the same burst of five images that the movement triggered each time and were easily identified as separate individuals. No instances of the same individual moving in the opposite direction were detected within a 10-minute interval; in fact, unless there were several individuals moving as a group, all observations were an hour or more apart.

Although some images were blurry due to quickly moving individuals, there were few to no instances of confusion in species identification for larger

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[18] The folder for this time period was labeled by the volunteer who sorted the images as "missing". If there had not been any animal sightings, the folder would have simply been empty.

[19] Camera IDs: Cn4, Cn6

mammals (i.e. deer, coyote, bear, bobcat, and moose). The unknown mammals recorded were medium sized and low to the ground, possibly porcupines or raccoons, but unlikely to be any of the larger species.

Species counts were separated into ‘Year 1’ for cameras that were operational from approximately June 2016-June 2017, and into ‘Year 2’ for those cameras that continued to record images for an additional year, until June 2018. This was done in an attempt to not misrepresent the number of individuals seen at each location, as some cameras were functional longer than others. Because not all cameras recorded images for a second year (either because the camera malfunctioned or was stolen), conclusions should not be made across years for species abundance.

4.3 Results

A total of 14 identified species and 281 individual animals were observed among the images from the six cameras, with 171 of those records in the first year when all six were operational (Table 8). The camera located at Cn4 (Yr 1) detected the highest identified species richness (n=8) and highest number of individuals (n=56) by location and year. The lowest identified species richness (n=2) was observed at CnLine (Yr 2) and Railway Tracks (Yr 1; Yr 2) sites, with the lowest number of individuals (n=2) at CnLine (Yr 2). White-tailed deer were observed at each location except at the CnLine site, and were the most abundant species detected overall, followed by Eastern coyote, and raccoon. The only bird observed more than once near the road on the ground was the ring-necked pheasant. One sighting of moose was made near Hwy 15 at the Marsh Edge Trail, and bobcat were also shown in the area with 10 sightings in total. When raccoons are excluded, the highest identified species richness (n=7) and highest number of individuals (n=43) remains at Cn4 (Yr 1), with the lowest identified species richness (n=1) and number of individuals (n=1) at CnLine (Yr 2)

Table 8. Species observed on the NCC's trail cameras from June 2016 - June 2018, separated by year one and year two.

Species Observed		**Number of Individuals Observed**											
		Cn3		**Cn4**	**Cn6**	**CnLine**		**Marsh Edge Trail**		**Railway Tracks**		**Species Totals**	
Common Name	**Scientific Name**	**Year 1**	**Year 2**	**Year 1**	**Year 1**	**Year 1**	**Year 2**	**Year 1**	**Year 2**	**Year 1**	**Year 2**	**Year 1**	**Year 2**
White-tailed deer	*Odocoileus virginianus*	19	12	12	2	0	0	11	36	31	21	75	69
Eastern coyote	*Canis latrans*	17	13	15	1	0	0	0	1	1	0	34	14
Common raccoon	*Procyon lotor*	5	17	13	0	3	1	1	0	0	0	22	18
Bobcat	*Lynx rufus*	0	1	5	1	0	0	2	1	0	0	8	2
North American porcupine	*Erethizon dorsatum*	0	0	5	0	0	0	0	0	0	1	5	1
Snowshoe hare	*Lepus americanus*	1	0	0	2	2	0	0	0	0	0	5	0
Canadian beaver	*Castor canadensis*	0	0	0	0	4	0	0	0	0	0	4	0
Black bear	*Ursus americanus*	0	0	1	0	0	0	0	0	0	0	1	0
American moose	*Alces alces* americana	0	0	0	0	0	0	1	0	0	0	1	0
Striped skunk	*Mephitis mephitis*	1	0	0	0	0	0	0	0	0	0	1	0

Species Observed		**Number of Individuals Observed**											
		Cn3		**Cn4**	**Cn6**	**CnLine**		**Marsh Edge Trail**		**Railway Tracks**		**Species Totals**	
Common Name	**Scientific Name**	**Year 1**	**Year 2**	**Year 1**	**Year 1**	**Year 1**	**Year 2**	**Year 1**	**Year 2**	**Year 1**	**Year 2**	**Year 1**	**Year 2**
Red fox	*Vulpes vulpes*	0	0	0	1	0	0	0	1	0	0	1	1
American red squirrel	*Tamiasciurus hudsonicus*	0	0	1	0	0	0	0	0	0	0	1	0
Unknown mammal		0	2	0	4	0	0	0	0	0	0	4	2
Ring-necked pheasant	*Phasianus colchicus*	4	2	4	0	0	0	0	0	0	0	8	2
Great blue heron	*Ardea herodias*	0	0	0	0	0	1	0	0	0	0	0	1
Unknown bird		0	0	0	1	0	0	0	0	0	0	1	0
Number of individuals by location and year		47	47	56	12	9	2	15	39	32	22	171	110
Number of individuals by location and year, excluding raccoon		42	30	43	12	6	1	14	39	32	22	149	92
Species richness by location and year (excluding ‘Unknown mammal’ and ‘Unknown bird’)		6	5	8	5	3	2	4	4	2	2	13	8
Species richness by location and year (excluding ‘Unknown mammal’, ‘Unknown bird’, and raccoon)		5	4	7	5	2	1	3	4	2	2	12	8

Species Observed		Number of Individuals Observed											
		Cn3		Cn4	Cn6	CnLine		Marsh Edge Trail		Railway Tracks		Species Totals	
Common Name	**Scientific Name**	**Year 1**	**Year 2**	**Year 1**	**Year 1**	**Year 1**	**Year 2**	**Year 1**	**Year 2**	**Year 1**	**Year 2**	**Year 1**	**Year 2**
Total species richness by location (excluding 'Unknown mammal' and 'Unknown bird')		7		8	5	4		6		3		14	
Total species richness by location (excluding 'Unknown mammal', 'Unknown bird', and raccoon)		6		7	5	3		5		3		13	

4.4 Discussion

White-tailed deer is a species with relatively high population sizes in both Nova Scotia and New Brunswick; not listed as a species of conservation concern, there were over 9,000 individuals harvested by hunters in 2018 in Nova Scotia (Province of Nova Scotia, 2019) and an estimated population of at least 70,000 deer in New Brunswick (NB ERD, unpublished data, as cited in Fowler, 2016). It is therefore not surprising that deer are represented as the largest group found near roads at these camera locations. It is also probable that large, quick-moving deer would trigger cameras more often than smaller, slow-moving animals such as raccoons or porcupines. Additionally, the number of deer in the dataset could also be misrepresented as a lower amount than what is actually approaching the roads, as it is possible that some deer may have triggered the release but left the frame too quickly for the camera to capture an image. This would result in image bursts with no photographs of wildlife but also with no way to determine if they were actually true positives where the camera did not capture the animal before it moved out of the frame. Images of deer (n=144 across the two years) were found in eight of the location/year datasets, representing five of the six sites. While it cannot be definitively concluded that every individual deer that triggered the camera crossed the road, safely or not, it is evident from these data that deer are not opposed to approaching roads. Deer fall into a category of road behaviour response categorized by Jacobson et al. (2016) as “speeders”. As speeders, this species tends to flee as its primary response to threat and will therefore quickly run across the road if traffic volumes are not extremely high (Jacobson et al., 2016). Because they are quick, and can often outrun cars, they may be crossing roads in much higher numbers than suggested by the roadkill surveys.

Coyotes, also abundant in the region, were seen often on the trail cameras (n=48 across the two years), especially at the woodlot crossings, and mainly at night. Images were captured in six of the location/year datasets, representing five of the six sites. Raccoons (n=40; captured at four of the six sites) displayed similar patterns to coyotes. Both species are likely “avoiders”, as characterized by Jacobson et al. (2016), tending to recognize moving vehicles as threats and avoiding roads with higher traffic volumes (Jacobson et al., 2016). There were almost no coyotes (n=1) represented in the roadkill surveys even though they are approaching roads fairly regularly; a possible explanation is that traffic volume is lighter at night when they are more active and likely to cross the road. Although raccoons do make up a large proportion of the roadkill survey dataset (Table 2.2), because they are also active nocturnally but smaller and less visible, they will potentially cross and still be hit at lower traffic volumes due to reduced driver visibility and also the perception that a collision with a raccoon will not cause as much damage to the vehicle.

As a species which generally avoids human disturbance and has a negative association with high road density (Donovan, et al., 2011), bobcats, although common in the region, were not found as roadkill during the surveys. Camera evidence shows, however, that they are present around roads nocturnally (n=10; images from four camera sites), and it is possible that they are using the clearings near roads as hunting grounds. Bobcats tend to hunt along forest edges where there is opportunity for increased prey availability, yet avoid roads, recognizing moving vehicles as threats (Jacobson et al., 2016; Reed, et al., 2017).

Two of the three woodlot crossings, which offered clear paths for wildlife on either side of the road leading into more dense vegetation, rendered the highest species richness, with eight species detected at the Cn4 crossing, and seven at the Cn3 crossing. Cn4 also showed the highest diversity of larger mammals, with deer, coyote, bobcat and bear appearing at this location, as well as the most individuals in a single year (n=56 in year one). The third woodlot crossing, Cn6, and the Marsh Edge Trail both detected six different species, however the Marsh Edge Trail experienced a higher number of individuals (n=15 in year one, and n=39 in year two, compared to n=12 for one year at Cn6). Although there was less diversity at the Railway Tracks, there was the greatest ratio of individuals (n= 32 in year one, n=22 in year two) to species richness (n=2 in both years), with all but two of the individuals across both years being deer.

This phenomenon could be due to deer using the railway underpass to traverse this busy 4-lane highway with less wide-ranging animals not recognizing the underpass as potentially safe passage.

Overall, the cleared land with no steep embankments or wetlands to navigate promoted the highest numbers of wildlife sightings, represented by camera locations Cn3 and Cn4, suggesting that these areas warrant follow-up studies to assess their potential for road mitigation as safe wildlife crossings to increase the permeability of Rte 134 to wildlife movement.

The crossing with the least potential for terrestrial wildlife appears to be the culvert[20] with water flowing through it. The only mammals detected at this crossing were raccoons, snowshoe hare and beavers. Although not providing potential for larger mammals to cross, maintaining aquatic connectivity across roads is also important for both fully aquatic animals but also semi-aquatic ones such as beavers which would try to access forested areas on both sides of the road.

No amphibians were seen using the aquatic crossing at CnLine, however this should not be taken as evidence that no (semi-) aquatic animals are using this crossing. Due to the high placement of the camera, it is likely that any organism swimming or moving low to the ground would either have been obscured by vegetation or not triggered the camera.

Camera data give very specific information related to the presence of an animal at that location at a certain date and time. It cannot be assumed that an animal is not present simply due to a lack of images, and individuals may pass the camera more than once. Accordingly, it is important to not make definitive conclusions on species absence or relative abundance from camera data alone (Silveira et al., 2003; Sollmann et al., 2013; Rafferty et al., 2016), nor about successful crossings. The totals of individuals observed in the images more accurately represent individual numbers of approaches to the road at individual locations, rather than number of individuals in the area or the number of crossings.

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[20] Camera ID: CnLine

As a method for quantifiying road avoidance behaviour, the positioning of cameras in such a way that the road is not visible is not ideal. However, if the road was within the camera frame, the number of false positive triggers due to vehicle traffic would be unmanageable in terms of available memory storage, battery life, and personpower in continuously checking and maintaining the cameras so close to the road and in sorting through the repository of images. Key recommendations for camera placement involve placing them at approximately chest height to avoid vegetative interference, towards north to avoid glare from the sun and false triggers at sunrise and sunset, and away from oncoming traffic (Rafferty et al., 2016; Steckler et al., 2016). If the road is not visible, it is always possible that the animal passes in front of the camera, then turns and follows the road, or circles back behind the camera. Potentially a short-term study could address this issue by placing the camera so that a minimal amount of road surface is visible (e.g. the shoulder), with the cameras checked and data downloaded weekly. A concern here would be in the ability to mount the camera safely on the roadside, given the heightened potential for damage or theft when visible by motorists.

Several recommendations were put forward from the study on wildlife use of a culvert on NS Hwy 104 for future camera placement that were specific to wildlife underpass use but could be generalized to monitoring road crossing locations with structures as well. Firstly, cameras should be placed at a 45° angle from the vertical on the post, tree, or structural wall on which it is attached to cover a wider view of the ground to detect more medium mammals (White, 2017). Secondly, signage on the camera should be included to inform the public of the purpose of the camera traps to both garner public support for the project and to deter theft (White, 2017).

As a method for describing species richness and presence/absence, and for determining which wildlife species will approach roads to a certain distance, camera traps do have potential utility. For this purpose, a location set back from the road without the road visible works well for camera placement, as was seen in this study. Additional cameras on Rte 134 or Hwy 15 sited to other points of connectivity identified by Chiasson (2016) could provide further evidence as to which species are most likely to use the hypothesized crossing locations, and a larger subset of camera locations will allow for greater comparison between sites.

Overall, the locations chosen for the placement of camera traps on Rte 134 and Hwy 15 do represent potential wildlife movement corridors, with the woodlot connections (i.e. Cn3 and Cn4) seeming to provide heightened opportunities for terrestrial mammals, and with the railway underpass on Hwy 15 (i.e. Railway Tracks) seeming to be most frequented by deer. The absence of wildlife at the only culvert monitored by cameras (i.e. CnLine) points to the fact that terrestrial and aquatic wildlife need different crossing structures to traverse roads. Culverts in a variety of sizes and substrate conditions should be chosen to better assess whether one type of culvert is more accessible and useful as a crossing structure than others. Additionally, cameras placed near culverts monitoring the surrounding habitat could provide evidence for the use of that site as a crossing location for terrestrial wildlife which may use riparian corridors or open wetlands for movement but cross on the road surface, rather than through a narrow culvert.

