Investigating Wildlife Movement Pathways through the Chignecto Isthmus:A Participatory Mapping Approach for Knowledge Co-Production

by

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Dalhousie University is located in Mi'kma'ki, the
ancestral and unceded territory of the Mi'kmaq.
We are all Treaty people.

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Abstract

Inclusive knowledge systems that engage local perspectives and social and natural sciences are critical for conservation planning. This thesis explores local tacit knowledge application to identify wildlife locations, movement patterns and heightened opportunities and barriers for connectivity conservation planning in a critical linkage area known as the Chignecto Isthmus in Canada. Thirty-four local knowledge holders with strong tacit knowledge of wildlife and the land participated in individual interviews and group workshops, both of which engaged participatory mapping. When the results were digitized and combined with formal-natural-science data collected from previous studies in the region, local knowledge provided rich explanatory and complementary data. Consistent with other studies, engagement of local knowledge was found to (i) provide important insights, knowledge translation, and dissemination to complement formal, natural science, (ii) help build a more inclusive knowledge system grounded in the people and place, and (iii) lend support to conservation action for connectivity planning.

Individuals' data were digitized, analyzed, and compiled into thematic series of maps, which were refined through participatory, consensus-based workshops. Locations of key populations and movement patterns for several species were delineated, predominantly for terrestrial mammals. When comparing local tacit-knowledge-based wildlife maps with those generated through other forms of data—a high-probability wildlife movement pathway modeled in GIS, roadkill hotspots based on roadside survey data, and vehicle-wildlife collision reports—, key differences and strong overlap were apparent. Insights from local knowledge identified important locations of wildlife populations and movement pathways and explanatory factors for changes in wildlife population, distribution, and movement patterns over time. Identified contributing factors primarily relate to habitat degradation and fragmentation from human activities (i.e., land use and land cover changes caused by roads, forestry, and climate change, primarily sea-level rise, and flooding), thereby supporting the need for conservation measures. This generated knowledge is important for consideration in local planning initiatives; it addresses gaps in existing formal-science data and validates or ground truths the outputs of existing formal-science-based research of wildlife habitat and movement pathways. Critically, awareness of the need for conservation and the value of the participants' shared knowledge has been enhanced, with potential influence in fostering local engagement in wildlife conservation and other planning initiatives. More broadly, these methods demonstrate an effective approach for representing differences and consensus among participants' spatial indications of wildlife and habitat as a means of co-producing knowledge in participatory mapping for conservation planning, leading to a more inclusive and diverse knowledge system.

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Chapter 1: Introduction

1.1 Overview

The conservation literature widely recognizes ecological connectivity as crucial to the long-term viability of species and biodiversity (Beazley et al., 2006; Fahrig, 2003; Heller & Zavaleta, 2009; Hilty et al., 2020; Krosby et al., 2010; Taylor et al., 1993). Ecological connectivity, as defined by Hilty et. al., is the 'unimpeded movement of species and the flow of natural processes' (pg. 4, 2020) and is key to maintaining genetic flow and other natural ecosystem processes throughout a region and is imperative when it comes to species conservation (Beazley et al., 2006; Beier et al., 2011; Crooks & Sanjayan, 2006; McRae et al., 2012). Ecological connectivity and landscape connectivity (hereafter referred to as connectivity) can be broken down further into both functional and structural connectivity (Hilty et al., 2020; Taylor et al., 1993). Functional connectivity is a description of how well individuals, genes and gametes can move through a landscape (Hilty et al., 2020). Structural connectivity is a measure of habitat permeability based on the arrangements of habitat patches, disturbances and elements that are important for species movement across a landscape (Hilty et al., 2020). Conservation measures are needed to maintain and restore ecological corridors to address ongoing threats to connectivity. However, these measures are often part of complex social and natural systems that require a multidisciplinary approach from both the social and natural sciences (Virapongse et al., 2016).

The Chignecto Isthmus is situated within the Canadian provinces of Nova Scotia (NS) and New Brunswick (NB) (Figure 1.1). The Isthmus is a high-priority linkage area for wildlife movement, critical to connectivity across the Northern Appalachian Acadian (NAPA) Ecoregion (Beazley et al., 2005; Reining et al., 2006; Woolmer et al., 2008). This ecological corridor is also crucial more locally as the only land bridge for terrestrial wildlife to move between the province of NS and the rest of North America (Macdonald & Clowater, 2005; Nussey & Noseworthy, 2018). Increased fragmentation pressures due to land use and climate change present several challenges in maintaining and restoring connectivity for ecological processes and wildlife across the Isthmus (Lemmen et al., 2016; Macdonald & Clowater, 2005). Roads, human infrastructural development, and forestry and agricultural practices fragment the landscape ecosystem, breaking it up into patches (Lemmen et al., 2016; Macdonald & Clowater, 2005; Mackinnon & Kennedy, 2008; Webster et al., 2012; Woolmer et al., 2008). The impacts associated with climate changes, such as storm surges, coastal flooding, and sea-level rise, also contribute to increasing connectivity pressures across the region, threatening both ecological and social-economic processes and structures (Greenberg et al., 2011; Macdonald & Clowater, 2005). However, while connectivity is acknowledged to be under threat across the Chignecto Isthmus, there remain significant gaps in the data regarding current distributions of local species within the region, with a recognized need to further investigate and identify potential corridors for connectivity and movement (Macdonald & Clowater, 2005; Nussey & Noseworthy, 2018). Restoring connectivity is especially urgent as the region also provides a crucial transportation and energy corridor; initiatives are underway to mitigate threats to infrastructure from sea-level rise (Forbes et al., 2006; Webster et al., 2012), with potentially serious associated implications for wildlife connectivity.

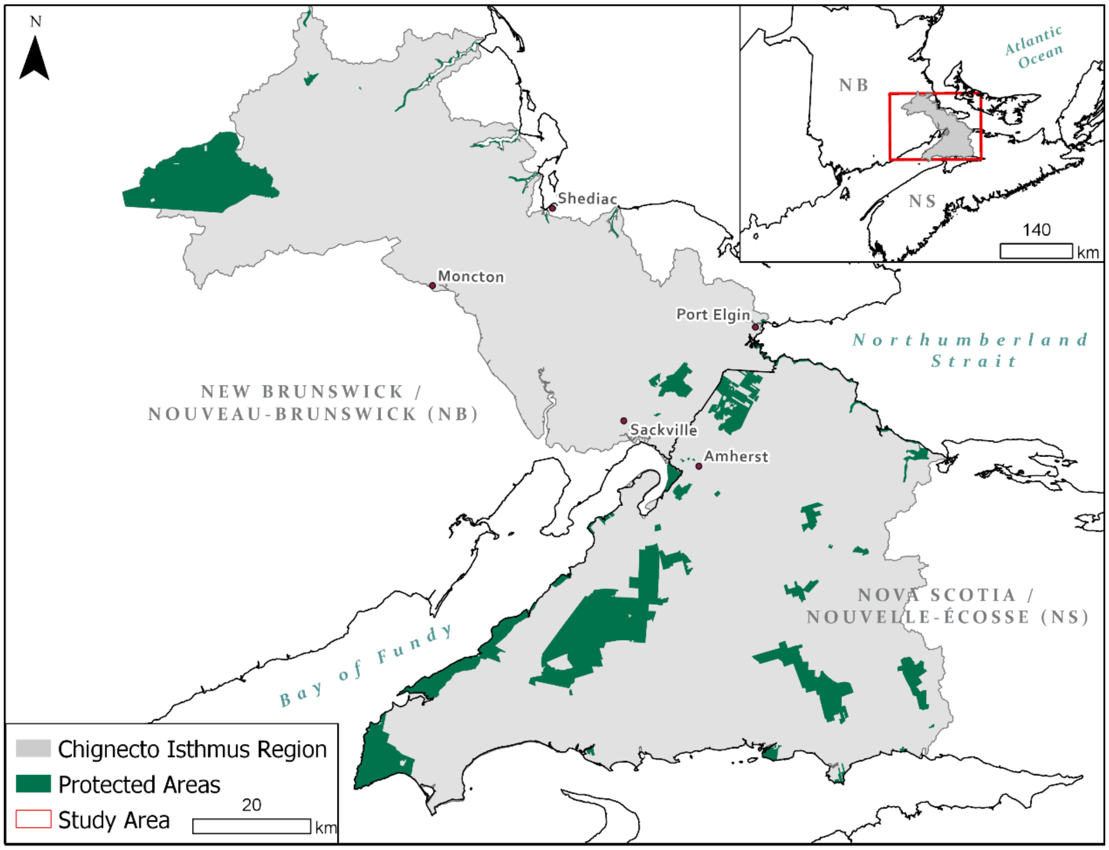

Figure 1.1 The Chignecto Isthmus Region in NS and NB, Canada. The region is delineated at a level 2 watershed by Nussey and Noseworthy (2018). Protected areas are from the Canadian Protected and Conserved Areas Database for terrestrial protected areas and other effective area-based conservation measures, compiled by Environment and Climate Change Canada (2020). Reproduced from Needham et al. (2020) as permitted under the Creative Commons Attribution License (https://creativecommons.org/licenses/by/4.0/).

To address wildlife knowledge gaps and better understand associated social and ecological patterns and processes in the region, local knowledge may prove an effective source (Cosham et al., 2016). Participatory research combined with geospatial technologies can generate local spatial knowledge to supplement existing empirical data (Noble et al., 2020). Developing a spatial representation of species distribution across a region can be a challenge in land planning and wildlife conservation management as it requires a considerable amount of data, and there are often gaps in data availability for some species (Noble et al., 2020). Supplementing scientific data with local ecological knowledge (LEK) is a means of addressing these data gaps and creating a richer picture for species distribution across a region (Noble et al., 2020). A key method of gathering LEK is through participatory mapping approaches, that can reveal ecological patterns and processes and underlying social uses and concerns shared by a range of rights holders (Noble et al., 2020). Integration of LEK can provide deeper insight into historical and current distributions of wildlife populations, creating a more nuanced and diverse knowledge base of wildlife movement and presence.

Participatory mapping approaches seek to represent and understand a diversity of values through exploring location-specific human preferences and perceptions (Fagerholm et al., 2021). Through participatory mapping, individuals can share spatial attributes of importance including spatial values and perceptions (Brown & Raymond, 2007), everyday practices and activities (Brown & Fagerholm, 2015), and geographic citizen science such as mapped roads, trails and wildlife observations (Brown, Rhodes, et al., 2018; Fagerholm et al., 2021). Participants can also share non-spatial attributes through the interview process including personal values and preferences, motivation, and socio-economic demographics (Fagerholm et al., 2021). While there is a diverse range of methods by which to analyze participatory data, Fagerholm (2021) presents a systematic framework to represent PGIS analyses as comprising three analytical phases: *Explore, Explain, and Predict/Model* within the context of conservation planning. This framework represents a progression of data analysis including: (1) initial data exploration and assessment (*explore)* through data visualization, (2) further analysis of the data in relation to other sources to explain observations (*explain)* through visual and overlay analysis, and finally (3) heuristic methods for spatial prioritization to identify conservation priorities *(predict/model)*.

There has been a call by conservation social scientists to increase multidisciplinary approaches within conservation (Bennett et al., 2017; Campbell, 2005; Mascia et al., 2003). Conservation policies and practices are governed by social phenomena such as human decisions and behaviors which influence the success of environmental policy (Mascia et al., 2003). The role of social factors influencing conservation suggests a shift is needed in viewing science and nature, placing the social sciences as central to conservation practice (Bennett et al., 2017; Mascia et al., 2003). Conservation social sciences have emerged as a way for the social sciences to inform policy and practice within conservation (Bennett et al., 2017). Similar research on social-ecological systems (SES) has emerged as a means of further integrating both social and ecological perspectives within conservation science (Bennett et al., 2017). Wholistic ways of viewing indivisible, more-than-human forms of ecological and social connectivity are emerging (e.g., for an overview, see Hodgetts, 2018), as is greater respect for and advancement of Indigenous knowledge systems in conservation (Artelle et al., 2019; M'sɨt No'kmaq et al., 2021; Zurba, Beazley, English, & Buchmann-Duck, 2019)

Perspectives such as SES and more-than-human recognize that human and biophysical components are interdependent, providing conceptual frameworks for community-based participatory research (Charles, 2021; M'sɨt No'kmaq et al., 2021). Through such lenses, human and natural systems are linked through a mutual respect, interdependence and reciprocal relationships (Charles, 2021; M'sɨt No'kmaq et al., 2021). From an SES perspective, for example, the integration of ecological and social systems is critical to conservation efforts as this approach considers these two systems as co-evolving and intertwined (Charles, 2021; Ostrom, 2009). Human-used resources are rooted within complex social-ecological systems, and using an SES framework recognizes that environmental issues are multi-faceted and involve diverse social and natural systems (Ostrom, 2009; Virapongse et al., 2016). Insights from social sciences such as these can be generative and innovative for conservation planning (Bennett et al., 2017). Engaging the social sciences within conservation initiatives can improve outcomes by ensuring that processes are guided by the best available information (Bennett et al., 2017). Accordingly, conservation social science should be seen as a critical component within conservation management and planning alongside the natural sciences, rather than as an optional supplement to conservation planning (Bennett et al., 2017).

This thesis infuses social science into connectivity conservation science and practice by co-producing local tacit knowledge and combining it with existing scientific knowledge of wildlife across the region. Findings provide a novel method and data to create a richer picture of opportunities and barriers for wildlife presence and movement across the region that can help inform future conservation and land management practices for facilitating connectivity and conserving habitat in the Chignecto Isthmus. More broadly, this research helps to address key connectivity challenges while contributing to the growing field of connectivity conservation science. The co-production and dissemination of local knowledge helps to address gaps identified in the literature (Macdonald & Clowater, 2005; Nussey & Noseworthy, 2018), which found that current knowledge of local species distribution in the region is lacking, making it difficult to assess current habitat connectivity. It also fosters support for local engagement in conservation initiatives, building a community or network of knowledgeable people and confidence in local knowledge. Finally, by responding to the recognized need to further study identified areas of concern in the region to address future land management and conservation, this research develops a robust set of data to inform and identify priority areas for conservation in the Chignecto Isthmus region.

1.2 Objectives

This thesis aims to enrich the understanding of wildlife connectivity opportunities and challenges through an exploratory and participatory analysis of local tacit knowledge and how it can supplement natural-science-based mapping and modeling of priority lands for wildlife conservation. The following objectives will achieve this goal.

(1) Explore thematic spatial patterns of participatory data describing opportunities and barriers to wildlife movement across the Chignecto Isthmus, including areas of consensus and divergence among participants' data;

(2) Combine thematic spatial layers generated from participatory data with other natural-science-based geospatial data through an overlay analysis to identify spatial patterns. This overlay will help to identify areas of consistency and complementarity (difference) between local knowledge and existing natural science data in the region, specifically:

   a. A modelled high-probability wildlife movement pathway derived from least-cost-path analysis executed in Geographic Information Systems (GIS) by the Nature Conservancy of Canada (NCC; Nussey and Noseworthy, 2018);

   b. Road segment locations with aggregations of significant wildlife road mortality derived from roadside survey data (Barnes, 2019); and,

c. Road segment locations with aggregations of significant wildlife road mortality derived from provincial vehicle-wildlife collision report data (NBDNRED, 2021; NSDLF, 2021).

This thesis is one of two complementary theses supervised by Professor Karen Beazley and conducted as part of a larger study supported through the Social Sciences and Humanities Research Council of Canada (SSHRC; Insight Development Grant #430-2018-00792 to K. F. Beazley and collaborators C. Smith and P. Noel) with in-kind support from NCC. Both theses contribute to the larger project and examine the insights derived from local knowledge data collected as part of it. First, my thesis aims to achieve a deeper understanding of the role local tacit knowledge plays in knowledge co-production and supplementing expert-derived natural science data, explicitly examining the spatial data derived from participatory mapping interviews and workshops. Second, another thesis, by Victoria (Vicky) Papuga (Master of Environmental Studies, Dalhousie University, 2021), uses textual data from the same interviews and workshops to explore conceptual patterns in local knowledge holders' relational values surrounding human-wildlife coexistence. Data collection was conducted collaboratively by Vicky and me. We co-authored, along with Professor Beazley, an open access article (Needham et al. 2020), for which I am lead author, and which comprises a chapter in this thesis. Together and separately, these two theses help build a richer picture of local tacit knowledge holders' conceptual and spatial perceptions of wildlife in the Chignecto Isthmus region.

1.3 Methods

This mixed-methods study employs several strategies for examining (i) local tacit knowledge of wildlife populations, distributions, and movement patterns within the Chignecto Isthmus study area, (ii) how local knowledge of wildlife are spatially represented, and (iii) how local knowledge can supplement existing natural-science-based data. Textual and spatial data comprise the primary data source, collected through participatory map-based interviews and workshops in July and August 2019 and January and February 2020, respectively. As part of the larger project, approval for the ethical conduct of research with humans was received from Dalhousie University's Social Sciences Research Ethics Board (file # 2019-4763). Additional material, which included a collection of secondary data from previous studies in the region, was used to glean how results from participatory mapping approaches complement or enrich predictive model outputs and natural-science-based field data within the region. These include high-probability wildlife movement pathways modelled through least-cost-path analysis (Nussey and Noseworthy 2018), and roadkill hotspots derived from analyses of data from roadside surveys (Barnes 2019) and provincial vehicle-wildlife collision reports (NBDNRED, 2021; NSDLF, 2021). To orient the reader, this section provides a condensed overview of the approaches used to achieve the research. Additional methodological details are provided in Chapters 2 and 3, along with consideration of how this research is situated within the context of the guiding literature.

In the summer months of 2019, we (Vicky and I) conducted a series of in-person, semi-structured interviews that included a participatory mapping component to gather qualitative textual and spatial data from 34 local hunters, trappers, woodlot owners, farmers, and naturalists within the Chignecto Isthmus region. Interviews explored participants' knowledge of the land and wildlife within the region and sought to gather data surrounding opportunities and barriers to wildlife movement. Participatory mapping was included as part of the interviews, which allowed participants to spatially record known locations and observations of species presence, movement, and population changes, and to identify areas of heightened opportunities or barriers to species movement or persistence across the Chignecto Isthmus.

Each participant's mapped spatial data was then digitized using a computer-based GIS. These were overlaid to visually detect similarities, differences, and patterns. Emergent themes were identified related to spatial patterns for specific species (e.g., moose, black bear, deer) and influencing factors (e.g., distribution, concentration, movement, roadkill, forestry practices). Mapped data from all participants for each theme were then compiled into a series of thematic maps, allowing for more detailed analysis of spatial correlations and differences amongst participants' responses. Two subsequent in-person, half-day, participatory workshops were then hosted within the region (at Aulac, NB) in January and February of 2020 to bring together a subset of the interview participants to review the compiled thematically mapped data. Participants provided input and feedback on the accuracy of our representation of their spatial knowledge (both location and attributes) and discussed their perceptions of the accuracy of the composite maps, comprised of their own and other participants' data. As part of the second workshop, the thematic composite maps were considered alongside the NCC's modeled high-probability wildlife movement pathway (Nussey and Noseworthy, 2018). Similarities and differences between participants' local tacit knowledge delineations and NCC's high probability movement pathway were identified and discussed. This process allowed for open discussion of key underlying factors for spatial patterns observed between participant-mapped data and modeled data. Together, these two workshops allowed for the addition and refinement of any data that may not have been adequately captured or delineated in the first iteration, and a subsequent review of any resulting revisions to the maps. Further, the workshops facilitated consensus-building among participants and co-validating of their experience-based contributions to a co-generated local knowledge base. The findings from these explorations are presented in chapter two, including descriptions of the emergent thematic maps and explanatory factors.

After the participatory phases of the interviews and workshops were completed, the generated spatially explicit thematic data from local tacit knowledge were overlaid with results from previous roadkill studies conducted in the Chignecto Isthmus region. Key areas of roadkill concern and movement pathways identified by participants were compared with Barnes' (2019) findings of significant aggregations of wildlife mortality along major routes intersecting with the NCC's modeled movement pathway. Barnes' results were generated from on-the-ground, roadside surveys of roadkill and hotspot analysis of those data points conducted using a Kernel Density Estimation in Siriema Road Mortality Software V. 2.0 (2014). I also extended Barnes' (2019) work in order to compare these data to those derived from provincial vehicle-wildlife collision reports across the region. The methods followed those of Barnes (2019), in which wildlife mortality data from provincially recorded vehicle-wildlife collisions were analysed within Siriema Road Mortality Software to identify significant aggregations along sections of roads. This extension captured roads that were not surveyed and analysed in Barnes' thesis but that did intersect with roads identified by participants as areas of concern for roadkill or influencing wildlife movement. This analysis provided an additional line of evidence alongside which to consider local tacit knowledge and its role in identifying spatial patterns relevant to wildlife distribution, movement, and conservation. These analyses are summarized in Chapter 3.

Together, these mixed methodological approaches co-generate and consider spatial patterns of local tacit knowledge of wildlife alongside a sampling of natural-science derived findings in the region. The results highlight key areas that may represent heightened opportunities and/or barriers to wildlife conservation in the Chignecto Isthmus. These findings serve to enhance understanding of wildlife patterns derived from local experiential knowledge, enriching diversity and inclusion in co-produced knowledge systems for conservation and other land and resource management and planning in the region. Key areas of consensus may represent priorities for conservation action and improved connectivity for wildlife, and areas of divergence highlight potential areas for future research. Importantly, the participation of local knowledge holders in the research may enhance their confidence in their individual and shared knowledge, strengthen social connections among them, and foster their engagement in and support for wildlife conservation initiatives.

1.4 Thesis Structure

This thesis comprises four chapters that address the objectives of the research. Chapter 2 is a stand-alone paper written in collaboration with Karen Beazley and Victoria Papuga and published in the journal, Land, in September 2020 (Needham et al. 2020). It introduces the study area and our exploratory methodological approach to utilizing participatory mapping as a means of knowledge co-production for investigating wildlife movement pathways in the Chignecto Isthmus. The chapter describes the thematic spatial patterns generated through participatory mapping and considers it alongside NCC's modeled high-probability wildlife movement corridor in the region. Because it is a stand-alone paper, some overlap in content with other chapters is unavoidable.

Chapter 3 expands upon a key theme—wildlife interactions with roads—from Chapter 2 by comparing results from the participatory data to those of previous natural-science-based studies in the region. Primarily, it combines results from roadkill hotspot analyses using roadside survey data and vehicle-wildlife collision report data to assess similarities and differences between these data and participatory mapped data surrounding roads in the region. The chapter also discusses these results briefly within the context of other key themes emerging for Chapter 2, including the influence of forestry practices on wildlife and wildlife movement, and suggested roadkill mitigation options, especially in key "pinch-point" areas of restricted movement opportunities.

The final chapter, Chapter 4, provides an integrative discussion of the research collectively. Common themes and patterns observed across chapters are discussed and key conclusions drawn as they pertain to the thesis as one body of work. Key findings that enhance understanding for wildlife connectivity conservation and other initiatives in the region are discussed, along with contributions to the broader fields of conservation science and participatory mapping.

The research is exploratory and explanatory. Anticipated contributions are to generate local tacit knowledge to enrich and help build a diverse co-produced wildlife knowledge base, identify heightened opportunities for and barriers to wildlife movement across the region, and highlight possible next steps for identifying areas of conservation priority. More generally, the work may help to enhance support for wildlife conservation within the Chignecto Isthmus and for the inclusion of local knowledge and social science in conservation science and practice.

Chapter 2: Accessing Local Tacit Knowledge as a Means of Knowledge Co-Production for Effective Wildlife Corridor Planning in the Chignecto Isthmus, Canada

This chapter was published on 20 September 2020 in the journal, Land (9 (9): 332. DIO: 10.3390/land9090332). Co-authors are Jessica L. Needham (lead author), Karen F. Beazley and Victoria P. Papuga. My contributions to the research and the writing of the paper include: assisting with the development of the project and methods; producing the base maps for interviews; assisting with participant recruitment, interviews and workshops, particularly leading the participatory mapping component; digitizing and analysing spatial data from the interviews; leading the identification of emerging map themes; creating draft and final maps; and, leading the writing, editing and revisions.

2.1 Introduction

Connected systems of effectively protected and conserved areas are considered critical to addressing both biodiversity and climate crises (Heller and Zavaleta, 2009; Hilty et al., 2020; Worboys et al., 2016; Woodley et al., 2019a,b;). Ecological connectivity is imperative to maintaining natural ecosystem processes such as genetic flow and the recolonization of patches (Taylor, Fahrig, Henein, & Merriam, 1993; Watkinson and Sutherland 1995; Dias 1996). Discontinuous and fragmented habitat can restrict the movement of wildlife and gene flow with adverse effects on populations and the persistence of species (Caprio 2001; Beazley et al., 2006). Connectivity facilitates genetic exchange among subpopulations (Beier 1993; Brussard 1985; Reed et al. 1986; Soulé 1980), helping to maintain genetic diversity and metapopulation viability (Fahrig and Merriam 1994, Beissinger & Westphal 1998), which support species resilience to changes such as disease and climate (Haig, 1998; Krosby, Tewksbury, Haddad, & Hoekstra, 2010; O'Brien 1994; Wayne et al. 1992;). In the face of climate change, ecological connectivity is considered crucial to species adaptation strategies (Chen et al., 2011; Heller and Zavaleta, 2009;). As temperatures rise, connectivity can enhance the ability of species to move in response to range shifts by utilizing ecological corridors (Chen et al., 2011; Krosby et al., 2010; Lawlor et al., 2013; McGuire et al., 2016).

Given on-going threats to connectivity, conservation measures are warranted to maintain and restore key ecological corridors (Hilty et al., 2020; Hodgson et al., 2011; Worboys et al. 2016). With competing demands on a limited land base, however, any plans for additional protected or conserved areas need to be grounded in rigorous evidence and supported by local people. Conservation issues are multi-faceted and involve complex social and natural systems that requires the integration of both the natural and social sciences to solve (Virapongse et al., 2016). For effective conservation decision-making processes to occur, there must be a mobilization of diverse knowledges and ways of knowing (Cvitanovic et al., 2015, 2016). However, knowledge systems that combine social and natural sciences, including local perspectives, are often difficult to generate and mobilize (Cvitanovic et al., 2015; Cvitanovic, McDonald, & Hobday, 2016; Nguyen, Young, & Cooke, 2017; Segan, Bottrill, Baxter, & Possingham, 2011; Sutherland et al., 2012). Yet, the importance of local and inclusive knowledges in conservation planning is increasingly recognized (Bennett & Roth, 2015; Cvitanovic, Cunningham, Dowd, Howden, & van Putten, 2017; Fazey et al., 2013).

This chapter accesses and generates local tacit knowledge of wildlife locations, movement patterns and landscape features that represent opportunities and barriers for connectivity conservation planning. Our study area is situated in the Chignecto Isthmus, a primarily rural region that serves a critical landscape linkage function in the eastern Canadian provinces of Nova Scotia (NS) and New Brunswick (NB). While the local findings and outcomes are important in their own right, the work contributes to the growing body of conservation planning literature that demonstrates the value and utility of local tacit knowledge as complementary, accurate information for decision-making in diverse contexts. The generation of local experiential knowledge in study regions where formal natural-science data and resources are sparse may represent a particularly important source of relevant data to address data gaps, validate modeling studies and weave in important social and ecological knowledge particular to the place and people.

Even in areas where formal science data are available, the engagement of local people and their tacit knowledge is important to expanding current research methods to integrate different ways of knowing, breaking down western-scientific notions of science, and whose information counts. At the same time, inclusion in the research process may increase awareness and potentially mobilize locally influential participants to engage in associated planning and management initiatives. In our case, the research process may foster consideration of wildlife and key wildlife movement pathways in government efforts to identify engineering solutions to protect infrastructure from sea level rise and engagement in on-going collaborative wildlife conservation initiatives in the Chignecto Isthmus.

The Chignecto Isthmus is a narrow strip of land (currently ~25 km in width, ~19 km as dry land) that connects NS and southeastern NB to the rest of mainland North America. The area is threatened by sea-level rise (Desplanque and Mossman, 2004; Forbes et al., 2006; Rahmstorf, 2007), storm surges and flooding (Greenberg, 2001), along with increasing human developments such as roads, railways, energy, and communication infrastructure (CBCL Limited, 2009; Webster et al., 2012). Effective mechanisms to conserve wildlife movement patterns are critical to biodiversity conservation and climate resilience and adaptation for species in this region. Although previous conservation planning studies have identified the region as of critical importance to species at risk and broader ecological connectivity (Beazley et al. 2005; Reining et al. 2006; Trombulak et al. 2008), there have been relatively few empirical and spatial analyses. Most assessments of wildlife habitat and connectivity have been based on computational models (Macdonald & Clowater, 2005; Nussey, 2016; Nussey and Noseworthy 2018), often at provincial and eco-regional scales (Beazley et al. 2005; Reining et al. 2006; Trombulak et al. 2008). In their 2005 study, Macdonald & Clowater noted that scientific knowledge of local species distribution in the region is lacking, making it difficult to assess habitat connectivity. This situation presently remains. Wildlife monitoring and management by provincial government agencies is not coordinated across Nova Scotia and New Brunswick; and the empirical wildlife data that do exist remain provincially specific and not readily accessible or compatible for application across the Chignecto Isthmus region (Macdonald & Clowater, 2005). Recent predictive modelling by the Nature Conservancy of Canada (NCC) has identified high-probability wildlife movement pathways between protected areas in the region, with the recognized need for model verification and further study of identified 'pinch points' to assist in future land management and conservation in the region (Nussey, 2016; Nussey & Noseworthy, 2018). Pinch points are habitat bottlenecks where there is a congregation of species paths which results from a lack of suitable habitat in the surrounding area (Nussey & Noseworthy, 2018). Some model validation has occurred through roadside surveys of wildlife roadkill (Barnes 2019; Barnes et al. 2020). Capacity for wildlife research is limited in the area, with a lack of financial and other resources for field studies across the entire region.

Until recently, regional efforts to mobilize knowledge have largely focused on natural science and nature conservation, rather than on local tacit experience and perceptions (except see MacDonald and Clowater, 2005). Yet, local knowledges are as important as those generated through formal natural sciences and models. Regional efforts have explored local perceptions of habitats, responses to climate change, biodiversity stewardship initiatives, and landscape change through various studies reflecting local, tacit knowledge in the Chignecto Isthmus (Chappell et al., 2020; Goodale, Yoshida, et al., 2015; Sherren et al., 2016; Sherren & Verstraten, 2013). It is likely that there is also a strong base of knowledge of the land and wildlife in the region, given long-standing traditions, livelihoods and pastimes associated with living off the land, seasonal hunting, trapping, and fishing in the area and other natural resource uses. Indigenous peoples—the Mi'kmaq—have lived here, in their ancestral and unceded territory—Mi'kma'ki, for 15,000 years and Euro-American settlements began in the 1600s (CIRNAC, 2010; M'sɨt No'kmaq et al., 2021).

Realizing that human factors have been largely neglected in conservation science (Bennett et al., 2016; Brown & Raymond, 2014; Charnley et al., 2007; Failing et al., 2007; Gruby et al., 2015; Raymond et al., 2010a), our work aims to enhance the generation and use of local tacit knowledge for connectivity-conservation planning and broader norms of human-wildlife co-existence in the Chignecto Isthmus. More specifically, our study seeks to address data gaps and limitations by engaging in participatory research with local knowledgeable people as a means of garnering important insights on wildlife habitat locations and movement patterns that are likely not adequately represented in the existing empirical and spatial data. At the same time, we hope to enhance the participants' support and engagement in conservation planning initiatives. In doing so, we aim to contribute to a more inclusive knowledge system and capacity base for potential infusion of local knowledge into conservation and other land planning initiatives in the region. Beyond the study area, our research contributes to the growing body of literature related to conservation planning, particularly for wildlife connectivity conservation and the use of public participatory geographic information systems (PPGIS).