4.5 Conclusion

While not providing ideal or complete evidence on their own, camera trap images provide important supplementary information to consider along with roadside surveys of vehicle-caused mortality, and official records of wildlife-vehicle incidents. While moose did not appear as roadkill in the weekly roadside surveys (Chapter 2), one image was obtained through camera trap data, thus confirming their presence in the general area, and therefore their potential to be involved in collisions with vehicles. Camera trap images provided further on-site evidence of other species, such as bobcat and coyote, that did not figure prominently in the other sources of data but may approach roads without often suffering mortality. Upon reviewing the data from the roadkill surveys, one might be tempted to conclude that coyote and bobcat are scarce in the region; the trail camera images suggest that they are present but interacting with roads differently than other species in such a way that they are either avoiding the road surface (e.g. few bobcat were seen in the camera record, suggesting they do not approach roads often) or recognizing low traffic densities and crossing at opportune moments (e.g. many coyotes were seen in several of the camera records[21] at night with no evidence that they retreated when approaching roads).

As a method for providing evidence of species' presence near roads without records of death or injury, the camera images served a unique, yet not fully realized purpose in this study. The potential utility of monitoring key crossing locations to view individual interactions with roads is high. The number of roads in the study area which are monitored with trail cameras should be increased, and the positioning of the cameras should be carefully considered so that they are as close to the road as is practical and feasible to increase the confidence in the actual interaction of the animal with the road. Additional sites along NS Rte 366 (on land protected by NCC), Rte 6 and Hwy 104, located within the modelled wildlife movement corridor, should also be chosen for additional camera sites to glean comparable data from Nova Scotia roads. When deployed regularly and consistently, trail camera data should provide key information as to which medium-large bodied species are successfully crossing roads and at which times during the day, as well as which species view the road as an insurmountable barrier.

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[21] Camera IDs: Cn3 and Cn4

Chapter 5: Discussion and Conclusion

5.1 Discussion

Through this research, three main data sources were collected and described for their usefulness in providing evidence for the interaction of wildlife with roads across a large regional-scale landscape: (1) systematic roadside surveys of vehicle-caused wildlife mortality; (2) wildlife-vehicle collision reports collected by government agencies; and, (3) trail camera images of wildlife proximal to roads. Taken together they reveal preliminary, yet strong, patterns of hotspots of roadkill mortality and wildlife activity in association with roads within and outside of modelled high-probability wildlife movement corridors in the Chignecto Isthmus region. These patterns can highlight potential areas warranting more detailed, site-specific and longer-term studies to provide high-confidence evidence in support of decision making for wildlife conservation planning and road mitigation strategies.

As a primary source of data, the roadkill survey undertaken in this region, along with the subsequent hotspot analyses, are first steps towards understanding the impacts on wildlife which directly interact with roads. While this short-term dataset can be implemented as one piece of evidence as to which species are impacted by road mortality, there are limitations to its use. The sample size is small in terms of number of survey days. Because of the nature of this type of data collection (i.e. recording the presence of roadkill and assuming absence when no carcasses are detected during a survey) with a bias trending towards underestimating the severity of the issue due to high removal rates of carcasses by scavengers or degradation by vehicle traffic (Antworth et al., 2005; Santos et al., 2011; Ratton et al., 2014), a high number of sampling days is required to increase the confidence in the results and the significance of the hotspots as true positive aggregations of mortality (Santos et al., 2011; Collinson et al., 2014; Santos et al. 2015). Not only will an increased number of survey days, as well as repetition over consecutive seasons for comparison purposes, decrease bias towards underreporting, it will also increase the statistical power of the hotspot analyses (Coelho et al., 2014). The dataset collected for this study is available in Appendix A, and provides a standard template for building a longer-term dataset in future years.

In follow up to this preliminary regional study, more intensive roadkill surveys should take place on selected roads with moderate to high traffic volumes which are shown to connect key areas of prime habitat for species such as moose and other medium to large mammals of either human safety (e.g. deer) or conservation (e.g. Canada lynx [*Lynx canadensis*]; listed as endangered in the area in 2002 (Province of Nova Scotia, 2017)) concern, or those with specialized habitat needs (e.g. amphibians associated with wetland features) (Langen et al., 2007; Gonález-Galina et al., 2013). Specifically, NB Rte 134, Hwy 15 and Hwy 16, as well as NS Rte 6 and Hwy 104 are key higher volume (especially Hwy 15) transportation routes which should be further examined for their role in impacting regional flow, with carcass surveys targeted to the sections which intersect the modelled high-probability wildlife movement pathway (and buffers either side). Additionally, wetland features along medium high AADT volume roads within the Chignecto Isthmus region, yet outside of the range of the modelled corridor, should be targeted for intensive herpetofauna carcass surveys. Due to the ephemeral nature of these carcasses once exposed to environmental factors such as scavenging, degradation, and desiccation, these taxa were difficult to detect when surveys covered such a large area. Daily surveys around wetlands located on NS Rte 6 near the Shinimicas Bridge area would be useful for describing the impacts of roads on amphibians and reptiles and would allow these animals to have better representation in the record than the weekly coarse-scale roadkill surveys allowed.

Two other sources of data were examined and discussed in the preceding chapters: 1) collision reports of large mammals collected by natural resource departments and law enforcement, and 2) camera trap images of species which approach roads. An advantage of using motorist and law enforcement collision reports is the ability to capture data, at low cost, that can be used to provide a supplementary picture of the impact of traffic on large mammals. The larger mammals (i.e. moose, deer, bear) which comprised these datasets were often removed from roadways shortly after the occurrence of the collision, and therefore were not often available as observations during the daily roadkill surveys. The few deer and bear discovered during the surveys were likely killed by collisions with large trucks which did not sustain damages and the drivers of which would therefore not be invested in reporting the collisions. A limitation to using a road mortality dataset, whether collected systematically or from collision reports, is that it underrepresents species with lower population numbers, potentially impacted by road mortality in the past, and those which are impacted by roads through their avoidance behaviour (Litvaitis & Tash, 2008; Eberhardt et al., 2013). Additionally, databases created for the purpose of collecting and storing wildlife collision reports are more effective for comparison across the regional scale when reports are standardized in terms of recording geographic locations and species identification. As such, regional databases (e.g. one that covers the maritime provinces[22]) should be established to collect all wildlife-vehicle collision reports which may be reported to various agencies, such as the RCMP, insurance companies, natural resource departments, and/or transportation departments. In this way, standardized recommendations for the collection of data can be established and publicized and each individual agency can submit their records in the appropriate format to a centralized data clearinghouse.

Placing motion-triggered trail cameras at potential crossing locations and/or habitat areas well connected except for roads can provide some limited information for understanding which species will approach roads, even if they are not prominent in the roadkill record. A drawback to their utility is the inability to directly observe the behaviour of the animal at the road surface as cameras pointed at the road would be triggered excessively by vehicle traffic. This limitation of camera trap data, due to the nature of the equipment used, is the main difficulty in determining which species will cross roads safely and which will

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[22] New Brunswick, Nova Scotia, and Prince Edward Island

choose to turn back, both leaving little to no image or roadkill record. Additionally, camera trap images only offer a very narrow view of which individuals are approaching the road at a given time, as the field of view captured is generally very small, less than 100 m radius. The field of view could be expanded by placing multiple cameras at the same location and at 45° angles to the vertical but would incur a trade-off in cost. Because of this limitation, camera trap data should be taken as only a supplement to a larger dataset, and other methods of determining wildlife presence near roads should also be utilized, such as sand and snow tracking surveys at multiple points along the road (Gunson & Schueler, 2019).

Despite the limitations, when taken together, the findings, though preliminary, show some clear and statistically significant patterns. These include roadkill hotspots that correspond with the NCC's modelled high-probability wildlife movement pathway, representing heightened road crossings in those locations compared to surrounding stretches of roads. Those patterns that are not as statistically rigorous also tend to display similar configurations which loosely correspond with the model and could gain significance with repeated data collection and increased sample sizes. The general trend, seen in roadkill survey data (Chapter 2) and repeated in provincial collision reports (Chapter 3), is for aggregations of wildlife mortality to fall mainly within areas where NCC's modelled high-probability wildlife movement pathways intersect with roads. This supports the hypothesis that this model accurately represents where some wide-ranging species are moving across the landscape within the Chignecto Isthmus region. This is not to say that wildlife-road interactions are only happening where ecological flows intersect major roads. There are aggregations of mortality that occur outside of the modelled corridor, and wildlife-vehicle collisions can and do occur on all road types if there are individuals present in the surrounding habitat which attempt to cross. As development in the region continues and environmental pressures such as sea level rise or increased storm surges potentially cause infrastructure to be relocated further inland, it is possible that the increased restriction of movement will intensify the region as a pinch-point or barrier to wildlife flow. As this happens, it is expected that roadkill patterns will continue to concentrate more towards the highest elevations along the isthmus, aligning more clearly with the modelled corridor as it represents some of the last remaining partially connected habitat between Nova Scotia and New Brunswick.

As previously established, the Chignecto Isthmus region of Nova Scotia and New Brunswick is a priority linkage area which, although serving as an essential movement corridor for wildlife, is also highly impacted by anthropogenic infrastructure including roads. A critical barrier between Nova Scotia, southern New Brunswick and the rest of North America is the segment of NB Hwy 15 which connects Dieppe and Shediac. This highway represents a high traffic volume road directly bisecting the NCC's modelled high-probability wildlife movement corridor (Nussey & Noseworthy, 2018). Roadkill hotspots for mammals derived from the 2018 field season data and the NB ERD collision reports should be further examined as potential siting locations for crossing structures, pending confirmation of the availability of habitat on both sides. Hotspots that correspond with the wildlife movement corridor should be prioritized for follow up field verification of habitat configuration, wildlife monitoring and earmarking for a potential vegetated overpass targeted at the larger mammalian species.

In Nova Scotia, NS Hwy 104 between Amherst and Springhill is also a high traffic volume road; it serves as the major transportation connector between the two provinces. Although it crosses the border and runs along the isthmus, it also crosses the modelled corridor near Amherst and potentially represents a barrier to wildlife movement. There is a clear hotspot that intersects with the NCC's modelled corridor and this is also a good location to consider for road-effect mitigation strategies on the Nova Scotia side. Consistent with recommendations from a wildlife culvert study in Antigonish (White, 2017), more locations for dedicated wildlife culverts paired with fencing on Hwy 104 should be identified. This section, located between Exit 4 at Amherst and Exit 5 at Springhill, represents a good potential location for a large culvert that should be built to accommodate as many species as possible. White (2017) suggests that underpasses for a major highway in Nova Scotia should be constructed as half-dome culverts large enough to accommodate streams with dry land on both banks for terrestrial mammal movement. To accommodate deer, a problematic species for wildlife-vehicle collisions in Nova Scotia, the underpass should have an openness factor[23] of 0.25 as well as landscaping to continue the natural terrain into the culvert and fencing to guide wildlife into the opening (White, 2017).

For road-effect mitigation considerations, there are several species in the Chignecto Isthmus region which are of conservation concern, wide-ranging, and cause frequent safety concerns for motorists. Species which fall under all three of these categories are therefore ideal candidates to serve as focal species for mitigating both wildlife-vehicle collisions and the barrier effect. One such species is the American moose (*Alces alces* americana). Moose are abundant in New Brunswick, with estimates of a population size of approximately 30,000 individuals (Fowler, 2017). In Nova Scotia, however, the moose population has dwindled to less than 1,000 individuals with genetic flow across the isthmus nearly nonexistent, and recent estimates placing numbers even lower, with potentially less than 100 individuals across the peninsular portion of the province (Timmermann & Rodgers, 2017; T. Millette, Nova Scotia Department of Lands and Forestry, unpublished data as cited in McGregor, 2019). Moose have been officially listed as endangered in mainland Nova Scotia since 2003 (Province of Nova Scotia, 2017). Factors influencing moose population persistence in Nova Scotia are varied and include their susceptibility to parasites contracted by the more numerous white-tailed deer (*Odocoileus virginianus*), tick infestations, and habitat conversion and fragmentation, among others (Snaith et al., 2004; Beazley et al., 2006). Restrictions in moose' ability to move freely across the isthmus due to roadways likely contribute to decreased genetic influx and inbreeding depression, which may be affecting population sizes (Snaith & Beazley, 2002). Moose have large home ranges, and road-related mortalities are common as

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[23] Openness factor refers to the amount of ambient light available in the underpass. Openness = (width x height)/length (Donaldson, 2005).

moose often have to cross major highways (Beazley et al., 2004; Fudge et al., 2007). News reports of moose-vehicle collisions in New Brunswick are frequent, always with instances of property damage and often loss of human life (Letterick, 2017). The barriers that roads present may be a significant factor in the ability of already depressed mainland Nova Scotia moose to maintain population viability.

As a focal species for mitigating wildlife-vehicle incidents, moose would benefit from tall wildlife fencing along controlled access highways keeping them from entering the roadway. To ameliorate habitat fragmentation, wildlife overpasses with vegetation mimicking the extension of natural habitat on either side of the highway would allow moose to cross safely. Large mammals' use of underpasses is highly variable, even when fencing guides these species towards the opening; however, overpasses have the potential to be more widely and frequently used than underpasses by these species (Huijser et al., 2016), especially in combination with fencing.

A second species for consideration in the Chignecto Isthmus region is the North American porcupine (*Erethizon dorsatum*). This species is quite common throughout the region and a frequent victim of road mortality, as evidenced by the appearance of many dead individuals along roadsides in the summer months. The porcupine has very few natural predators and identifies those predators by smell rather than sight; when it is faced with threat it employs the response to freeze and present its quills (Pokallus & Pauli, 2016; Osburn & Cramer, 2013). This response, described by Jacobson et al. (2016) as the "pauser" response, results in high rates of road mortality because these individuals do not react to the threat of a moving vehicle in such a way that will allow them to escape danger. Due to its preferences for foraging along the disturbed roadside and no aversion to the road surface (Woods, 1973), the porcupine is at high risk for road-related mortality. Although not currently listed as a species of conservation concern, the high road mortality rate in both provinces combined with a low reproductive rate (Woods, 1973) puts the porcupine at risk of population depression from road-mortality effects if mitigation strategies are not implemented.