2.1.1 The Chignecto Isthmus in Context

The Chignecto Isthmus is a unique study region as it plays a critical role in landscape connectivity (Beazley et al. 2005; Macdonald & Clowater, 2005; Reining et al. 2006; Trombulak et al. 2008) (Figure 1.1). Recognized nationally and internationally as a high priority corridor, both for wildlife movements and linear human infrastructure such as roads, railways and energy pipelines, this region is key to maintaining connectivity between Nova Scotia, southeastern New Brunswick and continental North America (Hilty et al., 2012; Lemmen et al., 2016; Nussey & Noseworthy, 2018). Its ecological importance is recognized through its designation as one of Canada's 15 Community-Nominated Priority Places[1] (Environment and Climate Change Canada [ECCC], 2019). Enhanced local awareness of its role in species' population persistence has been raised through NCC's 'Moose Sex' project (NCC 2012; Holland 2014). Several challenges emerge, however, in understanding, maintaining, and restoring connectivity for wildlife and other ecological processes through this narrow region, particularly in the context of a complex network of roads and other human infrastructure. Bounded by the Northumberland Strait and the Bay of Fundy, the Isthmus is fragmented by seven two-

[1] NS and NB – 'A community of practice to protect and recover species at risk on the Chignecto Isthmus': Nature Conservancy of Canada and partners (e.g., Birds Canada, Community Forests International, Fort Folly Habitat Recovery Program, Confederacy of Mainland Mi'kmaq - Mi'kmaw Conservation Group) aim 'to build and strengthen community relationships, develop a conservation plan, build public awareness and deliver programs benefiting species at risk. The project will benefit 20 listed species at risk…and 20 additional species of concern. It will occur in the Chignecto Isthmus region of both Nova Scotia and New Brunswick, covering 739,596 hectares.' (ECCC, 2019)

lane roads that transect the region (Macdonald & Clowater, 2005; Barnes et al. 2020), compounded with the Trans-Canada Highway and the Canadian National Railway that transverse the region (Mackinnon & Kennedy, 2008; Webster et al., 2012).

Sea-level rise (Forbes et al., 2006; Rahmstorf, 2007), storm surges and flooding (Greenberg, 2001; Shaw et al. 1998) threaten terrestrial connectivity across the Isthmus, compounded by habitat loss and fragmentation (CBCL Limited, 2009; Webster et al., 2012). Drivers include urban and rural development; transportation, energy and communications infrastructure; forestry and agricultural activities; and climate change (Lemmen et al., 2016; Macdonald & Clowater, 2005; Woolmer et al., 2008). At times, historically and during the Saxby Gale in 1869 (Abraham et al. 1999; Parkes et al., 1997), the Isthmus has been inundated with waters from the Bay of Fundy (Desplanque & Mossman, 2004; Peltier, 2004). Storm surges funnel up the Bay of Fundy—a dynamic marine system with the highest recorded tides in the world (16.3 m)—culminating in the Chignecto Bay (Canadian Hydrographic Service 2006; Greenberg et al. 2012; Shaw et al. 2010). The elevation of the entire region is less than 90 m above sea level and is dominated in the southern region by low lying salt marshes, wetlands, and bogs (Macdonald & Clowater, 2005). Beginning with French Acadian settlement in the late 1600s, large areas of salt marsh were transformed into dykelands for agricultural use (Butzer 2002; Shaw et al. 2010). The northern portion of the region is at higher elevation and relatively better drained, supporting mixed forests (Macdonald & Clowater, 2005). Higher elevations also occur towards the Northumberland Strait, rated by Canada's Climate Change Impacts and Adaptation Program as of 'medium' sensitivity to sea-level rise compared to areas of 'high' sensitivity in the Isthmus' southern portion (Lemmen & Warren, 2004).

Projected sea-level rise[2], extreme weather events and storm surges threaten to breach the dykes, flooding parts of the Isthmus including the towns of Sackville, NB and

[2] An average of tide gauge records at Saint John, NB, estimates sea-level rise as 22 cm over the past century in the Bay of Fundy. This suggests that the current level is approximately 32 cm higher that at the time of the Saxby Gale when a storm surge breached the dykes, causing flooding that temporarily severed NS from NB (Webster et al. 2012, p. 9). Historic trends and modelled projections show that even in the absence of climate change an increase in tidal high water in the order of 0.3 m can be expected in the Bay of Fundy over the next century. Combined with the influence of climate change, "high water in the Bay of Fundy is predicted to rise on the order of 0.5 m over the next 50 years, and on the order of 1 m by the end of the century" (Greenberg et al. 2012, p. 274).

Amherst, NS (CBCL Limited, 2009; Forbes, Parkes, & Ketch, 2006; Greenberg, 2001; Rahmstorf, 2007; Webster, Kongwongthai, & Crowell, 2012). Over the past two centuries, major storm events have breached the dykes and caused extensive flooding around the perimeter of the Bay of Fundy (Webster et al. 2012). Flooding threatens the Trans-Canada Highway and the Canadian National Railway, which move an estimated 50 million CAD per day in trade (Lemmen et al., 2016; Webster et al., 2012), potentially causing detrimental economic impacts (Smith, 2020). As climate change adaptations become necessary, human infrastructural demands could put increased adverse pressures on wildlife habitat across a narrow five-kilometer-wide strip of higher elevation land at the NS-NB border (Nussey & Noseworthy, 2018). Further fragmentation of habitat would restrict the movement of wildlife, with negative consequences for the persistence of populations of wide-ranging, sensitive and vulnerable species (Beazley et al., 2006). Alternatively, if carefully planned, adaptation measures could potentially provide opportunities to mitigate barriers and pinch points to wildlife movements. Conserving connectivity would facilitate geneflow between subpopulations of species, helping to maintain genetic diversity and species resilience in response to climate and other changes (Beazley et al., 2006).

The NCC's recent predictive modelling (Nussey & Noseworthy 2018) of high-probability wildlife movement pathways in the region may serve to identify priority areas for conserving connectivity. They modelled habitat suitability and least-cost-paths for 15 terrestrial species[3] selected to capture a range of territory sizes and habitat requirements. Their least-cost-path analysis identified routes requiring the least energetic cost, providing the lowest risk to mortality, thereby minimizing risks to movement between habitat patches. The predictive modelling of potential corridors and pinch points has provided key information for future land management and conservation in the region (Nussey & Noseworthy 2018). Subsequent roadside surveys and roadkill hotspot analyses have helped to validate some of the model outputs (Barnes 2019; Barnes et al., 2020). Hotspots are areas where there are significant aggregations of wildlife mortality along a

[3] The 15 focal species chosen for the NCC Chignecto Isthmus connectivity analysis included: Moose, Black Bear, Red Fox, Bobcat, Snowshoe Hare, Fisher, Northern Flying Squirrel, Barred Owl, Northern Goshawk, Pileated Woodpecker, Yellow Warbler, Brown Creeper, Ruffed Grouse, Boreal Chickadee and Blackburnian Warbler (Nussey & Noseworthy, 2018)

segment of road (Coelho et al., 2014). Yet further validation and consideration of areas outside of modeled and field-surveyed sites are warranted.

At the same time, there are increasing pressures to protect human infrastructure in the Chignecto Isthmus from impacts of climate change. In January 2020, the Province of New Brunswick sought professional assistance to explore climate mitigation solutions for the transportation corridor (Fournier, 2020). An engineering firm is leading, with the Provinces of NB and NS and the federal government, a 700,000 CAD feasibility study with the aim to design engineering adaptations that are resilient to climate change and protect the trade corridor by preserving roads, dikes and infrastructure (Tutton, 2019). A previous cost-benefit analysis of adaptation measures to mitigate the impacts of sea-level rise and storm surges included scenarios of reinforcing and raising dikes and barricades, building new dykes further inland, and relocating and re-routing current transportation routes (Parnham et al., 2016). The need to 'engineer' new 'solutions' provides a potential opportunity to infuse an ecological lens into the mix, such as by considering opportunities to maintaining wildlife connectivity. It is imperative to identify and accommodate critical areas of ecological significance, especially if there is the need to relocate infrastructure and mitigations that could impact wildlife, positively or negatively. Critical areas should include pathways that are important to wildlife, as the Isthmus plays an essential role in not only trade and transportation but wildlife connectivity between the provinces. Successful implementation of any such conservation solution or initiative, however, will require political support, including engagement and buy-in by local communities and key local people with relevant knowledges.

2.1.2 Conservation Planning and Local Knowledge

Over the past 20 years, since the early 2000s, there has been a shift in the way science has been used in conservation planning (Margules & Pressey, 2000; Groves et al. 2002), recognizing the importance of considering social factors along with ecological ones (Bennett & Roth, 2015; Mascia et al., 2003; Sanborn & Jung, 2021). The social and natural sciences are now seen as complementary, with the challenges now being how to bring them together without privileging one over the other and how to infuse them into conservation planning and practice (Mascia et al., 2003; Bennett & Roth, 2015; Bennett et al., 2017). As such, conservation planning has begun to draw on transdisciplinary approaches from human geography, social ecological systems (SES), public participatory geographic information systems (PPGIS) and others. Such concepts are commonly applied in mapping and modeling studies of human-environment relationships, such as spatial patterns of land use and land cover (Bennett et al., 2017). Core principals are that conservation efforts ought to be systems oriented and cognisant of dynamic social-ecological interconnections between humans, culture, wildlife, and ecosystems that are influenced by broad scale forces such as political, economic, and biogeochemical conditions (Bennett & Roth, 2015; Bentley Brymer et al., 2016; Karimi, Brown, & Hockings, 2015; Ostrom, 2009; Virapongse et al., 2016). Ideally, both society's and science's perceptions of conservation issues should be collaboratively considered (Fry 2001; Reyers et al. 2010; Brown et al. 2010; Virapongse et al., 2016). As such, conservation planning is challenged to apply innovative models through engagement of diverse communities, facilitate co-learning about conservation and derive solutions through the co-development of knowledge and practice (Bennett, Roth, Klain, Chan, Christie, et al., 2017; Fox et al., 2006; Jacobson & Duff, 1998). Accordingly, there is a growing interest in engaging local people and diverse knowledges to help interpret, frame, verify[4] or groundtruth and otherwise complement knowledge gained through formal natural science methods, including addressing its gaps and limitations (Anadon et al., 2009; Close & Hall, 2006; Loftus & Anthony, 2018).

There is ongoing debate about the use of the term knowledge 'integration', referring to the inclusion of both local knowledge and scientific knowledge within environmental management (Gray, 2016), and with important relevance for conservation planning. While the importance of inclusion of local knowledge has been acknowledged, studies focused on knowledge 'integration' can struggle with considering which forms of knowledge are being privileged, sometime favouring scientific knowledge over local (Raymond et al., 2010). Differing epistemological beliefs about what and how things are known may constrain researchers' abilities to engage fairly or 'in a good way' with the

[4] Terms such as 'validate' and 'verify' can be contentious when talking about bringing together formal science and local tacit knowledge. Such words can imply a privileging of one form of knowledge over the other in terms of veracity, value, etc. What we mean by 'verify' is a form of 'ground truthing' based on local experiential and tacit knowledge, to identify areas of agreement and disagreement, which may then be further explored. In light of such concerns, we at times use 'verify' and at others 'ground truth', although we have not done ground checks in the field.

process of integration (Gray, 2016; Raymond et al., 2010b). Challenges may also arise with distrust among researchers and local knowledge holders and through institutional power dynamics and privilege (Gruby, Gray, Campbell, & Acton, 2015; Raymond et al., 2010). Such issues are inherent in attempts to 'validate' local or traditional knowledge with science. The desire to validate can derogate the legitimacy of local tacit and experiential knowledge, especially when the knowledges derive from fundamentally different epistemological systems, such as with traditional knowledge and scientific knowledge (Matsui, 2015; Widdowson & Howard, 2008). To acknowledge and address these challenges and barriers, conservation planning approaches are needed that facilitate the co-production of knowledge, engage more inclusive knowledge systems, and represent different forms of knowledge.

Connectivity conservation is a subset of conservation planning in which inclusive and collaborative efforts are particularly necessary, as it aims to address the conservation of public and private lands and Indigenous territories between protected areas (Wyborn, 2015; Hilty et al., 2020; Zurba et al., 2019; Artelle et al., 2019). The broader landscape is often highly contested space, with multiple demands and claims over a limited land base. Nonetheless, it is important to maintain and restore connectivity across human-dominated landscapes because habitat fragmentation is a key cause of wildlife decline (Hilty et al., 2020). Linear human developments such as roads are increasingly recognized as predominant impediments to habitat connectivity (Forman, Sperling, Bissonette, & Clevenger, 2003; Forman et al., 2003; Fudge, Freedman, Crowell, Nette, & Power, 2007; Robinson, Duinker, & Beazley, 2010; Spanowicz & Jaeger, 2019). There is also growing recognition that, particularly in coastal areas, responses to sea-level rise will require adaptation measures such as relocations of linear and other infrastructure from low lying areas to higher elevations, with potential risks of further incursions into wildlife habitat and disruptions to wildlife movement patterns with implications for population persistence (Lemmen et al., 2016; Rapaport et al., 2017). In order to protect and maintain ecological connectivity, appropriate conservation planning strategies must be developed at local, regional, and national scales underpinned by an understanding of species distribution, barriers to movement and threats to their persistence, consideration of the complex social-ecological contexts and broad support of local people.

Given the challenges inherent to considering multiple, diverse layers of natural and social information and landscape spatial patterns in conservation planning, geographical information systems (GIS) are often used to facilitate data compilation and analyses (Brymer et al., 2016; Sieber, 2006). The mapped outputs of such analyses are powerful tools for communication and decision support, yet they are strongly influenced by the choices of input data and the rules around interpreting it, such as in setting goals and targets for conservation modelling. These technologies, data sets and decisions about objectives and rule-setting have been dominated by the formal natural sciences. To make these systems more inclusive and transparent and to bring other participants to the table, (public) participatory GIS approaches (P)PGIS have been developed (Lovett & Appleton, 2008). While helping to democratize the planning process and enrich the data, questions remain as to how best to reach consensus and how to accommodate and incorporate differences in knowledges and values (Brown & Kyttä, 2018). Methodologies for representing differences and building consensus in participatory mapping are needed and is especially important given that including local knowledge in planning and decision-making is always troubled with questions of whose knowledge is included and privileged (Gray, 2016; Matsui, 2015; Raymond et al., 2010). PGIS methods provide an interesting model for engaging multiple viewpoints without assuming sameness in a local community (Orban, 2011). Distinct from building consensus among diverse stakeholder groups, managers and planners, the question arises as to how to build consensus *within* distinct groups, such as among local knowledge holders engaged in a participatory mapping exercise.

While the infusion of local perspectives and uses of participatory mapping have expanded over the past two decades (Brown & Kyttä, 2014; Joa et al., 2018; Loftus & Anthony, 2018), there has been relatively little uptake in their combined application to wildlife connectivity planning. Local knowledge provides a key tool for understanding the complex social and ecological systems in which conservation planning operates and for which solutions are increasingly coming from models that are unconnected to local people and place. The Chignecto Isthmus provides a study area where conservation planning is not only imperative for maintaining local wildlife, but also for broader national, and international connectivity. Monitoring of wildlife movement, distribution and abundance is time consuming and costly, and large gaps in knowledge for conservation planning remain. Local knowledge provides a means to help address these data gaps and limitations, while engaging local people and contributing to a more inclusive knowledge system. Accordingly, this study focuses on generating local tacit knowledge to help identify areas important to wildlife connectivity at a regional scale through an exploratory analysis using a participatory mapping approach. We focus on the local experiential knowledge of wildlife species, locations, movement pathways and landscape features that present opportunities or barriers to wildlife movement. We address how such local knowledge enriches existing data and models, not simply through gap filling, but by offering a deep understanding of interrelating factors that influence wildlife patterns within the region. We explore means of spatially delineating 'fuzzy' boundaries – areas where spatial reality is not precise or is ambiguous where boundaries do not exist in isolation, representing diverse perspectives and generating consensus in local knowledge (McCall, 2006). The mapped outputs may be used to supplement and validate formal scientific data and models relevant to delineating areas for wildlife connectivity and adapting human infrastructural developments in the region. Through the process, we seek to enhance local participants' confidence in their knowledge and foster their support and future engagement in local conservation and other planning initiatives in the region, while contributing to more inclusive knowledge systems. We propose that the generation and engagement of local experiential knowledge can enhance understanding and support for wildlife connectivity planning. Our study provides broad intellectual contributions around validation or 'groundtruthing' of modeling studies, where local knowledge provides a key tool for understanding knowledge about complex social-ecological systems that is increasingly coming from models that are unconnected to place and local people. As such, our approach and findings contribute to the scholarship and practice of connectivity conservation planning and PPGIS.

2.2 Materials and Methods

We used a mixed methods approach engaging qualitative and quantitative social and natural sciences to create a spatial dataset of wildlife connectivity patterns across the region. A combination of participatory one-on-one mapping interviews and two focus-group mapping workshops elicited local, tacit knowledge. Individual participants' maps were digitized and compiled into a digital mapping system. Spatial analyses using visual overlay were conducted to capture themes, similarities, and differences among the compiled mapped data from the individual interviews and group workshops. Maps were prepared to overlay local knowledge maps with NCC's modeled wildlife habitat and movement pathways for discussion purposes. Explanatory texts from the participants interviews and workshop discussions were used to enrich, support, and interpret the participants' mapped data. As part of a parallel study (Papuga, 2021), the interview transcripts are being further coded and qualitatively analyzed to more deeply explore their thematic content and nuances. The methodological details associated with each step are provided in the following sections.

2.2.1 Participatory Mapping Interviews

We conducted participatory mapping interviews (Brown et al., 2017; Brown, Sanders, et al., 2018; Karimi & Brown, 2017; McCall, 2006) with local knowledge holders to gather textual and spatial data representing their knowledge of wildlife species, population locations, habitat and movement patterns in the Chignecto Isthmus. Recruitment purposefully targeted people with long-term, lived experience on the land such as subsistence harvesters, woodlot owners, farmers, naturalists and recreational users of the land and wildlife. We conducted initial recruitment through local and provincial hunting and trapping, fishing, and naturalist organizations, and in collaboration with the Nature Conservancy of Canada who had preestablished relationships with individuals and organizations in the region. Supplemental 'chain-referral' or 'snowball' sampling (Biernacki & Waldorf, 1981; Sedgwick, 2013) was then employed, wherein interviewees were asked to suggest other potential participants knowledgeable of the land and wildlife. Recruitment ceased when no new referrals were forthcoming. Efforts were made to represent both provinces, aiming for 15-20 participants in each, and a breadth of experience and backgrounds. The participant sample was designed to represent a large proportion of the target population and provide a reasonable complement (n=30-40) in terms of pragmatic logistical constraints such as time and funding, balanced against obtaining a range of viewpoints from knowledgeable individuals. The intent was to explore the deep experiential knowledges within this sub-section of the population, rather than be generalizable to the broader public. Preliminary screening ensured participants were knowledgeable of the region, identifying the nature of their relationship to the land and the time they had spent there. For the purpose of our study, "the local knowledge of an individual is unrelated to any institutional affiliation and is the product of both the individual's cultural background and of a lifetime of interaction with [their] surroundings" (Loftus & Anthony, 2018, 158). Knowledge sought from participants was to be based on the livelihoods and pastimes of the individuals and gained through "extensive observation" (Huntington, 2000) of the land and wildlife across the region over time. While it not possible to separate an individual's tacit knowledge gained through their time spent on the land from their training within organizations and institutions, we asked participants to share their personal and experiential views and information, rather than represent the perspectives or provide formal data gleaned from their employers or member organizations.

A total of 34 local people with tacit knowledge of wildlife in the region participated in one-on-one participatory mapping interviews. Often participants did not identify as one specific type of knowledge holder, but rather had experience through a variety of work and recreational activities. Participants were engaged in hunting and trapping for sport, sustenance, and income; farming and agriculture; forestry both at industrial and private woodlot scales; wildlife rehabilitation and photography; as naturalists and trail groomers; and in other recreational uses such as fishing, canoeing, hiking, birding, snowmobiling, biking and cross-country skiing. Many participants have spent their lifetimes growing up and working in different capacities in the Chignecto Isthmus, with 11 participants from NS, 18 from NB and five who had lived on both sides of the border. While some participants are not originally from the region, their connection to the land is strong through their work and long-term residence in the area. The shortest time a participant has lived in the region is 10 years, but a large part of that involved being out on the land. We did not seek other demographic data from our participants as we did not intend to stratify our sample into sub-groups. Since we intentionally targeted recruitment toward people with longer histories of time and relevant experience in the region, participants tended to be middle-aged and older. Due to their long-term, deep engagement and familiarity with the region, we were able to collect a wide temporal range of data based on their knowledge, from the past to the present. Though significant effort was made to increase recruitment of younger adults, women and Mi'kmaw individuals, these were largely unsuccessful, with only 5 women and none who identified as Indigenous participating in interviews. Particularly, we recognize that the inclusion of Mi'kmaw individuals is important, as the Chignecto Isthmus is situated within Mi'kma'ki, their ancestral and unceded territory. Unfortunately, the time frame of the study was insufficient to develop the relationships of trust and Indigenous methodologies necessary to meaningfully engage Mi'kmaw individuals in culturally appropriate ways. Inclusion of the Mi'Kmaq in dialogues and decision-making within their territory is important, as are the insights likely to emerge and as such their engagement in co-production of knowledge should be sought in future efforts.

We conducted semi-structured, face-to-face interviews in June-August 2019 in both NS and NB, at locations convenient for participants, such as at their farm, hunting cabin, or a central coffee shop in a nearby town. Interviews of 1- to 2-hour duration explored how participants view and value wildlife and wildlife habitat within the region. Interview-guide topics centered around several key questions used as prompts as they arose in natural conversations (Appendix A). Questions were not necessarily all asked or addressed in any specific order as interviews were conversational and participant driven, based on their own experiential knowledge of the region. The first portion of the interview established context and built rapport to learn more about where participants live, how they came to live in the area, where they have spent their time in the region and the activities through which they have experienced the land. The second portion focused on core topics involving wildlife species, population distributions, movement patterns, habitat, conservation, roadkill hotspots, threats, and mitigation.

We solicited spatial data during the interviews through a participatory mapping component. Participants selected base maps from among five options at three scales (1:30 000, 1:60 000, 1:170 000) upon which to convey their knowledge of the region. These scales were chosen to show various levels of detail and extents of the Chignecto Isthmus to provide participants the opportunity to talk more broadly about regional based patterns and movement or more locally about observational and location-based knowledge. The base maps were centered around the NS-NB border and showed major highways and secondary roads, towns, protected and conserved areas, lakes and rivers, forest[5] cover and elevation contours, all sourced from 1:50 000 Topographic Data of Canada (CanVec Series, 2017). Land cover was classified simply as forest or non-forest. Often, forest cover served to orient participants to specific areas in the region such as the location of a pipeline right-of-way (i.e., a distinct linear feature of non-forest) and frequent occurrences of wildlife road crossings (i.e., adjacent known patches of forest cover on both sides of a highway). Elevation contours were often used to identify areas of higher elevation around Hall's Hill and Uniacke Hill associated with known movements of terrestrial wildlife. Elevation contours were also useful for participants to orient themselves within the two main watersheds in the region and to identify two distinctive ridgelines in the region that were used as landmarks for recording wildlife observations. After the first few interviews, significant local landmarks emerged as identified by participants and were often used as points of reference for orienting and locating spatial data; these landmarks were added to the base maps. Key landmarks include the Old Ship Railway—a historical ship-railway route which is now used as a multi-use trail connecting the Bay of Fundy to the Northumberland Strait running from Tidnish to Fort Lawrence—and the CBC radio towers located in the Tantramar Marsh near Sackville, NB, which were distinctive landmarks at the border region for decades but have since been demolished.

Participants chose the map(s) on which they felt most comfortable identifying their key areas and observations, with the option to use multiple maps at various scales. Paper maps provide an integral elicitation and engagement tool and a means of physically recording participants' responses in a method that was explicitly spatial. Participants were encouraged to draw directly on the maps, indicating any insights and tacit knowledge pertaining to wildlife, such as wildlife presence, absence, and movements, particularly around roads, areas of concern for conservation, features that represent barriers to or heightened opportunities for wildlife movement, key areas used for their

[5] The forest cover layer comprises a single land-cover category which did not classify dominant species or forest type across the region. Available: https://open.canada.ca/data/en/dataset/80aa8ec6-4947-48de-bc9c-7d09d48b4cad

livelihood or recreational activities and their perception or the spatial extent of the Chignecto Isthmus as a region.

Individually mapped data were scanned and georeferenced to align with base map coordinates within a Geographic Information System (i.e., ArcGIS™) and all data were projected to a common spatial reference, NAD 1983 UTM Zone 20N. The maps were then digitized to identify specific species' presence, movement pathways and barriers to movement using layers of points, polylines, and polygons. The individual maps were compiled and organized to form a thematic series of maps representing participants' landscape-based and experience-based knowledge of wildlife presence and pathways in the region. These were combined and overlaid to form group-consolidated thematic maps providing a composite landscape-scale perspective of wildlife presence and pathways in the region. Following the proposed methods outlined by McCall (2006) for representing local spatial knowledge through dynamic mapping, composite areas were shown as multi-layered zones with fuzzy boundaries in recognition that individually delineated boundaries were not identical to each other. Local spatial knowledge often includes descriptive spatial terms (e.g., near/far, few/many) and fuzzy boundaries which are not always perceived by participants as the same place or as existing in isolation (McCall, 2006). There are also multiple levels of detail that are not single occurrences of location but rather represent temporal and spatial ranges, such as those used for hunting and trapping, and seasonal wildlife usage. In this analysis, spatial patterns shared through our interviews were portrayed through the compiled thematic maps, whereas underlying temporal patterns related to the spatial components are described through a textual analysis only; temporal patterns are not reflected within the spatially mapped aspects. The need for precision in participatory GIS can change in accordance with the intended output and goals of the research. As outlined by McCall (2006), there is a need for less precision and lower resolution to represent various levels of certainty and confidence in the data. Such flexibility is appropriate in participatory GIS applications aimed at eliciting and transferring generational knowledge for analysis of conflict or consensus and management applications (McCall, 2006), such as in the case of our study.

2.2.2 Participatory Mapping Workshops

Subsequent to the individual map interview phase of our research, we held two sequential, half-day mapping workshops near the border in Aulac, NB, in January and February 2020. The aim was to review and refine the map series derived from the interviews. We invited a subset of 20 individuals from among the 34 interview participants, selected on the basis of their demonstrated, strong experiential knowledge of the land and wildlife in the region and high regard as such by those in the larger group. Eight of these individuals participated in the first workshop, in which we sought to verify the consistency and accuracy of our interpretations and compilations of the individual data. Spatial data were presented and discussed as a series of thematic consolidated maps of wildlife habitat, movement pathways and associated threats and barriers. The second workshop brought together the same group of participants with an additional two who were unavailable for the first workshop but were identified by others as key knowledge holders and leaders in the community who were important to include. Workshop participants continued to represent a mix of diverse roles and knowledge of the region including hunters and trappers, farmers, loggers, birders, wildlife rehabilitation workers, wildlife photographers, active members of the Chignecto Naturalist Club and conservationists. This active engagement across various livelihoods and lifeways provided the opportunity for a mix of diverse perspectives and expertise and allowed for strong consensus building across experiential domains to develop a robust data set of spatially mapped local, tacit knowledge.

Workshop participants were asked to comment on the consolidated maps and whether or not they thought they accurately and/or completely represented their knowledge of (1) areas of wildlife presence, habitat and movement pathways and (2) areas that represent heightened opportunities or barriers to wildlife passage, such as landscape features or changes. Participants were encouraged to note areas of similarities and differences in the maps and factors such as level of confidence, agreement/consensus, and rationale. The workshop facilitated the pooling of participants' knowledge and collective markings directly on the maps through round-table map breakout groups, where refinements were noted, such as additional or missing data and spatial revisions. Large, printed maps were provided of the compiled, thematic spatial data. Participants were broken into two smaller groups to assess each map sequentially and provide opportunity to comment and draw on the maps, working through any areas of disagreement or uncertainty. Open focus-group discussions at the start and end of each workshop facilitated the sharing of participant's views, thoughts, and opinions on the mapped data, expanding upon conversations and topics that had emerged.

After consensus was reached at workshop 1 on refinements to the initial consolidated thematic maps, the maps were updated to reflect the received inputs. In preparation for workshop 2, the outputs from NCC's wildlife movement pathway model (Nussey & Noseworthy 2018) were also overlaid with the local knowledge holders' consensus maps to develop a new series of thematic maps, and wildlife roadkill hotspots identified by Barnes et al. (2020; Barnes, 2019) were presented for comparison. The resultant composite maps reflected themes based on species distribution, movement patterns and wildlife-road interactions derived from both local-tacit knowledge and formal-science models, privileging neither.

In the second participatory mapping workshop held with the same subset of participants, the composite maps were reviewed for accuracy and completeness and to explore whether and why there may be similarities and differences in the results derived from their knowledge and those generated from the two formal-science data sources: i) NCC's model outputs of high-probability wildlife movement pathways derived from habitat-suitability and least-cost-path analyses for the 15 local species; and, ii) roadkill hotspots statistically derived from roadside survey data in the region (Barnes, 2019; Barnes et al. 2020). Any differences between their tacit representations and the models were identified and discussed. Discussions also provided an opportunity to identify missing information regarding other areas of habitat, wildlife movement or pathways and roadkill evidence. Questions explored whether they perceived problems with the model outputs; whether we had interpreted their feedback correctly or if further refinement was required in the maps; and why there may be differences between the model outputs and among their own knowledges of the land and wildlife. Questions also explored what the most important patterns revealed through the maps were, such as critical areas for supporting wildlife species and for addressing key threats to wildlife, and asked which species, if any, warrant heightened conservation attention.

After the second workshop, maps were refined based on participant feedback to create a series of final, local-consensus maps. Participants' input and remaining similarities and differences between local-consensus and formal-science-derived maps were thematically and spatially analyzed. Points raised by the participants during the second workshop were used to understand patterns which emerged in the local data and how they compared to the modelled data.

2.3 Results

2.3.1 Predominant Species and Threats

During the interviews, participants were first encouraged to speak freely about their knowledge of wildlife and wildlife movement in the region and were later asked about the species (see footnote 3) considered in NCC's modeling. Species that featured prominently were closely tied to the livelihoods or relationships participants held with the land. These were predominantly large mammals, including moose (*Alces alces*), white-tailed deer (*Odocoileus virginianus*) and black bear (*Ursus americanus)* and other furbearing species that were hunted and trapped, including beaver (*Castor canadensis)*, otter (*Enhydra lutris),* mink (*Mustela vison*), muskrat (*Ondatra zibethicus)*, coyote (*Canis latrans),* hare (*Lepus americanus)* and fisher (*Pekania pennanti).* Others were porcupine (*Erethizon dorsatum*), various bird species, including waterfowl, songbirds, and birds of prey, along with fish, primarily Alewife (*Alosa pseudoharengus*). Often these lesser-mentioned species were talked about more generally across the expanse of the region or as species affected by barriers, such as roads, but were not considered of conservation concern. A common theme was the general decline in species abundance across the region over the past few decades. As noted by a local forest ecologist, biologist, and birder, "essentially every animal that belongs in this ecosystem is still there, although in depleted numbers, from predators to songbirds" (P27) [6,7].

Of the species modelled by the NCC, participants elaborated on four, namely moose, black bear, hare and fisher, and showed considerable knowledge of habitat, movement

[6] We assume that 'essentially' means 'almost', in this case, since wolf, eastern cougar, woodland caribou and others historically present have been extirpated over the past few centuries since Euro-American settlement.

[7] Participant numbers (e.g., P27, P22) are used to anonymise individual participant identity consistent with our approved research ethics procedure for attributing paraphrases and quotes to those who have conferred ideas, trends and information in reporting results.

pathways and barriers for black bear and moose (Figure 2.1a, b). Bears were said to be numerous and increases in bear activity across the region were noted, especially in NS, and often associated with forestry practices and agriculture, both of which were considered to provide enhanced food sources for bear. While key areas of habitat and points of observation were mapped for bear (Figure 2.1a), the common response was that you could find black bear ‘everywhere’ and that the population was increasing: “years ago there was hardly a bear around, but now they’re everywhere” (P25); and, “I mean, there’s bears everywhere. More than people realize” (P15).