Because they have a relatively small home range, fencing along highways would serve as less of a barrier for porcupines in terms of dispersal and ability to interact with other members of the species than for those that need large swathes of connected habitat. Therefore, erecting fences with mesh sizes small enough to exclude porcupines from the road would reduce instances of road mortality for the species without greatly impacting their population viability. However, access to resources such as bodies of water might also be considered on a site-specific basis when determining whether the barrier effect is indeed impactful for a species like this, and thus connectivity through the installation of wildlife crossing structures should be maintained. As wildlife overpasses, such as those designed for moose, are often used by many other species because they connect natural terrain (Glista et al, 2009), investing in this type of mitigation for moose may also benefit smaller species, such as porcupines. Therefore, it is likely that porcupines and many other small animals would also benefit from underpasses.

Limiting factors that prevent mitigation from being immediately and universally applied include economic costs, lack of public support, and a need for more evidence on their ability to increase gene flow between populations (Corlatti et al., 2009; Bager & da Rosa, 2010; Polak et al., 2014). Although mitigation can be expensive, the economic and social costs associated with continuing to allow wildlife to interact with roads, if carefully considered, should outweigh the monetary concerns for improving roads with wildlife-friendly mitigation. For example, a study which assessed costs related to deer-vehicle collisions in Utah, without taking into account collisions which were indirectly caused by deer, such as swerving to avoid a collision and going off of the road, found that over 50% of the costs related to deer-vehicle collisions were related to human fatalities, with upwards of an extra 40% associated with vehicle damage and human injury (Bissonette et al., 2008).

When mitigation is applied post road-construction, it can be costly to integrate crossing features into the existing infrastructure. Before constructing new roads, environmental impact assessments should be carried out to assess the impact on surrounding habitat features, the impact on observed or modelled wildlife movement patterns, and the current status of species of conservation interest that are present in the area. Potential crossing opportunities should be assessed and built into new road construction. The construction of new roads, especially those which represent new development into otherwise natural areas, should be heavily scrutinized, and where possible, under-utilized roads should be decommissioned (Trombulak & Frissell, 2000; Beazley et al., 2004; Robinson et al., 2010). No matter the type of mitigation chosen, maintenance of fences and crossing structures is key for their effectiveness. Additionally, once constructed, regular monitoring should take place to describe which species are making use of the crossing structures to lend further evidence for their conservation value beyond the reduction of roadkill (Clevenger, 2005; Lesbarrères & Fahrig, 2012).

A less expensive, more immediately accessible form of mitigation for wildlife-vehicle collisions is the introduction of speed limit reductions at known areas of problematic wildlife-road interactions. While actions targeting motorists' behaviour are not as effective in reducing collisions as those which exclude wildlife from the road, they are more feasible for roads where implementation of fencing and crossing structures is not possible (Hedlund et al., 2003; Eco-Kare International, 2015). Roads without controlled access (i.e. major highways) that experience relatively high traffic volumes (e.g. above 3,000 vehicles/day in New Brunswick; above 1,500 vehicles/day in Nova Scotia) and have higher posted speed limits (above 80 km/h) would benefit from the following recommendations. Either 1) permanently reduce speed limits (by 10-30 km/h) in zones which correspond directly to roadkill hotspots for medium to large mammals, giving drivers more response time where collisions are known to be frequent (Meisingset et al., 2014), or 2) temporarily reduce speed limits along larger stretches of the same roads at dawn and dusk, giving drivers more response time when wildlife are the most active. Additionally, although targeted signage that specifies which species are most at risk is popular, it has not been shown to be more effective than generic wildlife crossing signs which remind the public to slow down and be vigilant (Magnus et al., 2004). What is effective on a wildlife crossing sign, however, is information on the time of day (e.g. dusk and/or dawn) or season when wildlife are most likely to be active near the roads as well as a reminder of the reduced speed limit in that area (Magnus et al., 2004). As such, NB Rte 134 and Hwy 16, with AADT volumes higher than 3,000 vehicles and speed limits above 80 km/h should be targeted for reduced speed limit mitigation along medium-large mammal roadkill hotspots. Although Rte 132 also falls in this category for traffic volume and speed limits, no significant roadkill hotspots were found after one season of data collection, and thus no recommendations are suggested at this time for speed restrictions on this road. NS Rte 6 and Rte 302 had the highest AADT for the Nova Scotia portion of the study area with speed limits above 80 km/h. NS Rte 6 did display significant roadkill hotspots for medium-large mammals in several sections which might benefit from speed limit reductions. Rte 302, however, did not show statistically significant hotspots after one season of data collection; more evidence should be collected before making conclusions on the speed limits for this road.

Moving forward, other sources of data are emerging with potential promise. With the increased use of smartphones with GNSS capabilities, one method of obtaining roadkill data that has become popular is the use of cellphone applications (“apps”) which allow volunteers to record and submit geotagged photos of wildlife found dead on the road (Waetjen & Shilling, 2017). Currently, the NCC, in partnership with the Staying Connected Initiative (SCI), is maintaining a citizen science portal for roadkill and live animal sightings on the app “iNaturalist”. The project, entitled “WildPaths Maritimes” collects observations from app users throughout the maritime provinces (i.e., Nova Scotia, New Brunswick and Prince Edward Island), but is specifically asking for volunteers to maintain frequent, regular observations on a road of their choice within the Chignecto Isthmus region. To date, since the project was launched in May, 2018, there have been over 500 observations recorded with more than 100 species represented. Although there have been 30 people who have contributed to the project thus far, the majority of observations were data entered from the roadkill surveys for this thesis, and from another observer located closer to

Fredricton. If volunteer recruitment in the key pinch-point of the Chignecto Isthmus increases, NCC-SCI's iNaturalist project has the potential to result in a large dataset for this region. Volunteer recruitment and dedication are challenging tasks, especially in terms of making the public aware of the project and convincing them to do the often unpalatable work of photographing and identifying dead animals. Media releases from the NCC stress the importance of participation in the project for the health of wildlife in the region (Palmeter, 2018; Cole, 2019).

When soliciting roadkill data from volunteers, consistency in how observations are recorded and reported is one of the biggest challenges to using these data for decision-making and planning purposes (Bíl et al., 2017). Often the general public has limited ability to identify species accurately (Bíl et al., 2017), which can lead to the data being skewed in favour of the most easily identifiable animals that a casual observer are most likely to identify and submit as roadkill records (Waetjen & Shilling, 2017; Périquet et al., 2018). Beyond issues with species identification, though, there is a lack of spatial homogeneity in citizen science, which can lead to clustering, simply due to where the volunteers are concentrating their efforts (Bíl et al., 2017). Data collection by the public is likely to be biased towards smaller roads with lower traffic volumes as most people would collect data while on foot, perhaps close to their homes (Waetjen & Shilling, 2017). Collecting data while driving would not be recommended if the observers were not prepared to stop. If the driver quickly approached a carcass in a vehicle moving at high speed it would be dangerous for them to stop quickly on a busy highway and it would be difficult to obtain an accurate location without stopping (by contrast, a researcher conducting a survey would be driving slowly with hazard lights activated, would be prepared to stop with reflective safety gear ready, and would often have a second observer to allow both sides of the road to be scanned simultaneously). Additionally, in some areas stopping on controlled access roads is prohibited by law. Despite these issues, Bíl et al. (2017) do predict that the species ratio of unidentified animals will be the same as for the identified carcasses, and Périquet et al. (2018) found that taxonomic ratios and spatial clusters were generally similar between trained and untrained observers. These findings point to the usefulness of collecting and maintaining a database for roadkill observations, apart from those collected by government agencies, from the public.

The main drawback to a citizen science approach to roadkill data collection is that, unless the volunteers are motivated, trained, and dedicated to recording every roadkill event they encounter, the observations are incidental, taken on whims depending on the mood of the observer, and lack consistency in collection methods. While roadkill observations are often solicited to support both conservation, and transportation safety goals, there is little research on whether conclusions drawn from these reports are as reliable as methodical surveys (Périquet et al., 2018).

Alone, each of these sources of data can only offer a limited picture of the state of wildlife-road interactions in a region. Multiple lines of evidence are necessary to describe and approach a more complete understanding of road effects on biodiversity throughout a large study area.

5.2 Conclusion

There exists a wide variety of sources and opportunities from which to gather information on how roads impact wildlife, and on how the interactions impact the ability of wildlife populations to maintain their numbers when faced with the increasing pressures of habitat loss and climate change. This thesis explored three methodologies involving the collection and analysis of primary and secondary data, from systematic roadkill surveys, wildlife incident reports supplied from provincial government agencies, and camera trap images provided by NCC.

The key message that should be taken from this thesis is that decisions on where to locate road-effect mitigation strategies, such as fencing and wildlife crossing structures, should take into account regional ecological flow and habitat connectivity to best support the needs of wide-ranging animals highly impacted by fragmentation and collisions with motor vehicles. The stated goal, to implement multiple sources of data related to wildlife-road interactions, was carried out through the use of the three methodologies and the subsequent quantitative and qualitative analyses. This thesis provided an example for the use of roadkill survey data at a regional scale to ground truth predictions for wildlife movement pathways within the context of the Chignecto Isthmus region. Further to this study, strategies to preserve and enhance wildlife pathways should be prioritized based on multi-season analyses of evidence of negative wildlife-road interactions, with applications to similar regions experiencing pinch-points and restricted ecological flow. This type of landscape level road ecology study is needed to address gaps in the literature related to assessing road effects on wildlife from a suite of roads in a network, rather than at the single road level. While individual, fine-scale road assessments do have their place, without understanding how each point of increased wildlife-road interaction impacts other points of conflict within the network, mitigation strategies could be implemented which lead wildlife towards further conflict. Thus, observing the region as a whole unit rather than as discrete sections centred around individual roads allows conservationists to make recommendations to transportation planners for either multiple mitigation strategies to be implemented due to multiple points of intersection between the road and potential movement corridors, or for strategic crossing structures based on overall regional flow. Connected landscapes, achieved through the reduction of barriers to wildlife movement are more resilient and provide options for wildlife to move, disperse, and seek out life requisites as they adapt to increased environmental change (Bennett, 2003; Reining et al., 2006; Trombulak et al., 2008; Graves & Wang, 2012).

For large regional-scale studies, both connectivity modelling and verification of models through the amalgamation of multiple sources of road mortality data can help determine the state of habitat connectivity and the effect of roads on this connectivity. Well-organized, systematically collected data with high sampling frequencies collected over multiple years should be employed for road mortality hotspot analyses to provide one source of information on the best locations at which to site road-effect mitigations to increase connectivity and decrease wildlife-vehicle collisions. When strengthened with wildlife-vehicle collision reports from standardized and centralized data hubs, a clear picture of both the small and large species impacted by roads through direct mortality should emerge, but especially the identification of key restrictions for wide-ranging mammals.

Qualitative observations, such as camera trap images of wildlife approaching roads, were not statistically rigorous. These observations were less useful for determining rates of road crossings, or crossing vs. avoidance behaviour for species than predicted. However, any evidence of wildlife presence near to and their interactions with roads can help to demonstrate which species to target for the road-effect mitigation strategies and to strengthen the choice of future roadkill survey locations.

This work has the potential to contribute important information for use in local planning and management. The Chignecto Isthmus was chosen as a case study site in which to verify regional ecological flows through the use of road mortality data. It was specifically chosen for its importance to regional connectivity and current lack of wildlife crossing structures, despite the numerous pinch-points to wildlife movement and potential for increased restriction due to human development and environmental change in the coming decades, as well as public concerns over moose-vehicle collisions in the New Brunswick portion. It is an introductory study, the first of its kind to detail the state of wildlife-road interactions over multiple roads in the Chignecto Isthmus. Recommendations for future work include: 1) repeating systematic surveys targeted at NB Rte 134, Hwy 15, and Hwy 16, and at NS Rte 6 and Hwy 104; 2) strengthening and supporting volunteer recruitment for citizen science initiatives such as the NCC/SCI's Wildpaths Maritimes roadkill tracking project; and 3) installation of trail cameras on a range of roads (most notably NS Rte 366, Rte 6, and Hwy 104) in Nova Scotia for comparison with the New Brunswick observations of species approaching roadways.

Ultimately, where there have occurred multiple moose-vehicle collisions in the past on NB Hwy 15 between Dieppe and Shediac, there should be a location chosen which corresponds with the NCC's modelled corridor (representing mostly connected habitat through the isthmus) for the installation of a wildlife overpass, with fencing. This would be the first vegetated wildlife overpass in the Atlantic Canada region. Planners should supplement the overpass with fences designed to guide wide-ranging wildlife to make use of the structure and to exclude them from the transportation corridor for the benefit of both increased habitat connectivity and human safety. The implementation of wildlife fencing and a crossing structure at a location supported with evidence for heightened wildlife-road interactions will help to increase the adaptability and resiliency of wildlife in the Chignecto Isthmus and the larger Northern Appalachian-Acadia ecoregion.

The use of a regional scale approach to road ecology may prove beneficial for application in similar study regions elsewhere. The consolidation of multiple lines of evidence and analyses on wildlife-road interactions will support decision making for transportation planners on wildlife-vehicle collision mitigation to reduce wildlife road mortality and increase ecological connectivity, while supporting human safety goals in reducing risks for serious collisions throughout the road network.

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Appendix A

Table A1. Raw Data from Roadkill Surveys, May- August 2018.