Moose distributions were mapped very differently from bears by participants (Figure 2.1b). They noted many factors impacting the locations and movements of moose across the region, including competing deer populations and the associated brain worm, climate change, heavy tick loads, poaching and habitat fragmentation, consistent with published explanations (for a summary, see Beazley et al. 2006). Many participants commented on the abundance of moose in NB and the dwindling population that persists in NS, with limited explanations as to why moose are not as abundant there. An avid hunter, trapper and past wildlife technician noted that moose “wander from the New Brunswick side, there’s no doubt about it, but they don’t seem to wander very far. Once they hit the Cobequid, along here, they just don’t seem to migrate much further than that” (P22). Participants recognized that there appears to be abundant moose habitat within Nova Scotia, but did not know why moose do not prefer that habitat, stating “I can’t really draw a conclusion if they will [move into Nova Scotia], because if they’re not using it today, what’s going to make them use it tomorrow” (P18), and “I often go into areas and scratch my head, ‘why aren’t there moose here?’ The feed is there. The water is there. Everything is there for a moose, but there’s no moose in the area” (P10).

a)

b)

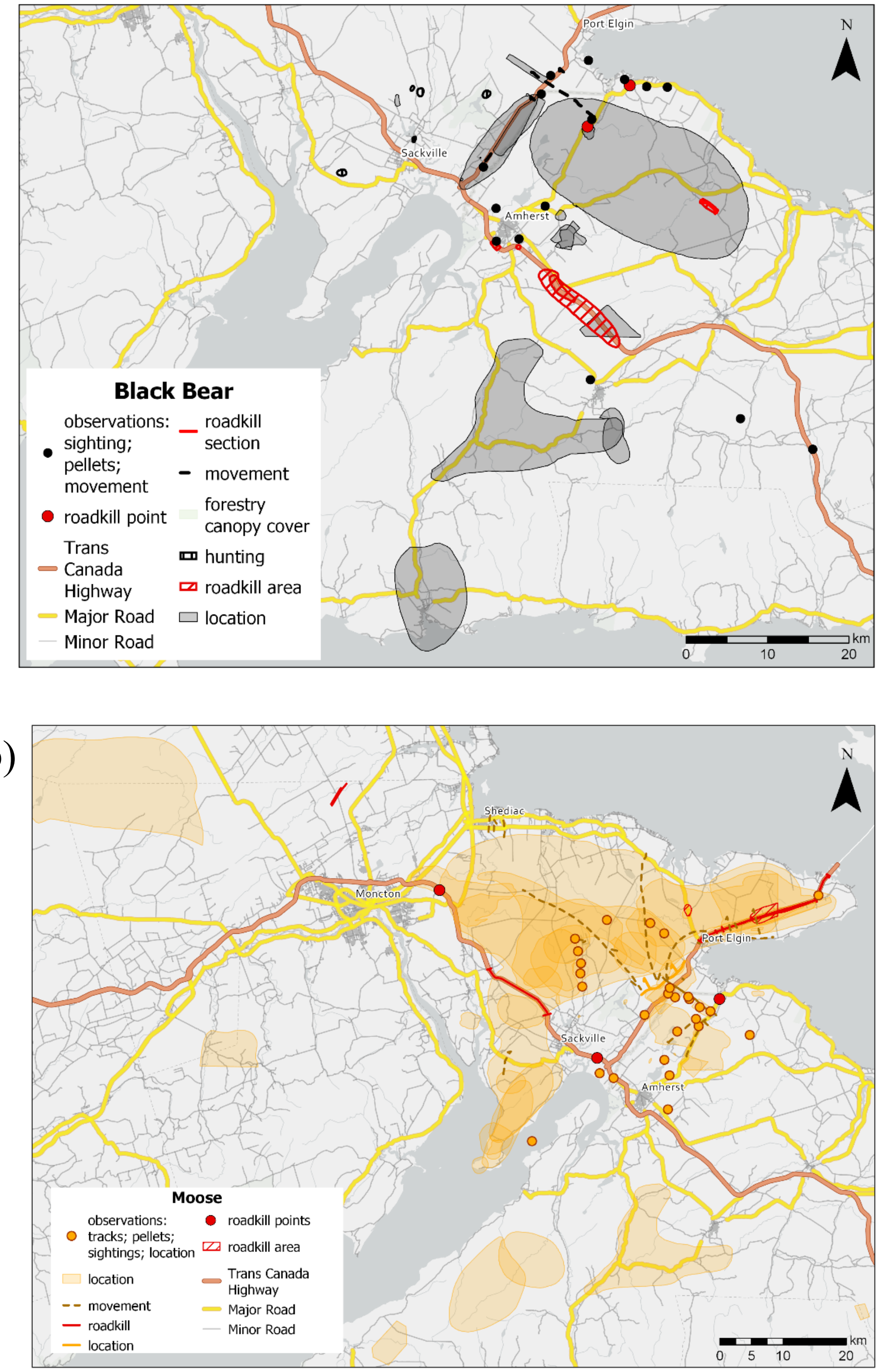

Figure 2.1 Observed and known locations, movement pathways and roadkill areas for (a) black bear and (b) moose collected and compiled from individual participatory mapping data collected in July and August 2019. Road data collected from Government of Nova Scotia Geographic Data Directory (2020) and GeoNB Open Data License catalogue (2020). Basemap provided by ESRI (2020).

There was speculation among participants as to why moose do not seem to persist in Nova Scotia yet remain abundant in New Brunswick. Poaching of moose in NS was raised as a concern by hunter, fisher, and wildlife-technician participants (e.g., P1, 7, 18). Because native moose (*Alces alces americana*) are officially listed as provincially endangered[7], it is illegal to hunt them in mainland Nova Scotia. Hunting for moose is allowed in the province of New Brunswick, with limiting regulations managed by a lottery draw for the ability to hunt them each season and a bag limit of one (Ministry of Natural Resources and Energy Development, 2020). However, illegal hunting was mentioned as a threat to moose moving into or on the Nova Scotia side of the border: "Yeah, all over this area, here, … poaching goes on, … as you get back in the woods. I played golf with this guy three years ago and he said, 'We poach one every year'!" (P7).

Another explanation that participants provided for relatively low numbers of moose in NS is increased temperatures impacting habitat selection, exacerbated by climate change. As a wildlife rehabilitation specialist noted, "they're [moose] starting to move further north, like up into the highlands, because of the temperature changes where there's enough variance that you can still get colder, snowier areas. The moose aren't going to like hotter areas" (P29). This same pattern was observed by hunters, trappers and lifetime farmers who commented on temperature being a large factor and noted that populations of moose tend to persist further north in New Brunswick where it is cooler. Although information specific to the study area is not available to substantiate temperature trends, regional temperatures in the Atlantic provinces are projected to increase by 3-4 degrees Celsius over the next 80 years (Nova Scotia Environment Climate Change Unit, 2005); and, annual average temperatures in Nova Scotia have increased by 0.5°C over the past century (1895-1998) and in 2020 Nova Scotia experienced temperature 1.5 degrees above the baseline average from the 1961-1990 reference value (Nova Scotia Environment Climate Change Unit, 2005;

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[7] The native moose species (*A. alces americana*) in NS was officially listed as provincially endangered in 2003 and remains only in small localized groups distributed across the mainland portion of NS, where hunting of this species has been prohibited since 1981; non-native moose introduced from Alberta in 1948–49 proliferate in Cape Breton Island, NS, where hunting of this introduced species is allowed (i.e., in Victoria County and Inverness County) (Parker 2003; Beazley et al. 2006).

Environment and Climate Change Canada, 2021). Due to latitudinal and ocean influences, temperature changes in the Atlantic region are projected to be relatively moderate; however, even small temperature changes are considered likely to have negative effects on populations of species at the limits of their thermal tolerances, which may be the case with moose in the Chignecto region and the rest of mainland NS (Snaith et al, 2004; Beazley et al. 2006). Loss of mature forest cover adds to heat stress by limiting important opportunities for thermal regulation near forage in both summer and winter (Snaith et al, 2004; Beazley et al. 2006).

Some participants noted some relative changes in species abundance over many years, observed over generally extended temporal time frames spent on the land or hunting and trapping specific species. A common thread was consistency over time in the relatively high abundance of moose in New Brunswick as compared to Nova Scotia. This trend remains evident in current distributions of moose shown in Figure 2.1b, where there is a dense number of moose related data recorded in New Brunswick versus smaller and more sparse pockets recorded in Nova Scotia. Population distributions of moose as identified through local knowledge aligns with studies conducted in Nova Scotia (Parker 2003; Beazley et al. 2006; NSDNR 2007). In the early 2000s it was estimated that there were approximately 1000 moose left in mainland NS, however recent aerial surveys conducted by T. Millette for NS Lands and Forestry has revealed very low numbers of moose, underlying concerns that there are likely far fewer left in the wild than previously thought (McGregor, 2019).

Generally, when participants were asked to consider the 15 focal species that the NCC used to model wildlife corridors, species were reported as present and well dispersed across the Isthmus. Red fox and deer were described as more likely to be found around towns where they were safer from predators and near food sources. Deer and bear were said to be abundant around foraging areas such as farmers' fields and deer wintering areas. In terms of relative declines and increases in abundances, deer and hare were frequently mentioned, noting a cyclical nature based on predatory pressures, hard winters, and food availability rather than a steady trend over the years.

As for the factors affecting species, several key themes arose from the interviews. Participants identified several barriers to wildlife movement across the Chignecto

Isthmus, indicating that while roads provide an obvious physical detriment to movement, factors such as highway speed and forest cover are likely compounding limiting factors. A resounding factor, deeply expressed and agreed throughout, was the relatively fast rate at which the landscape has been changing over the past 30, 10 and as recently as 5 years. Landscape changes were considered to have not only impacted the resilience and abundance of species, but also their ability to move freely between Nova Scotia and New Brunswick. Participants remarked on the proliferation of roads, especially for forestry, which have also facilitated access into natural areas; an increase in extent and intensity of forestry activities, which have diminished old growth forests and converted habitat through frequent clear cutting and herbicide spraying regimes; and noticeable increases in road speed, traffic, and tourism-related travel.

Though anecdotal and relative, these qualitative observations are consistent with landscape changes reported in other studies. Human footprint (HF) scores in the Isthmus are higher than average distributions across the larger Acadian/Northern Appalachian ecoregion, with HF scores of 21-30 (out of 100) assigned to most of the Isthmus and higher HF scores (41-60) in a broad swath dissecting the Isthmus; as such, the Chignecto Isthmus region is classified as 'high threat', defined as 'above average' levels for the entire ecoregion (Woolmer et al 2008; Trombulak et al 2008). In general, many wildlife species are negatively affected by roads (for overviews relevant to the study area see, Fudge et al 2007; Beazley et al. 2004). Moose populations have been shown to be vulnerable to increased hunting pressure near roads, especially illegal hunting; and in NB, 92% of moose killed by hunters occurred within 1 km of forest roads (Boer 1990). Densities for roads and trails across the study region are 'moderate' to 'very high' (Snaith et al. 2004; Beazley et al. 2004) and higher than a suggested threshold (0.6 km/km2) for sustaining mammal populations in naturally functioning landscapes (Forman et al. 1997). Once road effect zones (REZ at 5km) are considered, remnant forest patches are small and fragmented (MacDonald & Clowater, 2005), and median forest patch size is < 5.0 hectares at the ecodistrict level for the portion of the region within Nova Scotia (Cunningham et al. 2020). Forestry practices, including clearcutting and herbicide spraying have been criticized in NS (see Lahey 2018 for an in-depth, independent assessment). Local species declines and the need for attention to such threats are documented in status reports and recovery plans for species at risk, provincially (e.g., Parker 2003; NS DNR 2007) and nationally (e.g., COSEWIC 2018; ECCC 2016), and reflected in the region's designation as one of Canada's Community-Nominated Priority Places for Species at Risk (ECCC, 2019). Accordingly, there is strong agreement between the participants' observations and the small number of potentially corroborating studies available, with the local descriptions infusing rich explanatory insights to the local socio-ecological context.

2.3.2 Patterns in spatial elicitation through participatory mapping

Based on predominant spatial data emerging from the participatory interview mapping, eight thematic maps were produced: 1) avian species presence, movement and roadkill; 2) movement pathways of terrestrial wildlife; 3) point locations, sections and areas of roadkill for terrestrial species; (4-7) location, movement and roadkill; 4) fur bearing species; 5) black bear, 6) moose and 7) deer; and, 8) moose and deer locations, movement patterns and observations (see figures 2.1-2.4). These maps served as the basis of discussion for workshop 1. At the workshop, participants indicated that the locations of species and other mapped spatial knowledges were reflective of what they had indicated in their individual interviews. Although there were instances where participants noted a gap, it was found that the data was included on a map other than the one they were examining. Consequently, the participants neither added nor removed information and requested no refinements to the consolidated, thematic maps, although encouraged to do so. Despite being mapped separately by 34 individuals, participants noted a high degree of agreement in their spatial representations. Accordingly, participants considered group consensus to have been established for the mapped information presented regarding species locations, movement pathways and roadkill areas for moose, deer and black bear and a suite of furbearing mammals. Participants in the two consecutive workshops reported that they were able to see their knowledge, along with the compilation of data from other participants, reflected in the maps, and that this increased their confidence in their knowledge in terms of its veracity and spatial accuracy.

That said, methods varied by which participants used base maps to record their knowledge. The spatial extent of their perceptions of the region, wildlife habitat, movement and barriers varied widely, drawing upon various map scales; 42 individual maps were produced at 1:30 000 (n=11), 1:60 000 (n=18) and 1:170 000 (n=13). Some spoke broadly about general patterns and habitats across large geographical extents at a coarse level of detail, while others conveyed finely detailed knowledge in local vicinities, recording a total of 556 discrete points, lines, and polygons to record their knowledge of 47 different species. Their degrees of confidence varied across scales and background knowledge. Participants often demonstrated a desire to record a precise location, yet if they felt any uncertainty in spatial precision, they hesitated to place a mark on the map. In such cases, we encouraged them to make the mark according to their best judgment while representing uncertainty by a dashed line. Interestingly, when data were later compiled and collectively reviewed during the workshops, it was clear that there was much consensus in the various attributes that had been marked by individual participants, with uncertainty at the individual level overcome at the group level.

Wildlife movement pathways - A total of 129 discrete points, lines and polygons were drawn for 15 different species to indicate movement pathways (Figure 2.2) along with 41 records of roadkill sections (Figure 2.3) along key stretches of road, which also are indicative of wildlife movement within these areas. Pathways were merged in a single map layer to represent composite movements for all species (Figure 2.2). There were differences in ways individuals represented and thought about wildlife movement pathways. Some thought in terms of roads and how species were forced to move either across or along them. Their notations would often indicate an area or section of road where species frequently moved along (n=12) or across (n=34), at times representing places where species would readily cross due to factors such as higher elevation (n=16) (versus low-lying wetlands and coastal marshes) or tree cover on either side of the road. At other times, these represented observations of wildlife crossing the road, wildlife tracks or high numbers of incidences of roadkill in the area. Of note was a 1-km road section along Highway 16 between Aulac and Port Elgin, NB, which is the sole area along that highway with remnant tree cover on both sides. Wildlife, both live and roadkill, were reported to be frequently seen in this location. The surrounding landscape has been cleared for agriculture, housing, and forestry.

Many participants noted that wildlife often travelled along ‘paths of least resistance’. The most frequently mentioned was a natural gas pipeline right of way, which runs

North-West to South-East across the NS-NB border and Highway 16 near Hall's Hill, NB. The pipeline is cleared of brush along its entire route but remains forested on either side and is relatively less frequently bisected by fences and devoid of other human developments as compared with other potential routes. Several participants have observed wildlife and other evidence of travel along this corridor, such as moose and black bear sightings, tracks, and scat. Similar use of human-made routes was noted for moose and black bear in areas where logging roads and other forestry activities have permeated forested regions. Participants often reported that wildlife may be seen travelling along logging roads as they move through an area, and often recorded observations of species sightings or signs (tracks and scat) along these routes when mapping out their spatial knowledge. Some participants reflected that there may be increased observations in these areas due to increased human presence facilitated by road or trail access, consistent with observational or sampling bias often reported in field studies. As one trapper, hunter and fisher said, "I'd see tracks all over where the cuts [clear cuts and logging roads] are. The only reason I would see them there is because those are the places where I have access, where I can get to" (P4).

Others described wildlife movement in a broader context in terms of how species move throughout the region, particularly across the NS-NB border and between suitable areas of habitat for specific species (Figure 2.2). At this broader scale, it was also noted by several participants that the region between Halls Hill and Uniacke Hill along Highway 16 is the highest point of elevation when crossing between the two provinces and provides a natural funnel where terrestrial wildlife is "streamlined" (P3) across the Isthmus. When describing how wildlife move between New Brunswick and Nova Scotia, some participants drew an hourglass shape which captured suitable habitat on either side of the border for terrestrial wildlife but was constricted through a pinch-point in the border region, along this area of higher elevation.

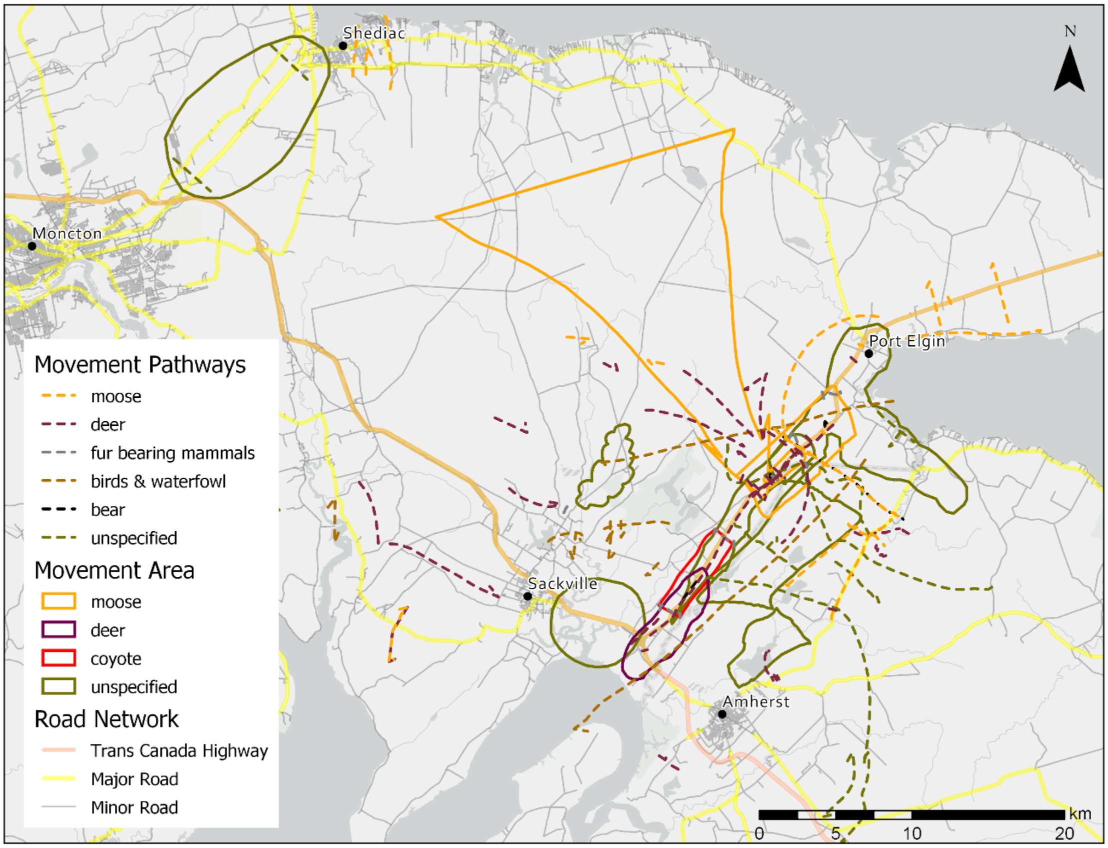

Figure 2.2 *Movement pathways recorded and compiled from individual participatory mapping interview (July and August 2019) identifying areas and pathways for terrestrial and avian species across the Chignecto Isthmus. Road data collected from Government of Nova Scotia Geographic Data Directory (2020) and GeoNB Open Data License catalogue (2020). Basemap provided by ESRI (2020).*

Temporal, daily and seasonal, movement pathways were also indicated, particularly for deer and migratory birds. Wintering areas and deer yards were often delineated, along with areas where deer would frequently graze in agricultural fields and near salt marshes, and spring and fall movement pathways in and out of wintering areas. These pathways often included areas along and across roads where high frequencies of vehicle-deer collisions and deer crossings were reported. Temporal movements were also recorded for migratory birds such as the American Black Duck and Common Eider. In contrast to most patterns, migratory birds were shown as moving across the Isthmus from the Northumberland Strait to the Bay of Fundy (Figure 2.2). Human changes to the landscape were noted as interfering with these daily and migratory flightpaths, acting as barriers to movement. A couple of participants who are hunters and also work in the conservation field identified power lines that stretch across pastures near the High Marsh Road just west of the NS-NB border that birds would strike on their daily flight paths at dusk and dawn. The powerlines were described as so frequently deadly that eagles have begun to perch and wait there to scavenge dead, stunned, or injured prey (P8, P9). The wind turbines located between Sackville NB and Amherst NS were also stressed as a deterrent to movement for bird species and associated fencing as a barrier to other species (P13).

Threats to wildlife habitat and movement - Roadkill in general was frequently mapped during the interviews (Figure 2.3), primarily for deer, moose, and black bear. Moose was noted as a hazard to drivers and most frequently hit in New Brunswick on HWY-16 between Port Elgin and the bridge to Prince Edward Island. This stretch of HWY-16 is notorious for vehicle-wildlife collisions and was highlighted 16 times as a hotspot for moose crossings and roadkill. Several participants indicated the surrounding area as moose habitat, supporting a healthy moose population (Figure 2.1b). Deer movements were also marked along the same highway, but south of the moose hotspot between Port Elgin and Halls Hill (Figure 2.3). Deer roadkill hotspots were also noted along the Tyndal road east of HWY-16 in Nova Scotia and at the Aulac, NB interchange at the start of HWY-16. Black bear roadkill locations were noted along the Tyndal Road in NS; near cottages in Tidnish, NS along the Northumberland Shore; and along the Trans-Canada Highway east of Amherst. The hotspot on the Trans-Canada Highway separates two large black bear habitat areas and populations identified by participants (Figure 2.1a).

Increasing human-wildlife conflicts (Manfredo, 2008), especially pertaining to moose both within the Chignecto Isthmus region and across Canada, can result in varying societal attitudes and values (Messmer, 2000). In New Brunswick where many rural routes and highways pass through moose habitat, there is the potential of increased risk of moose-vehicle collisions which could cause damage to vehicles or have the potential to injure and kill both wildlife and humans. Individual and social characteristics can influence one's risk perception; the evaluation of the probability and consequences of an unwanted outcome or probability of one experiencing the effects of danger (Peters-

Guarin, Mccall, & van Westen, 2012; Sjöberg, Moen, & Rundmo, 2004). Risk perception can be amplified by a mixture of individual, social, and environmental factors combined with perceptions and attitudes influenced by testimonials of extreme events (Manfredo et al, 2009). This may well be the case with the participants in our study. New Brunswick Department of Energy and Resource Development's vehicle-wildlife collision data show 13 records of dead moose on NB routes 15 and 16 from 2013-2018 (Barnes, 2019), and in an eight-week period in May-June 2017, vehicle-moose collisions averaged one per week (Letterick, 2017). Related media and other attention may have fostered a heightened sensitivity to moose-road interactions among our participants, resulting in its prevalence in their reports; however, it is also the case that high rates of vehicle-moose incidents do occur in this area of NB.

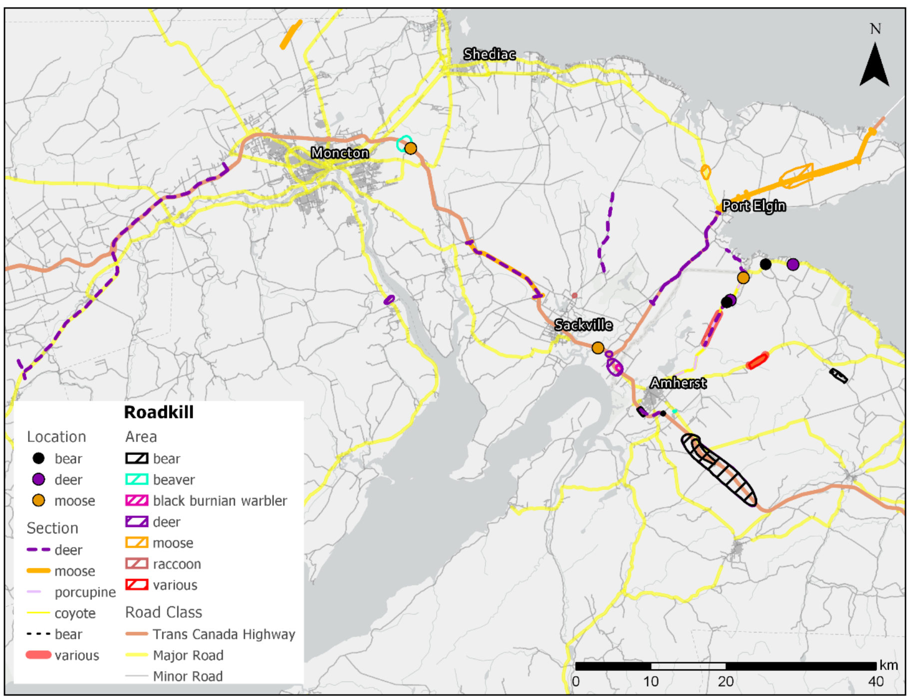

Figure 2.3: Points, lines, and polygons of recorded areas of roadkill for various species, compiled from individual participatory mapping interviews, July, and August 2019. Road data collected from Government of Nova Scotia Geographic Data Directory (2020) and GeoNB Open Data Licence catalogue (2020). Basemap provided by ESRI (2020).

Forestry was another predominant emerging theme that was often discussed and sometimes mapped during the interviews. Except for providing improved forage habitat for black bears, forestry was often discussed with a high level of frustration and concern for the 'devastation' it causes, resulting in a continuously changing landscape across the

Chignecto Isthmus. Although some participants have worked in the industry and privately log wood from their land, there was overwhelming consensus that industrial silvicultural practices have rapidly shifted the landscape and negatively impacted habitat quality and quantity in the region.

> We can go for a drive today and drive up in this area and see moose tracks, but does it represent or have any remnants of what it was like 35 or 40 years ago? Not even close, and it never will. That piece of ground will never be the same. Those things in itself, to me, are changes that are irreversible and are going to represent some sort of adversity to wildlife [referring to swaths of land currently being used for industrial forestry] (P10).

Referred to as "death by a thousand cuts" (P27), the impacts of forestry across the region have "devastated diverse ecology" (P27). What was once a mature, mixed Acadian Forest is now younger plantations of jack pine and balsam fir, creating monocultures which have stripped away wintering areas for deer and feed for moose (P17, P18, P28). Participants criticized such practices, calling the push toward monoculture as 'borealization' due to the focus on specific softwood species, disrupting the balance in Acadian forests (P27, P28).

2.3.3 Comparison with Modeled Wildlife Movement Pathways and Roadkill Hotspots

Local, tacit knowledge maps were overlaid with NCC's high-probability wildlife movement pathways (Nussey &Noseworthy, 2018). This resulted in four additional maps being created and discussed at Workshop 2. Two maps overlaid participatory mapping for moose and bear with outputs from NCC's population patch, breeding patch and least-cost-path models for these species (Figure 2.4a, b). Two other maps overlaid NCC's modelled wildlife movement pathway with participatory mapping of roadkill, habitat, and species occurrence observations (Figure 2.5) and movement patterns for all species (Figure 2.6). Spatial similarities were evident when participants' mapped data were compared to NCC's modelled outputs for both moose and bear (Figure 2.4a, b). The existing protected areas used as 'patches' to be linked in NCC's pathway modelling were also identified by participants as habitat areas for several species, including moose and bear. NCC's modeled suitable habitat and breeding patches were also similar to areas captured by participants' location, habitat, and movement pathway data. A population patch is the minimum area which can sustain a breeding pair for ten years and a breeding patch is the minimum area needed for a breeding pair (Beier, 2006). Nonetheless, the participants also noted other wildlife movement patterns lying outside of the high-probability movement pathway and other areas for species that were not modelled by NCC.

Participants had identified three major hotspots of roadkill across the NS-NB border that also fall within the NCC's modelled high-probability wildlife movement pathway (Figure 2.5). These three major roadkill hotspots were along Rte. 940, and Hwy 16 for deer and the Tyndal Road (Rte. 366) for deer, porcupine, bear, and coyote. These three major roads run parallel to each other and transect areas identified by both participants and the modelled data as an area with an abundance of wildlife movement and habitat location. For the deer population specifically, their species presence was noted in abundance to be concentrated along the NS-NB border in the agricultural belt along Hwy 16 between Point de Bute and Baie Verte as well as in another pocket East of Hwy 940. Deer movement was noted to be heavy between habitat patches alongside HWY 16, with increased roadkill occurring during spring movements from wintering areas. Roadkill hotspots identified through roadside field surveys conducted in the region in 2018 (Barnes 2019; Barnes et al. 2020) revealed overlap with road sections that intersect with NCC's modelled high-probability wildlife movement pathway. Some of these overlapping areas are also consistent with movement and roadkill observations indicated by participants including areas highlighted along Rte. 366 and Hwy 16 (Figure 2.5). Most of the species' movements mapped by participants converge into a major pinch-point across the border, as in NCC's model (Figure 2.6). There was group consensus that their compiled spatial data bore strong similarities to the modelled outputs, with no outliers or glaring differences to address between the two sources of information. The NCC's modelled pathways aimed to include optimized landscape conditions and minimize movement costs for the suite of species considered, including bear and moose, which participants also mapped. The similarity in patterns seems to suggest that the participants and the modelers have consistent understandings of the conditions favorable to these species and where they occur on the landscape. It likely also reflects the somewhat limited options for wildlife in making their way through the region.

The conversation transitioned to possible factors as to why the observed trends were occurring, particularly pertaining to the types of landscape changes impacting wildlife. Once again, forestry impacts dominated the conversation (i.e., excessive clearcutting, use of herbicides and logging roads). Participants reported increasing human access into once remote spaces through the development of access roads without restrictions on recreational users. Concerns were also raised about increased highway and road traffic in general, which they attributed in part to increased tourism. Little regard for speed limits by many drivers on some of the highways was noted, with participants recommending better outreach and mitigation in terms of signage to raise awareness of high vehicle-wildlife collision risk. Overall, landscape changes were considered the major driver of wildlife locations and movement patterns, most often as direct limiting factors and barriers, but also including indirect effects such as related to increased disease and ticks.

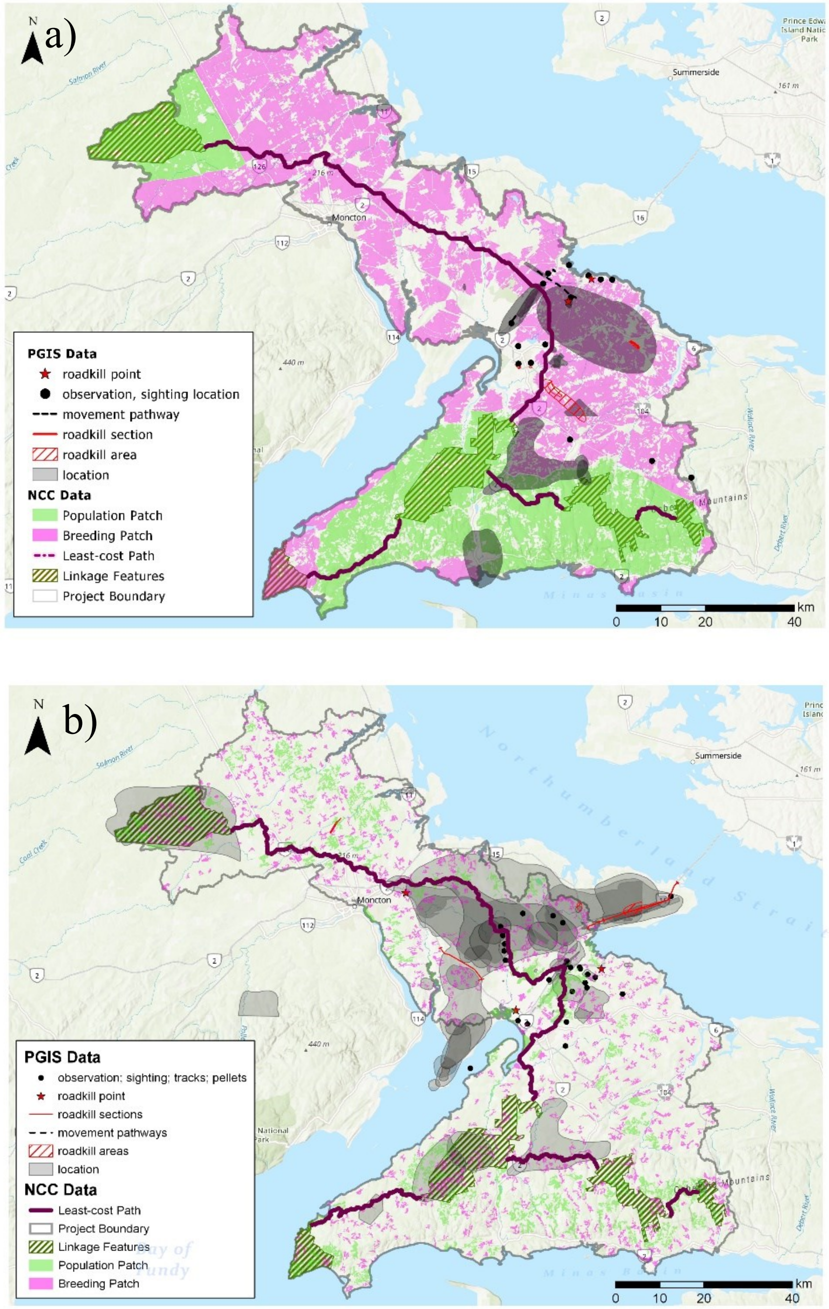

Figure 2.4: NCC modelled connectivity data (Nussey & Noseworthy, 2018) overlaid with participatory GIS data for (a) black bear and (b) moose.