ID #	Date	Road	Latitude (DD)	Longitude (DD)	Taxa	Species	Size
M1	06-06-18	940	46.06584	-64.27962	Mammal	Porcupine	Medium
M2	06-06-18	940	45.98886	-64.29681	Mammal	Porcupine	Medium
M3	06-06-18	940	45.95499	-64.33307	Mammal	Porcupine	Medium
M4	29-06-18	940	45.94992	-64.33978	Mammal	Chipmunk	Small
M5	29-06-18	940	45.9656	-64.31302	Mammal	Snowshoe hare	Medium
M6	29-06-18	940	46.01416	-64.29221	Mammal	Porcupine	Medium
M7	29-06-18	940	46.01701	-64.29033	Mammal	Raccoon	Medium
M8	29-06-18	940	46.13316	-64.23217	Mammal	Common yellowthroat	Small
M15	04-07-18	940	46.07258	-64.27801	Mammal	Skunk	Medium
M16	05-07-18	940	46.09995	-64.25715	Bird	White-throated sparrow	Small
M19	11-07-18	940	45.97235	-64.3036	Bird	Unknown bird	Small
M20	20-07-18	940	45.93862	-64.34966	Mammal	Chipmunk	Small
M21	20-07-18	940	45.94654	-64.34261	Bird	Unknown bird	Small
M22	20-07-18	940	45.99804	-64.30032	Mammal	Snowshoe hare	Medium
M24	20-07-18	940	46.11531	-64.24561	Mammal	Raccoon	Medium
M26	20-07-18	940	46.15184	-64.19918	Mammal	Raccoon	Medium
M28	25-07-18	940	46.03274	-64.28512	Mammal	Raccoon	Medium
M30	08-08-18	940	46.09407	-64.2617	Mammal	Raccoon	Medium
M31	15-08-18	940	46.10046	-64.25683	Amphibian	Green frog	Small
M32	15-08-18	940	45.95618	-64.3308	Mammal	Skunk	Medium
M33	22-08-18	940	45.9526	-64.33584	Mammal	Skunk	Medium
Z2	31-05-18	933	46.0797	-64.4368	Mammal	Porcupine	Medium
Z4	07-06-18	933	46.1719	-64.41972	Bird	Robin	Small
Z5	07-06-18	933	46.10174	-64.41402	Mammal	Snowshoe hare	Medium
Z6	07-06-18	933	46.02596	-64.48788	Bird	Thrush species	Small
Z19	12-07-18	933	46.17802	-64.42274	Bird	Northern parula	Small
Z20	12-07-18	933	46.17651	-64.42249	Mammal	Porcupine	Medium
Z35	02-08-18	933	46.18163	-64.42306	Reptile	Garter snake	Small

ID #	Date	Road	Latitude (DD)	Longitude (DD)	Taxa	Species	Size
Z36	09-08-18	933	46.1262	-64.39343	Amphibian	Green frog	Small
Z38	09-08-18	933	46.05246	-64.46902	Amphibian	Green frog	Small
Z39	16-08-18	933	46.12624	-64.39378	Mammal	Unknown mammal	Small
Z41	16-08-18	933	46.06409	-64.456	Amphibian	Green frog	Small
Z22	18-07-19	933	46.20319	-64.42248	Mammal	Chipmunk	Small
Z23	18-07-19	933	46.17262	-64.42042	Bird	American redstart	Small
Z10	18-06-20	933	46.17705	-64.42271	Mammal	Porcupine	Medium
Z31	18-07-26	933	46.10355	-64.41352	Amphibian	Green frog	Small
Z12	18-06-29	933	46.18845	-64.42303	Mammal	Woodchuck	Medium
Z13	18-06-29	933	46.0944	-64.41862	Mammal	Snowshoe hare	Medium
Z14	18-06-29	933	46.0187	-64.49887	Amphibian	Green frog	Small
E1	18-05-18	366	45.87473	-64.13145	Mammal	Porcupine	Medium
E2	18-05-18	366	45.93898	-64.08556	Mammal	Porcupine	Medium
E3	18-05-18	366	45.92543	-64.09488	Mammal	Porcupine	Medium
E4	18-05-18	366	45.92098	-64.09812	Mammal	Porcupine	Medium
E16	30-05-18	366	45.91946	-63.83685	Mammal	Red fox	Medium
E17	30-05-18	366	45.94427	-63.8726	Mammal	White-tailed deer	Large
E18	30-05-18	366	45.98959	-63.98563	Mammal	Raccoon	Medium
E53	11-06-18	366	45.92641	-64.0944	Bird	Hermit thrush	Small
E57	11-06-18	366	45.92802	-64.09301	Mammal	Snowshoe hare	Medium
E69	11-06-18	366	45.93608	-64.0891	Bird	Common yellowthroat	Small
E72	13-06-18	366	45.91747	-63.83371	Bird	Northern flicker	Small
E98	17-06-18	366	45.93924	-64.08537	Bird	Northern parula	Small
E104	19-06-18	366	45.98911	-63.94704	Mammal	Raccoon	Medium
E105	19-06-18	366	45.98837	-63.9808	Bird	Cedar waxwing	Small
E110	26-06-18	366	45.93788	-64.08755	Bird	Unknown bird	Small
E112	26-06-18	366	45.92662	-64.09448	Mammal	Porcupine	Medium
E114	26-06-18	366	45.93466	-64.08993	Amphibian	Red-spotted newt	Small
E116	26-06-18	366	45.93654	-64.08888	Mammal	Shrew species	Small
E120	26-06-18	366	45.94479	-64.0733	Bird	Northern flicker	Small
E126	26-06-18	366	45.89111	-64.11767	Mammal	Porcupine	Medium
E127	26-06-18	366	45.8682	-64.13284	Mammal	Snowshoe hare	Medium

ID #	Date	Road	Latitude (DD)	Longitude (DD)	Taxa	Species	Size
E129	02-07-18	366	45.9292	-63.85878	Mammal	Raccoon	Medium
E130	02-07-18	366	45.94119	-64.08078	Bird	American robin	Small
E131	04-07-18	366	45.98476	-63.93695	Mammal	Deer mouse	Small
E132	04-07-18	366	45.9183	-64.10031	Mammal	Porcupine	Medium
E133	04-07-18	366	45.86196	-64.13425	Mammal	Porcupine	Medium
E141	09-07-18	366	45.91604	-64.10194	Mammal	Red squirrel	Small
E151	09-07-18	366	45.924722	-64.095278	Mammal	Red squirrel	Small
E155	09-07-18	366	45.85609	-64.15723	Mammal	Skunk	Medium
E156	11-07-18	366	45.97883	-63.91282	Mammal	Red squirrel	Small
E158	11-07-18	366	45.98731	-63.94101	Bird	Grackle	Small
E159	11-07-18	366	45.98832	-63.96664	Bird	American goldfinch	Small
E160	11-07-18	366	45.98804	-63.96918	Mammal	Snowshoe hare	Small
E162	16-07-18	366	45.88726	-64.1174	Mammal	Porcupine	Medium
E163	20-07-18	366	45.98843	-64.01229	Bird	Ruffed grouse	Small
E164	20-07-18	366	45.9907	-64.00304	Mammal	Red squirrel	Small
E165	20-07-18	366	45.99133	-63.99586	Mammal	Red squirrel	Small
E166	20-07-18	366	45.97639	-63.90567	Mammal	Chipmunk	Small
E167	24-07-18	366	45.87122	-64.13212	Mammal	Raccoon	Medium
E168	24-07-18	366	45.85768	-64.15228	Mammal	Skunk	Medium
E169	25-07-18	366	45.98895	-63.95647	Mammal	Raccoon	Medium
E170	25-07-18	366	45.99069	-63.99106	Mammal	Snowshoe hare	Medium
E171	01-08-18	366	45.94867	-63.87194	Mammal	Raccoon	Medium
E172	01-08-18	366	45.97627	-63.9054	Mammal	Red squirrel	Small
E194	06-08-18	366	45.852555	-64.109817	Mammal	Raccoon	Medium
E173	08-08-18	366	45.89025	-63.82066	Amphibian	Northern leopard frog	Small
E174	08-08-18	366	45.92364	-63.84798	Mammal	Porcupine	Medium
E175	08-08-18	366	45.98306	-63.93256	Mammal	Mouse species	Small
E176	08-08-18	366	45.99045	-64.00541	Mammal	Red squirrel	Small
E177	08-08-18	366	45.97864	-64.04179	Mammal	Raccoon	Medium
E178	13-08-18	366	45.98031	-64.06836	Mammal	Raccoon	Medium
E179	13-08-18	366	45.87919	-64.12756	Mammal	Raccoon	Medium
E180	15-08-18	366	45.89417	-63.82241	Amphibian	Pickerel frog	Small

ID #	Date	Road	Latitude (DD)	Longitude (DD)	Taxa	Species	Size
E181	15-08-18	366	45.89492	-63.82284	Amphibian	Pickerel frog	Small
E182	15-08-18	366	45.92727	-63.85522	Mammal	Raccoon	Medium
E184	15-08-18	366	45.9621	-63.88223	Amphibian	Green frog	Small
E185	15-08-18	366	45.96944	-63.89504	Mammal	Skunk	Medium
E186	15-08-18	366	45.98834	-63.96642	Mammal	Raccoon	Medium
E187	20-08-18	366	45.94602	-64.07163	Mammal	Chipmunk	Small
E188	20-08-18	366	45.90475	-64.10873	Amphibian	Green frog	Small
E189	20-08-18	366	45.85169	-64.1694	Mammal	Skunk	Medium
E190	22-08-18	366	45.9244	-63.85068	Mammal	Porcupine	Medium
E191	22-08-18	366	45.92515	-63.852	Mammal	Porcupine	Medium
E192	22-08-18	366	45.98659	-63.94007	Bird	Northern flicker	Small
E193	22-08-18	366	45.97824	-64.04002	Mammal	Red squirrel	Small
O1	11-06-18	302	45.59919	-64.24802	Mammal	Porcupine	Medium
O2	11-06-18	302	45.73311	-64.24991	Mammal	Porcupine	Medium
O3	17-06-18	302	45.61412	-64.24052	Bird	Flycatcher species	Small
O4	30-06-18	302	45.76414	-64.24122	Bird	Starling	Small
O5	30-06-18	302	45.76411	-64.24119	Bird	Starling	Small
O8	04-07-18	302	45.71763	-64.23932	Mammal	Red squirrel	Small
O9	04-07-18	302	45.71354	-64.23515	Bird	Common yellowthroat	Small
O11	04-07-18	302	45.71263	-64.23492	Mammal	Red fox	Medium
O13	04-07-18	302	45.62092	-64.23686	Mammal	Skunk	Medium
O14	09-07-18	302	45.7578	-64.24018	Mammal	Raccoon	Medium
O15	16-07-18	302	45.77502	-64.21635	Bird	Starling	Small
O16	16-07-18	302	45.77445	-64.21973	Bird	Starling	Small
O17	16-07-18	302	45.74163	-64.24761	Mammal	Raccoon	Medium
O18	16-07-18	302	45.72381	-64.25169	Mammal	Coyote	Large
O19	16-07-18	302	45.71744	-64.23885	Bird	Yellow warbler	Small
O21	16-07-18	302	45.6457	-64.23382	Mammal	Red fox	Medium
O22	16-07-18	302	45.63792	-64.23456	Mammal	Raccoon	Medium
O23	16-07-18	302	45.63115	-64.23624	Mammal	Red squirrel	Small
O24	16-07-18	302	45.60456	-64.24449	Mammal	Raccoon	Medium
O25	24-07-18	302	45.62321	-64.23607	Mammal	Chipmunk	Small

ID #	Date	Road	Latitude (DD)	Longitude (DD)	Taxa	Species	Size
O26	24-07-18	302	45.67668	-64.21646	Mammal	Raccoon	Medium
O29	30-07-18	302	45.68267	-64.21928	Bird	Unknown bird	Small
O30	06-08-18	302	45.66537	-64.22348	Mammal	Raccoon	Medium
O31	06-08-18	302	45.67275	-64.2172	Mammal	Red squirrel	Small
O32	06-08-18	302	45.7266	-64.25188	Mammal	Raccoon	Medium
O33	06-08-18	302	45.72649	-64.25195	Mammal	Raccoon	Medium
O34	20-08-18	302	45.60456	-64.24453	Mammal	Raccoon	Medium
O35	20-08-18	302	45.71477	-64.2358	Mammal	Raccoon	Medium
K11	02-06-18	301	45.74892	-63.84387	Mammal	Woodchuck	Medium
K13	08-06-18	301	45.74927	-63.8434	Bird	Crow	Small
K15	08-06-18	301	45.84725	-63.76278	Mammal	Porcupine	Medium
K30	15-06-18	301	45.84434	-63.76376	Mammal	Raccoon	Medium
K44	22-06-18	301	45.75662	-63.82978	Mammal	Chipmunk	Small
K64	06-07-18	301	45.80128	-63.77203	Bird	Crow	Small
K77	13-07-18	301	45.85188	-63.75697	Bird	Yellow warbler	Small
K82	18-07-18	301	45.76043	-63.82148	Bird	Merlin	Small
K96	27-07-18	301	45.7526	-63.83864	Mammal	Raccoon	Medium
K97	27-07-18	301	45.78199	-63.788	Amphibian	Pickerel frog	Small
K98	27-07-18	301	45.83859	-63.76575	Mammal	Porcupine	Medium
K99	27-07-18	301	45.87264	-63.91093	Bird	Warbler species	Small
K108	10-08-18	301	45.78223	-63.78724	Amphibian	Unknown amphibian	Small
K109	10-08-18	301	45.80424	-63.76772	Mammal	Raccoon	Medium
K167	17-08-18	301	45.76402	-63.81492	Mammal	Raccoon	Medium
I1	21-05-18	204	45.76492	-64.1133	Mammal	Porcupine	Medium
I2	21-05-18	204	45.76665	-64.09792	Amphibian	Unknown amphibian	Small
I3	01-06-18	204	45.77048	-64.12295	Mammal	Unknown mammal	Small
I7	01-06-18	204	45.76942	-64.08514	Mammal	Raccoon	Medium
I9	08-06-18	204	45.81382	-64.17186	Mammal	Raccoon	Medium
I11	15-06-18	204	45.77692	-64.12974	Amphibian	Red-spotted newt	Small
I14	15-06-18	204	45.77463	-64.12764	Amphibian	Red-spotted newt	Small
I18	15-06-18	204	45.76593	-64.10098	Bird	Unknown bird	Small
I21	15-06-18	204	45.77399	-64.12713	Bird	American redstart	Small