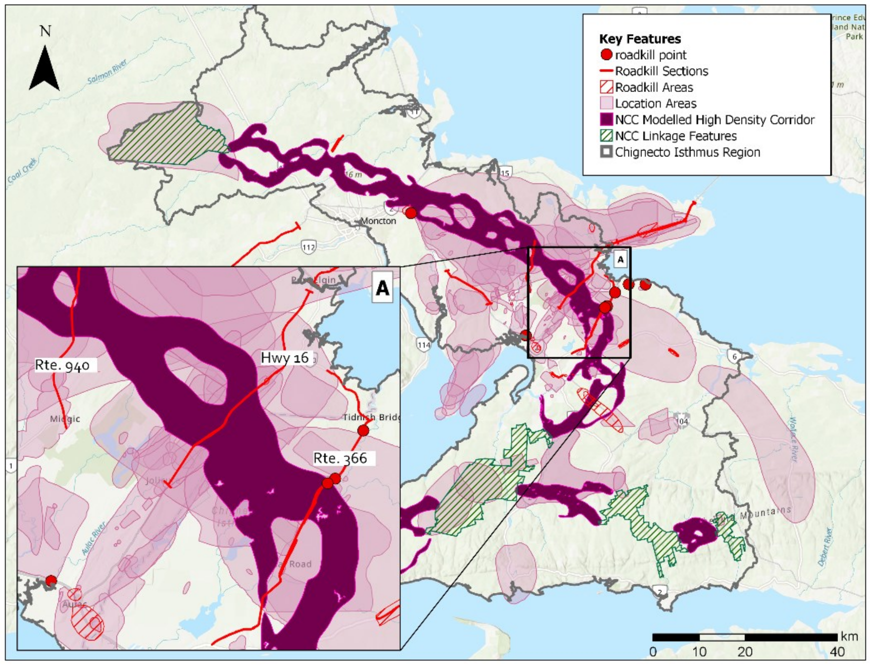

Figure 2.5 Species location and roadkill data for all species mapped and compiled from individual interviews (July and August 2019) overlaid with NCC's modelled high-probability wildlife movement pathway. Inset A highlights the 5-km wide pinch point along the NS-NB border identified in the NCC report (Nussey & Noseworthy, 2018).

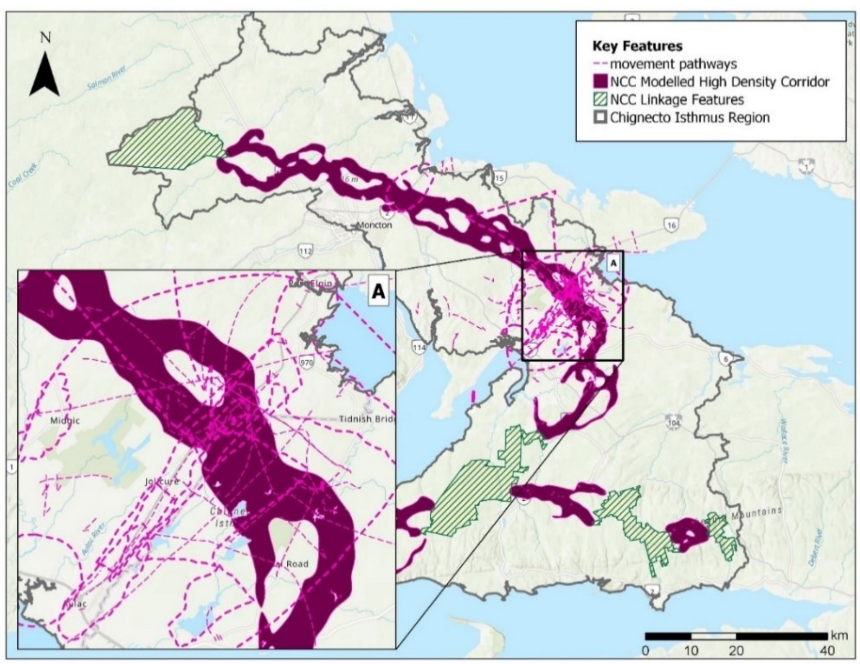

Figure 2.6 Movement pathway data for all species mapped and compiled from individual interviews (July and August 2019_ overlaid with NCC's modelled high-probability wildlife movement pathway . Inset A highlights the 5-km wide pinch point along the NS-NB border identified by participants and in the NCC report (Nussey & Noseworthy, 2018).

2.3.4 Emergent themes

Species of conservation concern - Participants agreed that moose are of conservation concern in NS, though plentiful in NB, and bear are increasing everywhere. Participants were relatively silent on other species, though concerned about general declines in wildlife. Less clear, though a recurrent theme in conversations, was the question of whether deer are a nuisance or a species of conservation importance. A total of 126 points, lines and polygons were mapped during individual interviews to indicate habitat, locations, movement, and roadkill for deer. While some viewed deer as pests who yard in their pastures and feed off their crops, in some cases these same participants also talked about deer in a positive light, indicating a complex relationship. Others simply enjoyed the sight of deer on their property and the opportunity to photograph them. Regardless, deer were talked about widely across all participants, who perceived the species as having the potential to shed light on key landscape changes and habitat fragmentation in the area. As noted by a local wildlife biologist, "…not that deer are endangered. That is not to say they're not important [….] It [deer] became a symbol of the corridor and the deer told that story. I don't know if you'd call it a keystone species, […] but I think it's a good indicator of why that corridor is important" (P15).

Participants also spoke to interactions between deer and moose, recognizing them as 'competing' species, and further, that they cannot inhabit the same space due to the detrimental impacts of a 'brain worm' on moose, which is a parasite (*P. tenuis*) carried by deer but deadly to moose (for a description, see Beazley et al., 2006). The participants acknowledged that deer and moose have different habitat requirements and that landscape changes from agriculture, forestry, roads, and other activities have favored deer and caused incursions into or overlaps with moose territory. At the same time, however, several noted that forestry activities also negatively impact deer, such as by interrupting their ability to move through areas or find suitable habitat and feed. As such, many saw deer as an indicator of the severity of the adverse impacts of landscape change and current forestry management practices for other, more sensitive species (P2, P4, P10, P20). These perceptions are consistent with those reported for these species more generally in Nova Scotia and elsewhere (see, for example, Snaith and Beazley, 2004b; Snaith et al., 2004; Beazley et al., 2006; Parker, 2003; Lahey, 2018).

Species and ecological interrelationships - References to ‘totality’ and interconnections were prevalent among participants, who acknowledged that ecological systems are intricate and complex, and therefore you cannot focus on one component alone. For example, “So, in terms of the Isthmus—in terms of the ecological things you can think about—it is so important, eh? … [J]ust the … different species, and so on” (P3); and,

> [I]f you get anybody out and then try to have a connection—let them have a connection and see that—what connects to what, like that salamander connects to that—it doesn't matter how big a snake, … anything. It all starts down here. You know, moss and the grass and then, you know, like, you gotta look at the whole picture (P27).

Participants recognized that wildlife, resource management systems and social interactions do not act independently and are intricately connected in the landscape. Such observations are reflective of systems thinking (Davis & Stroink, 2016) and social-ecological systems (SES) frameworks (Kittinger et al., 2013; Ostrom, 2009a), in which humans are intertwined with their environment. They situate the wildlife patterns within the complex social-ecological systems of the region, enriching existing data and models. During an interview, one participant, a wildlife rehabilitation technician, remarked, “[F]ew biologists will sit down and look at these issues in their totality, […] and that’s what a project like this can do, is bring some clarity to those kinds of issues” (P29). Recognizing what the project can do—situating formal data within broader local tacit knowledges to bring context, clarity and utility to decision-making—is consistent with social-ecological-systems thinking, as is its representation through participatory mapping (Karimi et al., 2015). The value of the larger story and inclusive knowledge mobilization was acknowledged by participants, such as in stating that “the problem is we have a lot of environmental groups and activists out there that don’t know what the story is…. So, what you’re doing is telling the story” (P29).

Participants are not naïve about the social-ecological complexities of the situation, however, and noted challenges associated with the geographical extent of the Chignecto Isthmus, recognizing it encompasses multiple jurisdictions. Not only do ecosystems vary across the region, but so do institutional mandates, policies and social relations, creating problems for conservation governance, as pointed out by Wyborn & Bixler (2013). The scale of the challenge, especially when considering the role of human values and pragmatic factors inherent to decision making, is recognized by participants:

> I mean, it's a massive undertaking. It's so complex and distanced from the realities in nature. The arguments, like, should we stop spraying the forests to protect the deer, when in both instances they're both invasive issues? […] We're no longer making choices of environmental stability; we're making choices of preferences over things that will make it (P29).

Adding to the complexity and urgency of the situation are uncertainties and measures needed to adapt to sea-level rise in this mostly low-lying, coastal region, both for wildlife and human infrastructure.

Sea-level rise- At the outset, our study assumed sea-level rise as a 'given', rather than as a research question. Accordingly, we did not ask participants specifically about the effects of sea-level rise. Regardless, several participants spoke about 'water' levels being an impediment to wildlife movements due to the large extent of wetlands and marshes and many streams and undulating coastline in the area. At least one participant fully recognized the effects of climate change and sea level rise on movement pathways, associating it with the funneling effect on wildlife movement visible in Fig. 2.2.

> And it's also the highest point of land on this size of the Isthmus. This is 350-foot elevation, and that's kind of important for looking at climate change and, you know, sea-level increases. Because, essentially, that elevation works like this: the elevations go from here, up through the top of this area here, which is the ridge—Jolicure. So, this is the highway, and this is all, of course, relatively low, compared to sea level, here. So that kind of constitutes an important movement area, especially with the climate change stuff happening (P 27).

The ridge of higher elevation traversing the Isthmus was recognized as an important movement pathway for animals; participants recognized it as a safe passageway for animals who could not make their way through boggy or wet areas. Although not all participants linked it to sea-level rise, some went on to elaborate that part of the change on the Isthmus was associated with water levels and that these water levels affected not only human activity but also influenced animal movements and wildlife populations (influencing decline of some species while others became ‘overpopulated’). The importance of the higher elevation area for movements was linked with seasonal effects on wet areas at lower elevations. Observations associated most wildlife movements with the higher ridge of elevation, while recognizing that wetter areas are used in the winter when the water and land is frozen, facilitating traverse over firmer terrain: "… [T]here's seasonal travel through this wet area, …. Yeah, that would be of concern to some species. And once you get up to here [inland], I know there's a rise in elevation, there's more forest" (P12). Terrestrial ungulates (i.e., deer and moose) were reported to move through water on occasion but only in areas with adjacent habitat for landing and shelter. Participants widely noted the negative influences of forestry practices on cover habitat and associated this loss of habitat with influencing movement not only in the obvious ways (e.g., cutting out that forest, fragmenting landscape etc.) but also by no longer providing landing sites for possible movements through water, which may be further exacerbated by rising water levels in the region.

> There's definitely a seasonal component, actually, to the animal movement through here, in my opinion. I hear—people would tell me stories when I was doing the wind farm bird surveys, they were telling me that—this is a long time ago, probably in the 1960s—they had this moose going out to the, to the water and swimming over here to this peninsula. And they, they saw it.... But I don't think it's happening today. P12

Other participants also recognized that changing water levels, particularly deeper levels, pose movement challenges for particular species (i.e., deer, bear, coyote, small mammals). Deeper water is recognized as a direct barrier to movement: "They [deer] could cross over [but] it's pretty deep water so they're not likely going across here because of that barrier” (P8). Some observed increases in siltation and how this has influenced water levels in the region, especially pertaining to rivers and the Bay of Fundy. Participants noted fish populations and movements as being affected by receding waterlines and muddied shorelines. Impediments to deer movements along shorelines of rivers to cool off and to access food and water were also noted as of concern, with muddied shorelines affecting their ability to walk.

> Into the Bay of Fundy. This is a tremendous change here, over the last 4 or 5 years.… I go down there every year …. [W]e used to walk the shore. Can't walk the

> shore anymore. There's a tremendous influx of silt, here, and the only open water now is over by the fields on this side…. On this side, this is all silted in. There's a tremendous amount of silt here, and that's 4, 5 years.... We suspect—my friend and I—that it's come down the Petitcodiac River after they opened the causeway. Yeah, and there was a lot of silt accumulated there.… [T]here's a tremendous, tremendous change there. That's probably going to be good for the shorebirds but it's just muck. You can't walk. It [deer] would be a fool to walk on it. But, uh, it's changed tremendously. (P1)

One participant spoke directly to the tenuous circumstance provided by the prevalence of water, recognizing the importance of the land bridge and associated infrastructure such as dykes to maintain terrestrial connections through the Isthmus, for both social and ecological reasons.

> Yeah, without it, Nova Scotia would become an island…. [T]here are big parts of the Isthmus that are protected by dykes; and, uh, if the dykes fail or the dykes are breached, Nova Scotia will very quickly run out of what they consume and buy in the store. The railway, the rail line, is right across the Isthmus, and all the roads go across the Isthmus …. So, the only connection NS would have to the rest of us in the case of breached dykes would be by air! But also, there's some very interesting wetlands up through the Isthmus. The Chignecto, … the Missaguash River, and all the complex of lakes and so on. The Isthmus is—it's an interesting canoe ride, to go from … Point de Bute… to Hall's Hill. (P5)

Observations like this recognize that sea-level rise presents an important current and future context for wildlife in the region. Local knowledge observations are consistent with studies showing that sea levels are rising, storm surges and flood events are increasing, and the land is subsiding due to post glaciation isostatic rebound (Webster et al., 2012; Shaw et al., 1998, 2010; Greenberg et al., 2012). As such, the already narrow land connection between Nova Scotia and the remainder of North America region is predicted to be much narrower, and in instances of storm surges, potentially severed completely, as has occurred at times in the past. Although our intention was not to address this issue explicitly, participants raised it nonetheless. It supports the rationale for generating local insights on current wildlife populations, locations, and movement pathways within the context of larger social-ecological contexts, to provide more inclusive knowledge systems as baseline data for various conservation and other planning responses to sea-level rise in the region.

2.4 Discussion

Knowledge creation such as in this study is important for conservation planning, particularly for connectivity conservation across broad landscapes of complex social-ecological systems. The use of local tacit knowledge and participatory mapping represents rich contribution to help develop a unique and robust data set for conservation planning, research and decision making. Using participatory research combined with geospatial technologies has provided a method to generate local tacit knowledge and represent its spatial components within a GIS to enrich and address current gaps and limitations in formal, natural science data and models. The contributed local knowledge provides insights into historical and current distributions, abundance and status of wildlife populations in the region, similar to findings elsewhere in Nova Scotia (Cosham et al., 2016). The engagement of knowledgeable community members was effective for eliciting and incorporating social and ecological knowledge. As observed by a renowned farmer and naturalist in the region during the second workshop, the dataset that we have been able to create through the collaboration of a diverse group of local knowledge holders is probably the best available data for illustrating trends and patterns for this region (P5). There was overwhelming support and buy-in for the participatory process we used to collaborate with local knowledge holders. The process incorporated a bottom-up approach, allowing for local participation, consensus building and the inclusion of local knowledge in the research.