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I22	15-06-18	204	45.78154	-64.02554	Mammal	Unknown mammal	Medium
I23	21-06-18	204	45.76985	-64.08302	Bird	Starling	Small
I24	21-06-18	204	45.76829	-64.09035	Mammal	Shrew species	Small
I29	21-06-18	204	45.78151	-64.02557	Mammal	Raccoon	Medium
I33	06-07-18	204	45.81588	-64.17645	Bird	Starling	Small
I34	13-07-18	204	45.81161	-64.16872	Mammal	Porcupine	Medium
I35	13-07-18	204	45.77811	-64.13107	Bird	Unknown bird	Small
I37	13-07-18	204	45.78025	-63.92046	Mammal	Raccoon	Medium
I39	18-07-18	204	45.79432	-63.93919	Mammal	Porcupine	Medium
I40	27-07-18	204	45.77846	-64.13155	Bird	Unknown bird	Small
I41	27-07-18	204	45.7641	-64.11004	Mammal	Porcupine	Medium
I42	27-07-18	204	45.78994	-63.93717	Bird	Sparrow species	Small
I44	27-07-18	204	45.76393	-63.89447	Bird	Crow	Small
I45	02-08-18	204	45.81416	-64.1729	Mammal	Raccoon	Medium
I46	02-08-18	204	45.78363	-64.13808	Mammal	Skunk	Medium
I47	02-08-18	204	45.78905	-63.99285	Mammal	Chipmunk	Small
I48	10-08-18	204	45.81329	-64.17111	Mammal	Raccoon	Medium
I49	17-08-18	204	45.7625	-63.89197	Bird	Northern flicker	Small
I50	17-08-18	204	45.75452	-63.88177	Mammal	Raccoon	Medium
I52	24-08-18	204	45.79779	-63.96725	Bird	Barn swallow	Small
I53	24-08-18	204	45.80164	-63.94855	Mammal	Porcupine	Medium
R1	14-05-18	134	46.13044	-64.69456	Mammal	Raccoon	Medium
R2	14-05-18	134	46.1501	-64.67044	Mammal	Unknown mammal	Medium
R3	14-05-18	134	46.16986	-64.64896	Mammal	Porcupine	Medium
R4	14-05-18	134	46.18116	-64.63242	Mammal	Porcupine	Medium
R5	14-05-18	134	46.18059	-64.63379	Mammal	Porcupine	Medium
R6	14-05-18	134	46.15416	-64.66723	Mammal	Raccoon	Medium
R7	14-05-18	134	46.15395	-64.6674	Mammal	Raccoon	Medium
R8	14-05-18	134	46.15098	-64.66958	Mammal	Raccoon	Medium
R9	14-05-18	134	46.14026	-64.68577	Mammal	Skunk	Medium
R10	14-05-18	134	46.13403	-64.6917	Mammal	Snowshoe hare	Medium
R11	14-05-18	134	46.13374	-64.69193	Mammal	Snowshoe hare	Medium

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R12	15-05-18	134	46.19271	-64.619	Mammal	Unknown mammal	Medium
R13	17-05-18	134	46.1481	-64.67282	Bird	Unknown bird	Small
R14	22-05-18	134	46.13041	-64.69462	Mammal	Raccoon	Medium
R16	24-05-18	134	46.18412	-64.62533	Bird	Blue-headed vireo	Small
R18	24-05-18	134	46.17585	-64.64184	Mammal	Porcupine	Medium
R19	24-05-18	134	46.18063	-64.6339	Bird	Duck species	Small
R21	29-05-18	134	46.16984	-64.64899	Mammal	Porcupine	Medium
R22	31-05-18	134	46.20662	-64.6031	Bird	Ring-necked pheasant	Medium
R23	31-05-18	134	46.17959	-64.63619	Mammal	Snowshoe hare	Medium
R24a	05-06-18	134	46.221	-64.58802	Mammal	Snowshoe hare	Medium
R24b	07-06-18	134	46.17282	-64.64539	Mammal	Unknown mammal	Medium
R29	07-06-18	134	46.18064	-64.63381	Bird	Unknown bird	Small
R34	07-06-18	134	46.18975	-64.62017	Bird	Northern parula	Small
R47	18-06-18	134	46.1354	-64.69106	Bird	Crow	Small
R52	20-06-18	134	46.19427	-64.61819	Mammal	Skunk	Medium
R59	28-06-18	134	46.13566	-64.69063	Bird	Grackle	Small
R62	28-06-18	134	46.14486	-64.67886	Mammal	Raccoon	Medium
R66	28-06-18	134	46.13489	-64.69125	Bird	Grackle	Small
R68	28-06-18	134	46.19996	-64.61149	Mammal	Raccoon	Medium
R70	03-07-18	134	46.15531	-64.66647	Mammal	Porcupine	Medium
R72	03-07-18	134	46.17613	-64.64146	Bird	Blue-headed vireo	Small
R74	03-07-18	134	46.20466	-64.60562	Bird	Woodpecker species	Small
R78	03-07-18	134	46.18063	-64.63387	Bird	Unknown bird	Small
R79	03-07-18	134	46.21167	-64.59737	Bird	Crow	Small
R80	05-07-18	134	46.13444	-64.69166	Mammal	Snowshoe hare	Medium
R85	05-07-18	134	46.17959	-64.63593	Mammal	Red squirrel	Small
R86	05-07-18	134	46.21812	-64.59039	Mammal	Porcupine	Medium
E87	12-07-18	134	46.14569	-64.67729	Mammal	Grey squirrel	Small
R88	12-07-18	134	46.16826	-64.65079	Mammal	Snowshoe hare	Medium
R89	12-07-18	134	46.2125	-64.59671	Mammal	Snowshoe hare	Medium
R90	17-07-18	134	46.15952	-64.66285	Mammal	Red squirrel	Small

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R91	17-07-18	134	46.20536	-64.60465	Bird	Cedar waxwing	Small
R92	19-07-18	134	46.16062	-64.66167	Bird	Alder flycatcher	Small
R93	19-07-18	134	46.20551	-64.60442	Mammal	Raccoon	Medium
R94	26-07-18	134	46.13961	-64.68655	Mammal	Raccoon	Medium
R95	26-07-18	134	46.13962	-64.68657	Mammal	Raccoon	Medium
R96	26-07-18	134	46.18132	-64.63214	Bird	Starling	Small
R97	31-07-18	134	46.16433	-64.6562	Bird	Crow	Small
R98	31-07-18	134	46.17886	-64.63739	Bird	Ring-necked pheasant	Small
R99	31-07-18	134	46.19148	-64.61941	Mammal	Porcupine	Medium
R100	31-07-18	134	46.19792	-64.61408	Mammal	Skunk	Medium
R101	31-07-18	134	46.19785	-64.61364	Reptile	Red-bellied snake	Small
R102	31-07-18	134	46.20229	-64.60864	Mammal	Porcupine	Medium
R103	07-08-18	134	46.16441	-64.65604	Mammal	Shrew species	Small
R104	14-08-18	134	46.14731	-64.67391	Mammal	Skunk	Medium
R105	14-08-18	134	46.21397	-64.59539	Bird	Unknown bird	Small
R106	16-08-18	134	46.16398	-64.65667	Bird	Crow	Small
R107	16-08-18	134	46.18209	-64.62897	Mammal	Porcupine	Medium
P1	18-06-18	132	46.11798	-64.57629	Bird	Unknown bird	Small
P2	18-06-18	132	46.11062	-64.57965	Mammal	Snowshoe hare	Medium
P3	18-06-18	132	46.10123	-64.60856	Mammal	Porcupine	Medium
P4	18-06-28	132	46.1668	-64.56178	Bird	American robin	Small
P6	18-07-03	132	46.20318	-64.56534	Mammal	Deer mouse	Small
P7	18-07-03	132	46.17137	-64.56096	Bird	Black-capped chickadee	Small
P8	18-07-03	132	46.13574	-64.57005	Bird	Unknown bird	Small
P9	18-07-03	132	46.12539	-64.57457	Bird	Woodpecker species	Small
P10	18-07-03	132	46.12539	-64.57457	Bird	Woodpecker species	Small
P11	18-07-03	132	46.09919	-64.59566	Mammal	Snowshoe hare	Medium
P12	18-07-17	132	46.20436	-64.56555	Mammal	Skunk	Small
P13	18-07-17	132	46.19587	-64.56367	Bird	Grackle	Small
P14	18-07-17	132	46.09862	-64.5876	Mammal	Porcupine	Medium

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P16	18-07-26	132	46.10216	-64.58491	Bird	Blue jay	Small
P17	18-07-31	132	46.14403	-64.5656	Mammal	Woodchuck	Medium
P18	18-08-14	132	46.16003	-64.56265	Mammal	Grey squirrel	Small
B2	18-05-18	104	45.75027	-64.09971	Mammal	Raccoon	Medium
B3	30-05-18	104	45.80182	-64.17706	Mammal	Raccoon	Medium
B4	30-05-18	104	45.80112	-64.1758	Mammal	Beaver	Medium
B5	30-05-18	104	45.77867	-64.13802	Mammal	Unknown mammal	Small
B7	30-05-18	104	45.80837	-64.19322	Mammal	Raccoon	Medium
B8	01-06-18	104	45.79644	-64.16761	Mammal	Porcupine	Medium
B10	01-06-18	104	45.74924	-64.09578	Mammal	Porcupine	Medium
B11	01-06-18	104	45.69249	-64.00355	Mammal	Raccoon	Medium
B12	01-06-18	104	45.69247	-64.00379	Mammal	Raccoon	Medium
B13	01-06-18	104	45.69206	-64.00513	Mammal	White-tailed deer	Large
B14	01-06-18	104	45.75139	-64.1015	Bird	Crow	Small
B15	04-06-18	104	45.80614	-64.18453	Mammal	Beaver	Medium
B16	06-06-18	104	45.76498	-64.12659	Mammal	Black bear	Large
B17	06-06-18	104	45.72427	-64.05626	Mammal	Porcupine	Medium
B18	13-06-18	104	45.80583	-64.18536	Mammal	Black bear	Large
B19	13-06-18	104	45.70194	-64.02737	Mammal	Raccoon	Medium
B20	13-06-18	104	45.75462	-64.10948	Mammal	Porcupine	Medium
B21	15-06-18	104	45.80502	-64.18281	Mammal	Unknown mammal	Small
B22	15-06-18	104	45.77178	-64.13183	Mammal	Raccoon	Medium
B23	15-06-18	104	45.77176	-64.13183	Bird	Crow	Small
B25	21-06-18	104	45.79485	-64.16482	Mammal	Porcupine	Medium
B26	30-06-18	104	45.75373	-64.10815	Bird	Myrtle warbler	Small
B27	30-06-18	104	45.75358	-64.1077	Mammal	Unknown mammal	Small
B28	30-06-18	104	45.75543	-64.11113	Mammal	Porcupine	Medium
B29	02-07-18	104	45.80501	-64.18282	Bird	Crow	Small
B30	02-07-18	104	45.7941	-64.16356	Mammal	Porcupine	Medium
B31	02-07-18	104	45.76897	-64.12933	Mammal	White-tailed deer (fawn)	Medium
B32	06-07-18	104	45.741	-64.079	Bird	Crow	Small

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B33	06-07-18	104	45.69701	-64.02159	Bird	Crow	Small
B34	06-07-18	104	45.74115	-64.0795	Bird	Crow	Small
B35	06-07-18	104	45.69221	-64.01126	Bird	Crow	Small
B36	06-07-18	104	45.72759	-64.06007	Mammal	Porcupine	Medium
B37	06-07-18	104	45.75804	-64.11768	Mammal	Raccoon	Medium
B38	06-07-18	104	45.80336	-64.17885	Mammal	Snowshoe hare	Medium
B39	06-07-18	104	45.80576	-64.18382	Mammal	Raccoon	Medium
B40	11-07-18	104	45.76638	-64.12783	Mammal	Raccoon	Medium
B41	11-07-18	104	45.77174	-64.13169	Mammal	Raccoon	Medium
B42	11-07-18	104	45.77209	-64.13192	Mammal	Raccoon	Medium
B43	11-07-18	104	45.77268	-64.13239	Mammal	Raccoon	Medium
B44	11-07-18	104	45.77283	-64.13261	Mammal	Porcupine	Medium
B45	11-07-18	104	45.79145	-64.1581	Mammal	Porcupine	Medium
B46	13-07-18	104	45.74364	-64.08366	Mammal	Porcupine	Medium
B47	18-07-18	104	45.77385	-64.13391	Mammal	Skunk	Medium
B48	18-07-18	104	45.75919	-64.12034	Mammal	Porcupine	Medium
B49	18-07-18	104	45.76436	-64.1256	Bird	Crow	Small
B50	25-07-18	104	45.74665	-64.09015	Mammal	Raccoon	Medium
B51	25-07-18	104	45.70491	-64.03194	Mammal	Porcupine	Medium
B52	25-07-18	104	45.76818	-64.12865	Bird	Crow	Small
B53	27-07-18	104	45.74645	-64.08994	Mammal	Raccoon	Medium
B54	27-07-18	104	45.75718	-64.11559	Amphibian	Green frog	Small
B55	27-07-18	104	45.77839	-64.1374	Bird	American robin	Small
B56	01-08-18	104	45.80794	-64.19224	Mammal	Black bear (cub)	Medium
B59	03-08-18	104	45.80494	-64.18266	Mammal	Raccoon	Medium
B60	03-08-18	104	45.71193	-64.04096	Mammal	Red squirrel	Small
B61	08-08-18	104	45.76252	-64.12451	Mammal	Raccoon	Medium
B62	08-08-18	104	45.75634	-64.11449	Mammal	Mink	Medium
B63	08-08-18	104	45.78501	-64.14705	Bird	Crow	Small
B64	10-08-18	104	45.80793	-64.1916	Mammal	Raccoon	Medium
B65	10-08-18	104	45.80794	-64.19174	Mammal	Raccoon	Medium
B66	15-08-18	104	45.80799	-64.19302	Mammal	Raccoon	Medium

ID #	Date	Road	Latitude (DD)	Longitude (DD)	Taxa	Species	Size
B67	15-08-18	104	45.71199	-64.04081	Mammal	White-tailed deer	Large
B68a	15-08-18	104	45.75648	-64.11388	Mammal	Raccoon	Medium
B68b	15-08-18	104	45.75648	-64.11388	Mammal	Raccoon	Medium
B69	17-08-18	104	45.71081	-64.03961	Mammal	Porcupine	Medium
B76	22-08-18	104	45.7055	-64.03204	Bird	Great-horned owl	Medium
J1	23-05-18	16	45.88684	-64.25542	Mammal	Porcupine	Medium
J2	23-05-18	16	45.98758	-64.1478	Mammal	Skunk	Medium
J3	23-05-18	16	45.9875	-64.14814	Mammal	Raccoon	Medium
J6	28-05-18	16	45.9301	-64.21596	Mammal	Muskrat	Medium
J8	02-06-18	16	45.91079	-64.23325	Mammal	Raccoon	Medium
J9	02-06-18	16	45.97066	-64.16819	Mammal	Porcupine	Medium
J11	06-06-18	16	46.02392	-64.11811	Mammal	Snowshoe hare	Medium
J12	22-06-18	16	45.97686	-64.16162	Bird	Crow	Small
J14	26-06-18	16	45.88389	-64.25891	Mammal	Porcupine	Medium
J15	26-06-18	16	45.9836	-64.15389	Mammal	Unknown mammal	Small
J18	02-07-18	16	45.98863	-64.14641	Bird	Crow	Medium
J19	02-07-18	16	45.98497	-64.15195	Bird	Unknown bird	Small
J20	02-07-18	16	45.98505	-64.15186	Bird	Common yellowthroat	Small
J21	02-07-18	16	45.96308	-64.18381	Bird	Crow	Small
J23	09-07-18	16	45.91389	-64.23029	Mammal	Porcupine	Medium
J25	09-07-18	16	45.9445	-64.20317	Mammal	Porcupine	Medium
J27	09-07-18	16	45.96029	-64.18877	Mammal	Woodchuck	Medium
J29	16-07-18	16	45.87236	-64.28068	Mammal	Porcupine	Medium
J30	16-07-18	16	45.89228	-64.25175	Mammal	Porcupine	Medium
J31	16-07-18	16	45.94582	-64.20186	Mammal	Snowshoe hare	Medium
J32	16-07-18	16	45.95174	-64.19646	Mammal	Skunk	Medium
J33	16-07-18	16	45.95164	-64.19669	Bird	Raven	Small
J34	16-07-18	16	45.9801	-64.15881	Mammal	Porcupine	Medium
J37	24-07-18	16	45.98713	-64.14828	Mammal	Porcupine	Medium
J39	30-07-18	16	45.96369	-64.18261	Mammal	Raccoon	Medium
J40	30-07-18	16	45.96367	-64.18262	Mammal	Raccoon	Medium
J41	30-07-18	16	45.89852	-64.24383	Mammal	Skunk	Medium

ID #	Date	Road	Latitude (DD)	Longitude (DD)	Taxa	Species	Size
J45	13-08-18	16	45.94221	-64.20533	Bird	Crow	Small
J46	13-08-18	16	45.96442	-64.18111	Bird	Magnolia warbler	Small
J53	20-08-18	16	45.88081	-64.26602	Mammal	Skunk	Medium
J54	20-08-18	16	45.88927	-64.25356	Mammal	Skunk	Medium
J55	20-08-18	16	45.94212	-64.2053	Mammal	Porcupine	Medium
J56	20-08-18	16	45.99193	-64.14089	Mammal	Porcupine	Medium
A1	16-05-18	15	46.1545	-64.64394	Mammal	Unknown mammal	Large
A2	16-05-18	15	46.16968	-64.62537	Mammal	Unknown mammal	Small
A3	16-05-18	15	46.15629	-64.64029	Mammal	Porcupine	Medium
A4	16-05-18	15	46.17292	-64.62051	Mammal	Porcupine	Medium
A5	16-05-18	15	46.19715	-64.59365	Mammal	Porcupine	Medium
A6	16-05-18	15	46.1767	-64.61746	Mammal	Muskrat	Medium
A7	16-05-18	15	46.17607	-64.61829	Mammal	Porcupine	Medium
A8	22-05-18	15	46.19642	-64.59415	Mammal	Porcupine	Medium
A9	29-05-18	15	46.15389	-64.64509	Mammal	Woodchuck	Medium
A10	05-06-18	15	46.19724	-64.59356	Mammal	Woodchuck	Medium
A11	05-06-18	15	46.18607	-64.60663	Mammal	Porcupine	Medium
A13	12-06-18	15	46.16074	-64.63478	Mammal	Porcupine	Medium
A14	12-06-18	15	46.18658	-64.60458	Mammal	Porcupine	Medium
A15	12-06-18	15	46.18969	-64.60092	Mammal	Porcupine	Medium
A16	14-06-18	15	46.1545	-64.64278	Mammal	Porcupine	Medium
A17	14-06-18	15	46.16909	-64.62507	Mammal	Porcupine	Medium
A18	14-06-18	15	46.1976	-64.59314	Mammal	Muskrat	Medium
A19	18-06-18	15	46.13546	-64.67059	Mammal	White-tailed deer	Large
A20	18-06-18	15	46.19962	-64.58928	Mammal	Porcupine	Medium
A21	28-06-18	15	46.1567	-64.6399	Mammal	Beaver	Medium
A22	28-06-18	15	46.17678	-64.61749	Bird	Crow	Small
A23	29-06-18	15	46.1741	-64.6206	Bird	Pileated woodpecker	Small
A24	03-07-18	15	46.17532	-64.61922	Bird	Crow	Small
A25	03-07-18	15	46.15855	-64.63885	Bird	Common eider	Medium
A26	05-07-18	15	46.14142	-64.66113	Mammal	Porcupine	Medium
A27	05-07-18	15	46.18075	-64.61137	Bird	Crow	Small

ID #	Date	Road	Latitude (DD)	Longitude (DD)	Taxa	Species	Size
A28	05-07-18	15	46.19537	-64.59451	Mammal	Woodchuck	Medium
A29	05-07-18	15	46.20617	-64.58186	Mammal	Woodchuck	Medium
A30	05-07-18	15	46.20403	-64.58569	Mammal	Woodchuck	Medium
A31	10-07-18	15	46.1473	-64.65313	Mammal	Porcupine	Medium
A32	10-07-18	15	46.17252	-64.62099	Mammal	Porcupine	Medium
A33	10-07-18	15	46.17693	-64.61609	Mammal	Porcupine	Medium
A34	10-07-18	15	46.17426	-64.62042	Mammal	Porcupine	Medium
A35	10-07-18	15	46.15081	-64.64951	Mammal	Raccoon	Medium
A36	10-07-18	15	46.15065	-64.6497	Bird	Raven	Medium
A37	12-07-18	15	46.17506	-64.61813	Mammal	Porcupine	Medium
A38	12-07-18	15	46.17356	-64.62128	Bird	Red-eyed vireo	Small
A39	17-07-18	15	46.14862	-64.65095	Mammal	Porcupine	Medium
A40	17-07-18	15	46.15044	-64.64846	Mammal	Porcupine	Medium
A41	17-07-18	15	46.16158	-64.63399	Mammal	Raccoon	Medium
A42	17-07-18	15	46.19637	-64.59436	Mammal	Red fox	Medium
A43	17-07-18	15	46.1966	-64.59429	Mammal	Porcupine	Medium
A44	17-07-18	15	46.1935	-64.59788	Mammal	Porcupine	Medium
A46	17-07-18	15	46.15018	-64.65038	Mammal	Porcupine	Medium
A47	17-07-18	15	46.14995	-64.65074	Mammal	Porcupine	Medium
A48	19-07-18	15	46.14336	-64.6599	Mammal	Snowshoe hare	Medium
A49	26-07-18	15	46.15486	-64.64228	Mammal	Snowshoe hare	Medium
A50	26-07-18	15	46.18213	-64.61002	Mammal	Porcupine	Medium
A51	26-07-18	15	46.20264	-64.58579	Mammal	Porcupine	Medium
A52	26-07-18	15	46.20615	-64.58192	Mammal	Raccoon	Medium
A53	26-07-18	15	46.21062	-64.57687	Mammal	Porcupine	Medium
A55	26-07-18	15	46.17514	-64.6194	Mammal	Porcupine	Medium
A56	26-07-18	15	46.17514	-64.6194	Mammal	Porcupine	Medium
A57	26-07-18	15	46.16357	-64.63296	Mammal	Snowshoe hare	Medium
A58	31-07-18	15	46.16874	-64.62555	Mammal	Porcupine	Medium
A59	31-07-18	15	46.141	-64.66313	Bird	Crow	Small
A60	31-07-18	15	46.14084	-64.66336	Mammal	Raccoon	Medium
A61	02-08-18	15	46.14605	-64.65465	Mammal	Ermine	Medium

ID #	Date	Road	Latitude (DD)	Longitude (DD)	Taxa	Species	Size
A62	02-08-18	15	46.19756	-64.59207	Mammal	Porcupine	Medium
A63	07-08-18	15	46.17802	-64.61465	Bird	Canada goose	Medium
A64	07-08-18	15	46.19707	-64.59382	Mammal	Porcupine	Medium
A65a	07-08-18	15	46.17014	-64.62526	Mammal	Porcupine	Medium
A65b	07-08-18	15	46.17006	-64.62534	Mammal	Porcupine	Medium
A66	14-08-18	15	46.16584	-64.62904	Bird	Hermit thrush	Small
A67	14-08-18	15	46.17072	-64.62313	Mammal	Porcupine	Medium
A68	14-08-18	15	46.1728	-64.62067	Mammal	Raccoon	Medium
A69	14-08-18	15	46.21138	-64.5761	Mammal	Porcupine	Medium
A70	16-08-18	15	46.21086	-64.57677	Mammal	Porcupine	Medium
A71	21-08-18	15	46.13875	-64.66528	Mammal	Raccoon	Medium
A72	21-08-18	15	46.1457	-64.65669	Mammal	Porcupine	Medium
A73	23-08-18	15	46.19671	-64.5927	Mammal	Porcupine	Medium
K1	23-05-18	6	45.8702	-64.02862	Mammal	Porcupine	Medium
K2	23-05-18	6	45.87841	-64.01305	Mammal	Raccoon	Medium
K5	30-05-18	6	45.86052	-64.06644	Mammal	Unknown mammal	Medium
K8	02-06-18	6	45.875	-63.91851	Mammal	White-tailed deer	Large
K9	02-06-18	6	45.86892	-63.88037	Mammal	Porcupine	Medium
K12	06-06-18	6	45.88905	-63.99006	Mammal	Raccoon	Medium
K16	11-06-18	6	45.84715	-64.15681	Bird	Song sparrow	Small
K20	13-06-18	6	45.8544	-64.08221	Mammal	Chipmunk	Small
K25	13-06-18	6	45.85423	-64.09899	Mammal	Porcupine	Medium
K26	13-06-18	6	45.854	-64.10084	Mammal	Unknown mammal	Medium
K27	13-06-18	6	45.85052	-64.11828	Mammal	Shrew species	Small
K32	15-06-18	6	45.881	-64.00689	Mammal	Raccoon	Medium
K33	15-06-18	6	45.8511	-64.11739	Bird	American robin	Small
K34	19-06-18	6	45.85258	-64.10993	Bird	Grackle	Small
K35	19-06-18	6	45.88247	-63.93129	Amphibian	Northern leopard frog	Small
K36	19-06-18	6	45.88247	-63.93142	Amphibian	Northern leopard frog	Small
K37	19-06-18	6	45.8718	-63.90811	Mammal	Shrew species	Small
K38	19-06-18	6	45.86963	-63.87569	Amphibian	Northern leopard frog	Small
K39	19-06-18	6	45.86971	-63.8752	Amphibian	Red-spotted newt	Small

ID #	Date	Road	Latitude (DD)	Longitude (DD)	Taxa	Species	Size
K42	20-06-18	6	45.88044	-64.00839	Mammal	Raccoon	Medium
K47	27-06-18	6	45.85078	-64.11803	Bird	Black-capped chickadee	Small
K55	27-06-18	6	45.87397	-63.80468	Bird	Ovenbird	Small
K56	27-06-18	6	45.87584	-63.81087	Mammal	Skunk	Medium
K58	02-07-18	6	45.86139	-64.0623	Mammal	White-tailed deer	Large
K59	02-07-18	6	45.8738	-64.01997	Bird	Grackle	Small
K60	02-07-18	6	45.87471	-64.01762	Bird	Grackle	Small
K61	02-07-18	6	45.87472	-64.01746	Mammal	Beaver	Medium
K62	02-07-18	6	45.87706	-64.0146	Bird	Crow	Small
K63	02-07-18	6	45.87182	-63.90818	Mammal	Skunk	Medium
K65	06-07-18	6	45.86285	-63.76227	Bird	American robin	Small
K66	06-07-18	6	45.86317	-63.76249	Bird	Northern flicker	Small
K67	06-07-18	6	45.87924	-64.01182	Bird	American kestrel	Small
K68	11-07-18	6	45.84825	-64.14001	Mammal	Raccoon	Medium
K69	11-07-18	6	45.84491	-64.12682	Mammal	Raccoon	Medium
K71	11-07-18	6	45.85926	-64.06959	Bird	Crow	Small
K72	11-07-18	6	45.86393	-64.05258	Bird	Starling	Small
K73	11-07-18	6	45.88013	-64.00949	Mammal	Skunk	Medium
K74	11-07-18	6	45.89323	-63.9716	Bird	Unknown bird	Small
K75	11-07-18	6	45.89648	-63.91398	Bird	Unknown bird	Small
K78	13-07-18	6	45.86871	-63.78293	Bird	Blue Jay	Small
K79	13-07-18	6	45.87112	-63.79429	Mammal	Porcupine	Medium
K80	13-07-18	6	45.89246	-63.9518	Mammal	Porcupine	Medium
K81	13-07-18	6	45.85427	-64.09789	Bird	Starling	Small
K83	18-07-18	6	45.87215	-63.85331	Mammal	Raccoon	Medium
K84	18-07-18	6	45.8688	-63.88175	Mammal	Raccoon	Medium
K85	18-07-18	6	45.87769	-63.9236	Mammal	Raccoon	Medium
K86	18-07-18	6	45.89312	-63.95543	Mammal	Skunk	Medium
K87	20-07-18	6	45.8786	-63.82571	Bird	Grackle	Small
K88	20-07-18	6	45.86887	-63.88133	Mammal	Raccoon	Medium
K89	20-07-18	6	45.85258	-64.1096	Mammal	Red squirrel	Small

ID #	Date	Road	Latitude (DD)	Longitude (DD)	Taxa	Species	Size
K90	20-07-18	6	45.85081	-64.11784	Mammal	Porcupine	Medium
K91	25-07-18	6	45.84612	-64.12302	Mammal	Red fox	Medium
K92	25-07-18	6	45.88489	-64.00079	Mammal	Raccoon	Medium
K93	25-07-18	6	45.89188	-63.94907	Mammal	Raccoon	Medium
K94	25-07-18	6	45.89143	-63.94739	Mammal	Porcupine	Medium
K95	25-07-18	6	45.89143	-63.94739	Mammal	Porcupine	Medium
K100	01-08-18	6	45.86956	-63.87619	Mammal	Raccoon	Medium
K101	03-08-18	6	45.87051	-63.79128	Mammal	Raccoon	Medium
K102	03-08-18	6	45.85282	-64.10525	Mammal	Raccoon	Medium
K103	03-08-18	6	45.85263	-64.10969	Bird	Cedar waxwing	Small
K104	08-08-18	6	45.84661	-64.13252	Mammal	Raccoon	Medium
K105	08-08-18	6	45.86875	-64.03119	Bird	Crow	Small
K106	08-08-18	6	45.89378	-63.96103	Amphibian	Green frog	Small
K110	10-08-18	6	45.8722	-63.79837	Amphibian	Green frog	Small
K111	10-08-18	6	45.87222	-63.7932	Amphibian	Green frog	Small
K112	10-08-18	6	45.87216	-63.79818	Amphibian	Green frog	Small
K113	10-08-18	6	45.87212	-63.79808	Amphibian	Green frog	Small
K114	10-08-18	6	45.87196	-63.79752	Amphibian	Green frog	Small
K115	10-08-18	6	45.87249	-63.79928	Amphibian	Green frog	Small
K116	10-08-18	6	45.87423	-63.8054	Amphibian	Green frog	Small
K117	10-08-18	6	45.87463	-63.80687	Amphibian	Green frog	Small
K118	10-08-18	6	45.87468	-63.8069	Amphibian	Green frog	Small
K119	10-08-18	6	45.87469	-63.80688	Amphibian	Green frog	Small
K120	10-08-18	6	45.87479	-63.80735	Amphibian	Green frog	Small
K121	10-08-18	6	45.8748	-63.80743	Amphibian	Red-spotted newt	Small
K122	10-08-18	6	45.87493	-63.80779	Amphibian	Green frog	Small
K123	10-08-18	6	45.87496	-63.8079	Amphibian	Green frog	Small
K124	10-08-18	6	45.87506	-63.80824	Amphibian	Northern leopard frog	Small
K125	10-08-18	6	45.87512	-63.80858	Amphibian	Green frog	Small
K126	10-08-18	6	45.87533	-63.80882	Amphibian	Red-spotted newt	Small
K127	10-08-18	6	45.87525	-63.80898	Amphibian	Green frog	Small
K128	10-08-18	6	45.87526	-63.80913	Amphibian	Green frog	Small

ID #	Date	Road	Latitude (DD)	Longitude (DD)	Taxa	Species	Size
K129	10-08-18	6	45.87497	-63.80807	Amphibian	Green frog	Small
K130	10-08-18	6	45.87844	-63.82481	Bird	Barn swallow	Small
K131	10-08-18	6	45.87891	-63.82684	Bird	Barn swallow	Small
K132	10-08-18	6	45.87919	-63.82803	Bird	Tree swallow	Small
K133	10-08-18	6	45.86981	-63.87487	Amphibian	Green frog	Small
K134	10-08-18	6	45.86988	-63.8746	Amphibian	Green frog	Small
K135	10-08-18	6	45.86979	-63.875	Amphibian	Green frog	Small
K136	10-08-18	6	45.86975	-63.87512	Amphibian	Green frog	Small
K137	10-08-18	6	45.86957	-63.87612	Amphibian	Green frog	Small
K138	10-08-18	6	45.86938	-63.87683	Amphibian	Green frog	Small
K139	10-08-18	6	45.86936	-63.87709	Amphibian	Green frog	Small
K140	10-08-18	6	45.86934	-63.87719	Amphibian	Green frog	Small
K141	10-08-18	6	45.86934	-63.87726	Amphibian	Green frog	Small
K142	10-08-18	6	45.86933	-63.87727	Amphibian	Northern leopard frog	Small
K143	10-08-18	6	45.86932	-63.87729	Amphibian	Green frog	Small
K144	10-08-18	6	45.86929	-63.87746	Amphibian	Green frog	Small
K145	10-08-18	6	45.86929	-63.87746	Amphibian	Green frog	Small
K146	10-08-18	6	45.86926	-63.87751	Amphibian	Green frog	Small
K147	10-08-18	6	45.86927	-63.87755	Amphibian	Green frog	Small
K148	10-08-18	6	45.86927	-63.87755	Amphibian	Green frog	Small
K149	10-08-18	6	45.86926	-63.87773	Amphibian	Green frog	Small
K150	10-08-18	6	45.86926	-63.87775	Amphibian	Green frog	Small
K151	10-08-18	6	45.86922	-63.87786	Amphibian	Green frog	Small
K152	10-08-18	6	45.86922	-63.87786	Amphibian	Green frog	Small
K153	10-08-18	6	45.86922	-63.87786	Amphibian	Green frog	Small
K154	10-08-18	6	45.86921	-63.87793	Amphibian	Green frog	Small
K155	10-08-18	6	45.86917	-63.87821	Amphibian	Green frog	Small
K156	10-08-18	6	45.86916	-63.87831	Amphibian	Green frog	Small
K157	10-08-18	6	45.86908	-63.8785	Amphibian	Green frog	Small
K158	10-08-18	6	45.8895	-63.94154	Mammal	Porcupine	Medium
K159	10-08-18	6	45.84789	-64.14702	Mammal	Raccoon	Medium
K160	15-08-18	6	45.8505	-64.1183	Mammal	Skunk	Medium

ID #	Date	Road	Latitude (DD)	Longitude (DD)	Taxa	Species	Size
K161	15-08-18	6	45.88751	-63.99498	Amphibian	Wood frog	Small
K162	15-08-18	6	45.89021	-63.94365	Mammal	Raccoon	Medium
K163	15-08-18	6	45.89012	-63.94334	Mammal	Raccoon	Medium
K165	15-08-18	6	45.87653	-63.92144	Mammal	Snowshoe hare	Medium
K168	17-08-18	6	45.87709	-63.8155	Bird	Starling	Small
K169	17-08-18	6	45.88609	-63.93501	Bird	Cedar waxwing	Small
K170	17-08-18	6	45.86444	-64.05074	Mammal	Red fox	Medium
K171	22-08-18	6	45.848	-64.14552	Mammal	Skunk	Medium
K172	22-08-18	6	45.88791	-63.99374	Mammal	Skunk	Medium
K174	24-08-18	6	45.88789	-63.99364	Mammal	Raccoon	Medium
K176	24-08-18	6	45.84837	-64.14043	Mammal	Red squirrel	Small
N1	04-06-18	2	45.67664	-64.07903	Mammal	Raccoon	Medium
N2	11-06-18	2	45.70672	-64.15029	Mammal	Snowshoe hare	Medium
N3	11-06-18	2	45.67827	-64.08213	Mammal	Raccoon	Medium
N4	11-06-18	2	45.60467	-64.09395	Mammal	Porcupine	Medium
N5	11-06-18	2	45.58871	-64.17554	Mammal	Raccoon	Medium
N6	17-06-18	2	45.59097	-64.22002	Mammal	Chipmunk	Small
N8	17-06-18	2	45.63992	-64.0702	Mammal	Raccoon	Medium
N10	04-07-18	2	45.66738	-64.06533	Bird	Red-eyed vireo	Small
N12	09-07-18	2	45.70829	-64.15287	Mammal	Chipmunk	Small
N13	09-07-18	2	45.70028	-64.1334	Mammal	Red squirrel	Small
N14	16-07-18	2	45.5909	-64.19925	Mammal	Chipmunk	Small
N15	16-07-18	2	45.58697	-64.16306	Mammal	Red squirrel	Small
N16	16-07-18	2	45.66623	-64.06487	Mammal	Chipmunk	Small
N17	16-07-18	2	45.75899	-64.18518	Mammal	Red squirrel	Small
N18	24-07-18	2	45.59915	-64.11089	Mammal	Porcupine	Medium
N19	24-07-18	2	45.58216	-64.14718	Amphibian	Green frog	Small
N20	24-07-18	2	45.58761	-64.17179	Bird	Savannah sparrow	Small
N21	30-07-18	2	45.59658	-64.11906	Bird	Starling	Small
N22	30-07-18	2	45.62061	-64.08582	Mammal	Raccoon	Medium
N23	30-07-18	2	45.76069	-64.18587	Mammal	Red squirrel	Small
N24	06-08-18	2	45.6021	-64.09619	Mammal	Raccoon	Medium

ID #	Date	Road	Latitude (DD)	Longitude (DD)	Taxa	Species	Size
N25	06-08-18	2	45.59657	-64.11932	Bird	Crow	Small
N26	06-08-18	2	45.59114	-64.12463	Bird	Crow	Small
N28	13-08-18	2	45.60196	-64.09637	Mammal	Raccoon	Medium
N29	20-08-18	2	45.7651	-64.18787	Mammal	Red squirrel	Small
N30	20-08-18	2	45.58628	-64.15717	Mammal	Chipmunk	Small

Appendix B

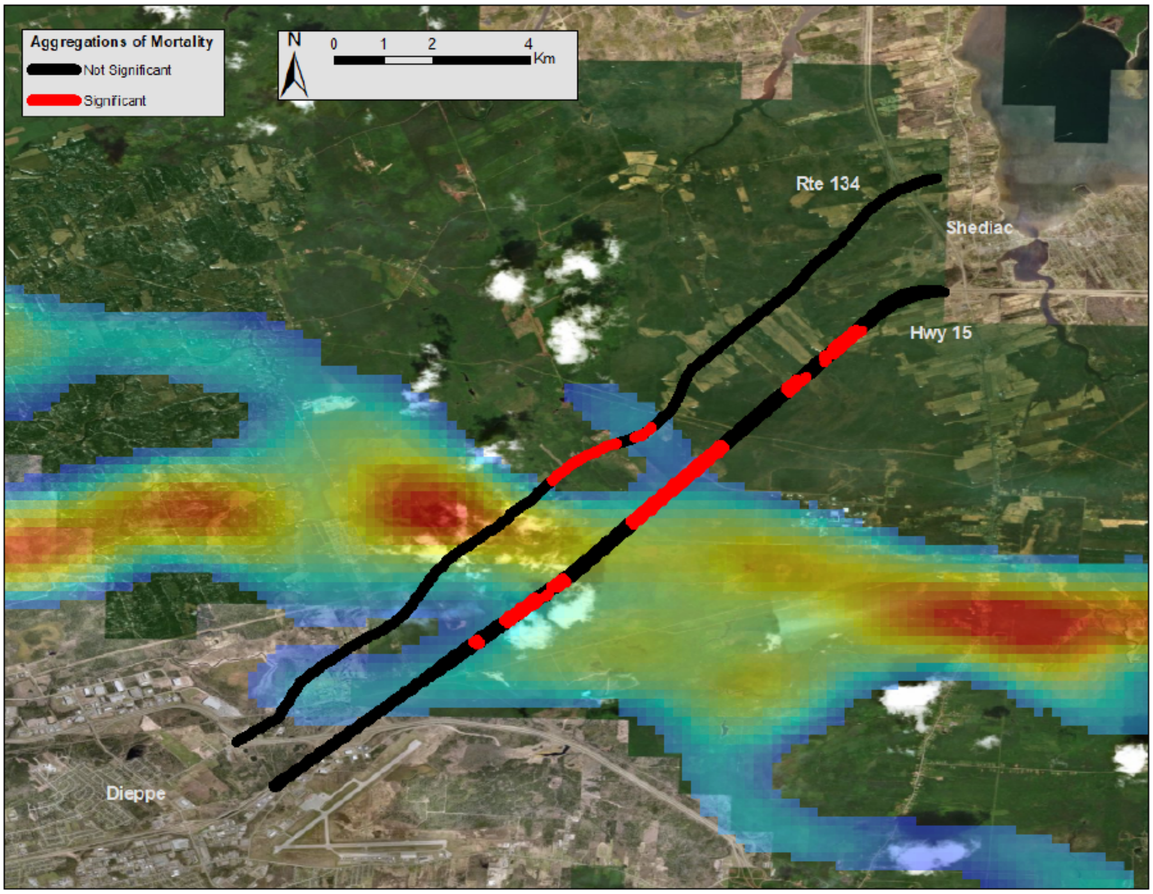


Figure B1. Close up view of hotspot analysis results for NB Rte 134 and NB Hwy 15.

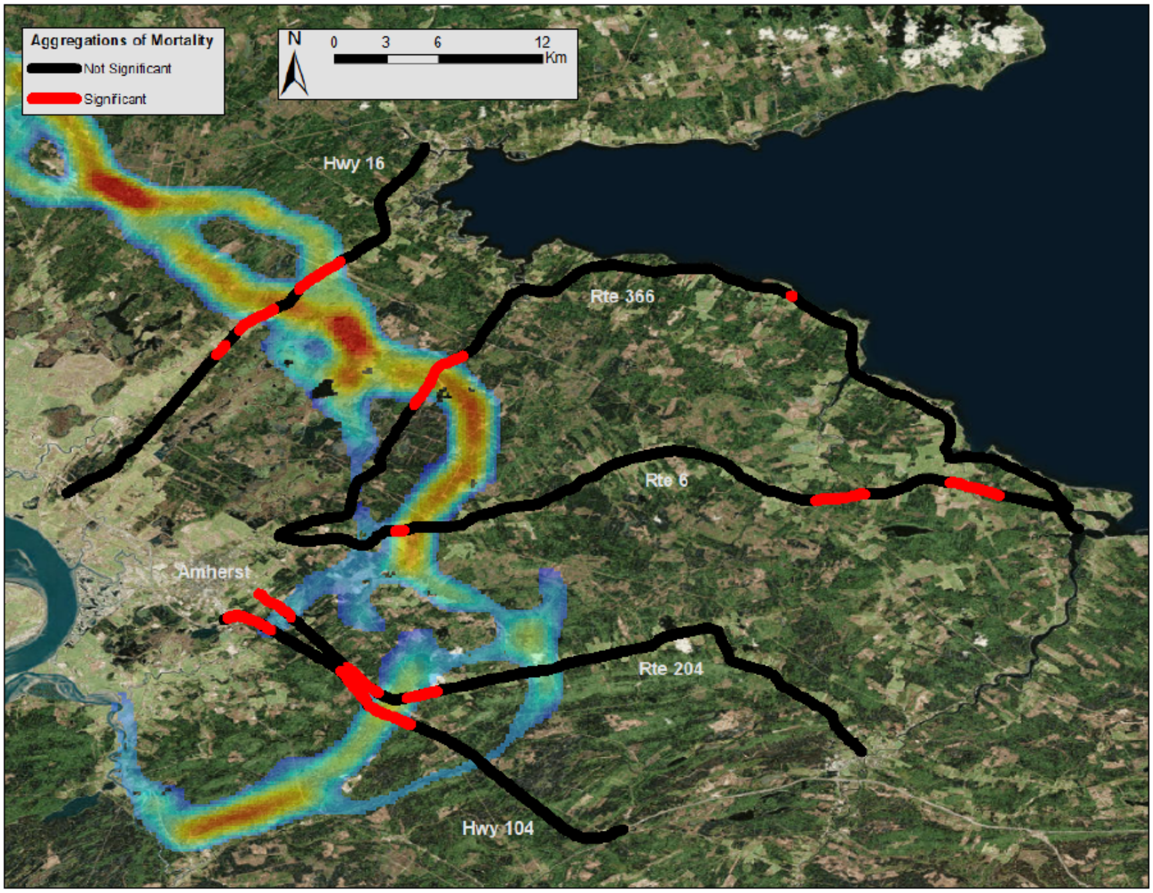


Figure B2. Close up view of hotspot analysis results for NB Hwy 16, NS Rte 366, NS Rte 6, NS Rte 204, and NS Hwy 104.

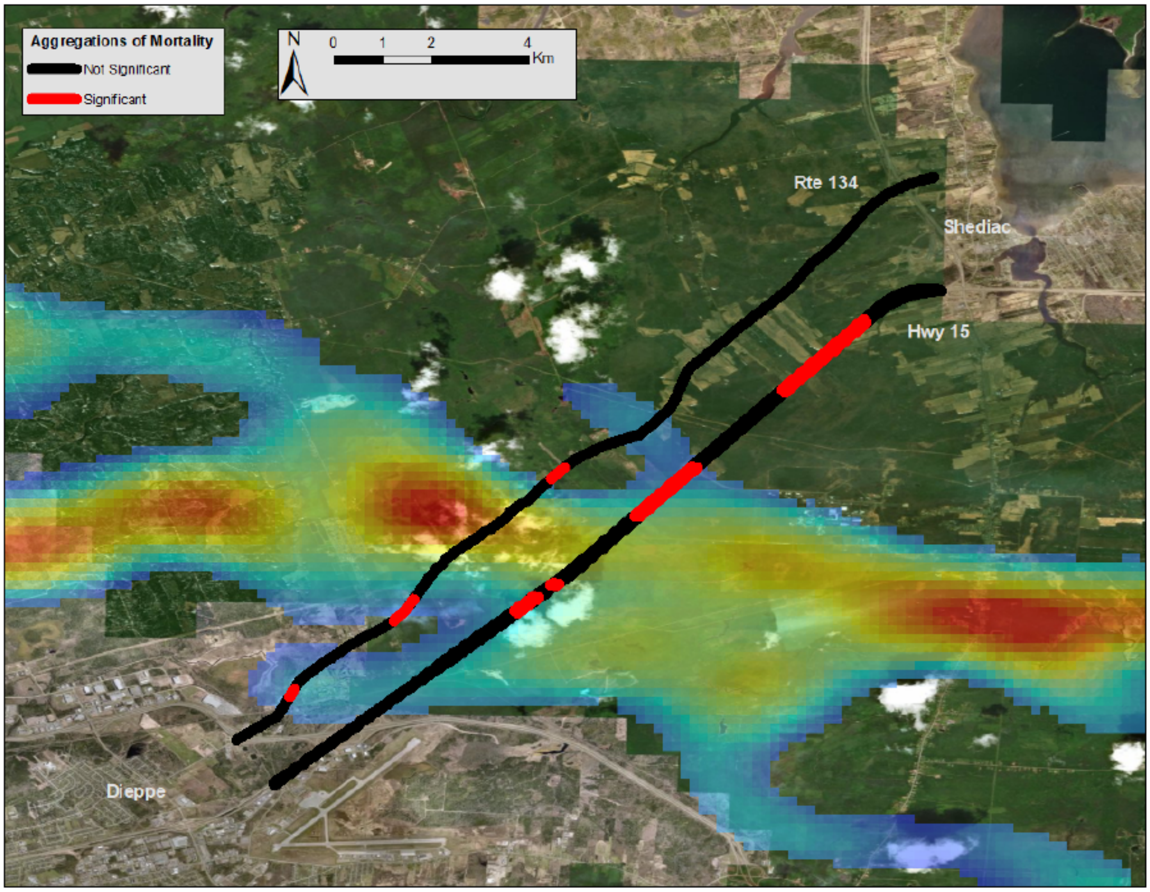


Figure B3. Close up view of hotspot analysis results for NB Rte 134 and NB Hwy 15 (mammals only).

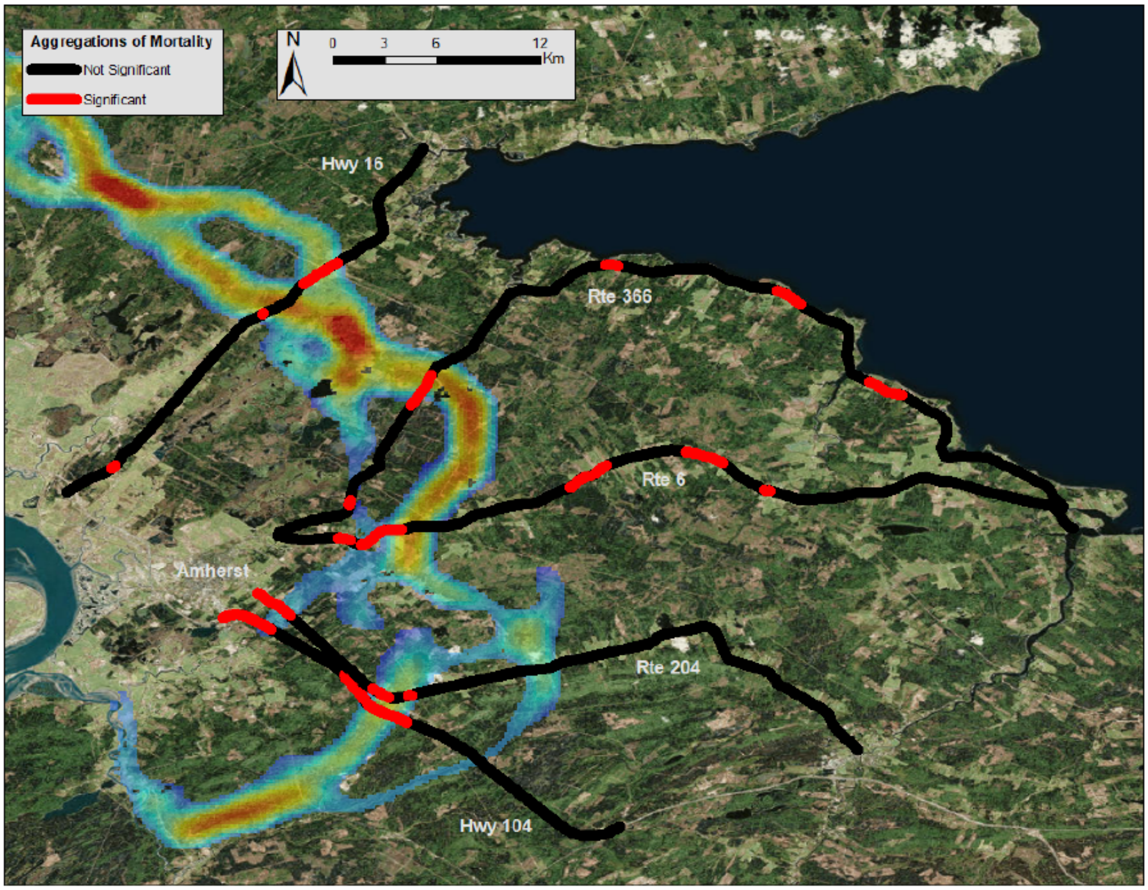
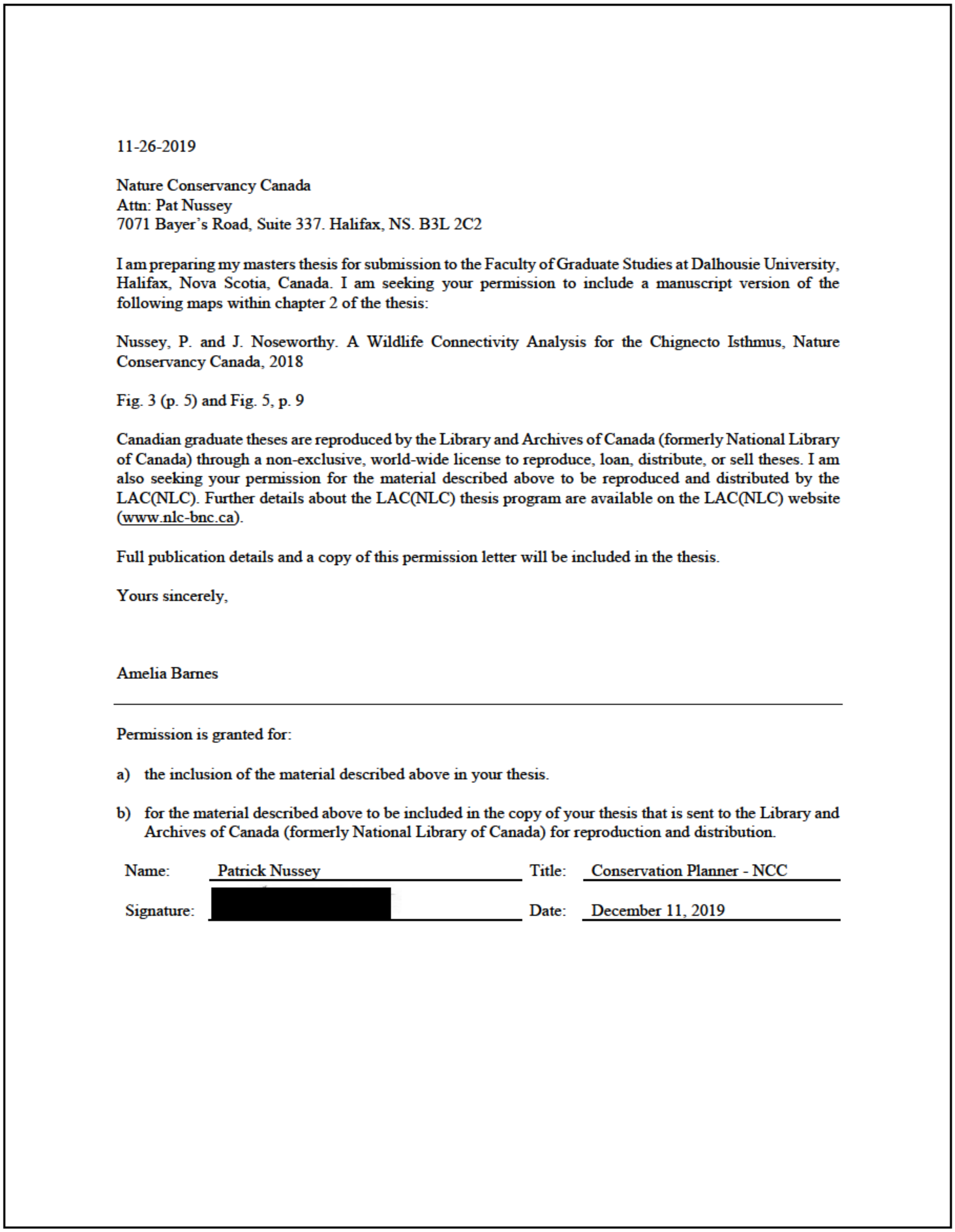


Figure B4. Close up view of hotspot analysis results for NB Hwy 16, NS Rte 366, NS Rte 6, NS Rte 204, and NS Hwy 104 (mammals only).

Appendix C



11-26-2019

Nature Conservancy Canada
Attn: Pat Nussey
7071 Bayer's Road, Suite 337. Halifax, NS. B3L 2C2

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Fig. 3 (p. 5) and Fig. 5, p. 9

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