The multi-directional learning relationships facilitated through our approach has led to increased awareness among participants about wildlife locations, populations, habitats and movements and threats to their persistence within the region. It has fostered and enhanced participants' interest and investment in conservation priorities across the Isthmus, providing a spatial focus for conserving key areas. Each participant created spatially referenced maps representing their lived, individual experience by employing overlay drawing onto topographic maps. Together they identified areas of combined experiences, noting strong, validating consensus, and thereby gaining confidence in their knowledge and its potential use in decision making processes. Not only did the methods serve to elicit spatial data, but the maps served as a method to facilitate conservation knowledge sharing throughout the interviews and workshops. Participatory mapping has been commonly used to create 'sketch maps' for such purposes (Boschmann & Cubbon, 2014; Chingombe et al., 2015; Dunn, 2007). Our use of maps increased participant involvement during the interviews and workshops by providing an anchor for the dialogue to revolve around, furthering conversations, and stimulating memories through the process, as was found by Boschmann and Cubbon (2014). Participatory GIS methods such as ours have been identified as serving to democratize research and planning processes (Barnett et al., 2016; Brandt et al., 2019; Canevari-Luzardo et al., 2017; Cutts et al., 2011) and build consensus between stakeholders and land use managers (Chung et al., 2019; Irvine et al., 2009). Knowledge exchange plays a key role in conservation management by facilitating the social, environmental and economic impacts of research (Cvitanovic et al., 2015, 2016). Not only is knowledge exchange critical to research during knowledge production and disseminating phases, but also during mobilization and translation for policy, planning and decision making.

Inclusive knowledge systems and participatory mapping approaches such as those applied in this study can help to guide knowledge production and contribute to novel solutions to conservation challenges at the intersection of human and natural systems, consistent with findings in environmental management in general (Brown et al. 2010; Berkes et al., 2016; Fry 2001; Revers et al. 2010; Virapongse et al., 2016). Significant work has been done in the realm of participatory GIS to operationalize concepts that bring social-ecological systems into spatial mapping frameworks (Karimi et al., 2015), and our study contributes to the field. Conservation planning approaches recognize the need to embrace local knowledge along with formal science data and models and to utilizing participatory methods to not only increase local participation, but to improve the validity of knowledge across spatial scales (Raymond et al., 2010a). A critical step to overcoming barriers to knowledge exchange is improving access to information to allow the coproduction of knowledge for use by decision-makers (Cvitanovic et al., 2015). Research such as ours facilitates local knowledge exchange and provides the opportunity to contribute to evidence-based decision-making in the region, responding within a timeline that can directly impact conservation planning, as urged by Lemieux, Groulx, Bocking, & Beechey (2018).

Local engagement and findings generated through our study are timely for supporting on-going work of NCC and partners in the NS-NB Community-Nominated Priority Place (ECCC, 2019), national efforts through the Pathway to Canada Target 1 Connectivity Working Group (Canada Parks Council, no date), the New England Governors and Eastern Canadian Premiers' Resolution 40-3[8] Working Group (NEG-ECP, 2016), and the joint NS-NB and federal feasibility study on infrastructural adaptations to climate change (Smith, 2020), among others. Opportunities to put this information into the hands of the decision-makers and have the voices of key local people from across the region included within the decision-making process have been heightened through the research. The relationship between knowledge and decision making has become increasingly important in scientific literature recognizing that there needs to be a convergence of disciplines in order to properly address complex environmental management problems (Cvitanovic et al., 2015). Several contributions of the conservation social sciences, as outlined by Bennet et al. (2017), are highlighted throughout our research including facilitated learning of conservation challenges and the innovation of novel models for conservation through engagement of local knowledge holders. Our methods represent a generative effort to better enable and improve conservation data, models, and planning. Such applications are vital to guiding processes with the best available and robust set of information (Bennett et al., 2017).

Collaborative approaches have been recommended to help improve evidence-based decision-making, and this extends to conservation planning. Often, however, there is a disconnect between research and planning for conservation. To address the disconnect, research should match the evidence needs for conservation priorities (Lemieux et al., 2018). Our research comes at a timely manner to address current concerns in the Chignecto Isthmus region surrounding climate change, biodiversity conservation and infrastructural adaptations such as those to be addressed in the feasibility study on the transportation corridor. Sea-level rise poses a heightened predicament for the tenuous

[8] Resolution on Ecological Connectivity, Adaptation to Climate Change and Biodiversity Conservation

land bridge provided to people and wildlife through the Chignecto Isthmus. The threats of climate change highlight the need to think proactively about conserving and restoring wildlife habitat connectivity through this restricted land base, especially in light of current projects aiming to identify ‘engineering solutions’ to safeguard and adapt highway and other human infrastructure and other associated land-use pressures. Adaptations are likely to entail in-land relocation of some infrastructure, to higher elevations, and raised levels of others in place, such as roads and dykes, to remain above water in flood events and coastal inundation scenarios. Such adaptations are likely to further fragment habitat and restrict wildlife movement. On the other hand, engineered solutions, if planned with wildlife in mind, may provide heightened opportunities to mitigate barrier effects and other threats that infrastructure such as roads and wind farms currently pose to wildlife populations, habitat, and movements.

Many known socio-ecological issues occur with human-wildlife interactions. Within the Chignecto landscape it is important to identify key wildlife conservation features (populations, habitat, and movement patterns) so that they may be considered in conservation planning and infrastructural adaptation studies. Local knowledge has been shown to improve understanding of species distributions and impacting environmental factors, especially where up-to-date shifts in these trends are required but are not currently captured in scientific data (Anadon et al., 2009; Austin et al., 2009; Cosham et al., 2016). While not only complementing but addressing gaps in the scientific literature, local ecological knowledge has successfully identified potential infiltration, distribution and migration of species within their study regions and offers highly valuable, tacit knowledge for both wildlife and fisheries resource management (Austin et al., 2009; Silvano & Begossi, 2010). In the case where timely conservation management decisions are required in regards to endangered, threatened and invasive species, local ecological knowledge can and has provided relevant and current information where scientific data is not regularly updated or available (Austin et al., 2009; Cosham et al., 2016).

While scientific data and models can reveal high-probability wildlife movement pathways or barriers to movement through the region, underlying factors as to what may be attributing to these spatial patterns can sometimes be left to speculation. Model outputs such as maps are limited by the accuracy, relevance and completeness of the data and are influenced by the optimization rules that drive the analysis. Such model outputs are powerful tools, yet they largely remain out of context of the complex social-ecological systems. Local tacit knowledge can help to explain the underlying 'why' of certain phenomenon in a region: what external and acting factors are directly impacting wildlife movement pathways, pinch-point locations, roadkill hotspots and other phenomena? The local knowledge generated through this study therefore not only contributes to a more robust dataset but provides additional explanatory context for the patterns and changes. In the Chignecto Isthmus, for example, NCC's model detected land-cover types and roads based on the best available georeferenced spatial data and projected habitat suitability and potential wildlife movement pathways based on these data. Local participants enriched and complemented these data, expanding upon the impacts of landscape changes on wildlife, such as due to forestry practices, road access and traffic, water levels and siltation, as well as human activities such as poaching and wildlife interactions, such as between moose and deer. Local knowledge also effectively reflected accelerated changes. One participant (P29) noted and another (P30) concurred that since moving to the Chignecto Isthmus,

> [W]e have really been recognizing just how important this area is because of animal movement, thinking how much small little sections of land are responsible for having to move so much land-based animals, and when you think of the type of traffic that's happening here …, the amount of change that we've seen in terms of development and car usage, it's insane (P29).

Our findings provide cross-validated information for delineating priority wildlife habitat and connecting corridors within the Chignecto Isthmus. The process has fostered a diverse base of local champions for wildlife conservation. The next step is to disseminate and mobilize the findings to inform future decision making for conservation planning and land and resource management in the region for a long-term outcome of enhanced human-wildlife co-existence.

2.4.1 Limitations

Some limitations exist when using local knowledge in this study (Brown & Kyttä, 2018; Corbett et al., 2006; McCall, 2006). There were moments when participants were hesitant to draw on the base maps in fear that the spatial data they would provide wouldn't be the exact location or area, or that they may be remembering certain events wrong. Shifting Baseline Syndrome, a concept coined to explain knowledge extinction, occurs when the knowledge of the past is lost and the human perception of biological systems changes (Loftus & Anthony, 2018). As such the analysis may be limited by the accuracy and reliability of shared information. On the other hand, there was strong group consensus among the local participants and good agreement with NCC's formal science model. Future research will integrate the local knowledge data with other data, such as species occurrences (AC-CDC, 2020) and roadkill hotspots (Barnes, 2019) to reduce uncertainty and enhance complementarity.

As the livelihoods of many of the participants are linked to their knowledge of the land for hunting, trapping, farming, and logging, the data could be seen as inherently biased. This may lead certain participants to talk more about a species than another. For example, a wildlife photographer enjoyed photographing black bears and much of the data represented areas where black bears may be spotted. As such, there is potential over-representation of certain species due to factors also recognized by Loftus & Anthony (2018): personal preferences for certain species; strategic choices in locations of travel; and, the ease of seeing or noticing a species. When interpreting results for wildlife planning and management, it is important to take into account that the species and habitats are directly connected to the hobbies and livelihoods of the participants.

There are some limitations to using participatory methods to gather local, spatial data (Corbett et al., 2006; McCall, 2006; Brown & Kyttä, 2018). Fuzzy boundaries are prevalent throughout the data and it was sometimes difficult to discern class boundaries between mapped spatial phenomenon. Inaccuracies in the spatial data collected may result in inaccurate definition of classes and assignment of phenomena to a class, which may raise uncertainties about the precision of the data and ultimately impact decision making (Corbett et al., 2006; ESRI, 2016). How participatory data represents participants' and researchers' interpretations of certainty and ambiguity is important: fuzzy data should not be misrepresented as being precise and accurate (Corbett et al., 2006). Spatial reality in participatory GIS is always fuzzy, and the accuracy and precision of data collected through participatory mapping methods when drawing on maps will also be impacted by factors such as scale and resolution (McCall, 2006). How to represent and interpret fuzziness was an important concept to frame for this study. A series of decision-making steps and guidelines were followed consistently when choosing how to classify points, lines, and polygons of mapped data into their categorical bins for mapping and representing spatial knowledge. Of course, this interpretation is unique to the classifier of data, using their best ability to accurately represent each participant's individual data.

In studies such as ours that engage relatively small numbers of participants in in-depth and qualitative explorations, questions may be raised about the representativeness of the sample and the generalizability and validity of the results. In our study, 34 participants with deep long-term experience of the region's land and wildlife shared their knowledge through interviews and participatory mapping. Eight of these individuals participated in two subsequent half-day mapping workshops. These participants likely represent a relatively large proportion of our target population—those with deep experiential knowledge of the land and wildlife—in this rural area: nearing the end of our recruitment phase, no additional referrals were emerging from our purposive, snowball sampling method. Near the end of the interviews, no new data were being contributed, which suggests that data saturation was reached. As a qualitative study, we were not aiming for statistically significant results or findings that may be stratified or generalized to the broader public. As such we are confident that the number of participants was sufficient to generate consensus-based insights about local knowledge on the subject. Although the participants represent a relatively small portion of the general public, their voices could potentially be disproportionately influential due to their knowledge base and locally recognized expertise. Now that they are more aware and confident in their insights as a consequence of participating in our research process, they are likely better positioned to influence local people and communities and related planning around wildlife, habitat, and connectivity conservation in the region.

2.4.2 Future research

While our study did not focus on assessing landscape changes due to climate change and related sea-level rise, some participants spoke to 'water' levels and temperature increases as potential reasons for wildlife declines and impediments to movements. Comprehensive studies assessing changes in water levels, temperatures and associated impacts on habitats and ecological corridors in the region do not exist. Similarly, impacts of forest clearcutting and forest roads on wildlife presence and movement pathways have not been assessed in the region, though many participants highlighted such relationships as a central concern, as did an independent review of forestry practices in NS (Lahey 2018). Quantitative data on landscape changes, irrespective of cause, similarly are not readily available nor to our knowledge have they been previously assessed at this scale. It is certain that the clearing of forests and construction of roads and dykes over the 400 or so years since Euro-American settlement have dramatically affected landscapes in ways that are important to wildlife, yet these have not been quantified in the region. In a petition to the colonial government in 1853, however, Mi'kmaw leaders expressed their concern with widespread changes throughout Mi'kma'ki:

> The woods have been cut down; the moose and the caribou, the beaver, and the bear, and all the other animals, have in most places nearly disappeared …. So that is it (sic) now utterly impossible for us to on Obtain a livelihood in the way our creator trained us[9] (Paul et al., 1932, as cited in Allan [2000, p. 111] as cited in Prosper et al. [2011, p. 9]).

To our knowledge, roads and dykes have not often or recently been 'relocated', per se, as a result of sea-level rise. Such complex inter-relationships and impacts warrant further analyses and some may well comprise portions of the 'engineering solutions' study currently being conducted in the region. In the meantime, our findings serve to enrich the socio-ecological baseline data (while pointing out important gaps) so that future planning for road, dykes or other infrastructural relocation may avoid ecologically important lands, specifically those that are important to wildlife and connectivity.

More proximately, the next steps in our study aim to further develop inclusive knowledge systems and their engagement in conservation efforts. Local participatory data will be combined with additional formal science spatial data sets, such as element occurrence records for key wildlife species compiled by the Atlantic Canada Conservation Data Centre; identified roadkill hotspots; forestry cover and roads; and model outputs of inundation from sea-level rise. Forthcoming insights gained through our on-going qualitative, thematic text analyses of participant interview and workshop

[9] (Petition of Francis Paul, Gorman Paul, Louis Paul and others to Queen Victoria, 14 December 1853, C0127/213.ff.8-25,@19, PANS m/f 13, 1932 in Allen 2000, p. 111, as cited in Prosper et al. p. 9).

transcripts will be incorporated and shared. Improved understanding about how efforts such as ours that engage local knowledge can lead to local knowledge holders' support for conservation decisions that emerge from the knowledge sharing process would be beneficial. Important questions also remain about how efforts to engage local knowledge can lead those knowledge holders to further contribute to and participate in conservation efforts. In collaboration with participants, NCC and other partners, we will seek opportunities for engaging, disseminating, and mobilizing the knowledges gathered through these processes for conservation planning initiatives in the region. Importantly, we will explore opportunities to build relationships and work with the Mi'kmaw peoples, who have lived, deeply immersed, within regional ecologies of reciprocal sharing interrelationships for 15,000 years (Young 2016, 2018). Their title, rights, laws, governance systems, responsibilities, stories, and ceremonies need to be honoured, and their insights would greatly benefit us all (Artelle et al. 2019; Young 2016; Zurba et al. 2019). As signatories to the Treaties of Peace and Friendship (1725–1779) between the Mi'kmaq and Canada, we are all Treaty people (NS Archives, 2020).

2.5 CONCLUSIONS

The Chignecto Isthmus is a critical land bridge between NS and continental North America, providing connectivity for wildlife populations and human infrastructure. Coastal inundation and flooding due to rising sea level and storm-induced tidal surges threaten this already tenuous connection. Existing wildlife data from formal science sources are limited and insufficient for use in regional conservation planning or on-going studies exploring 'engineering solutions' for safeguarding and adapting human infrastructure. Accordingly, our study aimed to generate complementary data based on local tacit knowledge, while enhancing local understanding and capacity for engagement in these local planning processes. To do so, we engaged local people with strong experiential knowledge of the land and wildlife in the region to participate map-based interviews and workshops. Thirty-four local hunters, trappers, loggers, farmers, naturalists, and others with strong tacit knowledge participated in individual interviews with map-based spatial elicitation tools to identify key areas of wildlife habitat and movement pathways across the Chignecto Isthmus. Individual mapped data were digitised, analysed, and compiled into a thematic series of maps, which were refined by subgroups of 8-12 of the participants through consensus-based workshop processes.

Locations of key populations and movement patterns for several species were mapped, consisting predominantly of terrestrial mammals, primarily moose, black bear, and white-tailed deer, along with a group of other fur-bearing mammals and migratory birds. Strong consistency was observed among the mapped elements, resulting in group consensus despite some uncertainty expressed by individuals about their precision in noting the exact locations. When comparing local tacit-knowledge-based maps with those derived from formal natural science data and models, a strong overlap was apparent. Not only did the local participants verify the formal data and model, but they highlighted areas and concerns outside of the model and their explanations lent complex social-ecological context to its mapped outputs. Further, their engagement in the process resulted in knowledge transfer within the group and increased confidence in their experiential knowledge and its value for decision making. The process also increased their support and buy-in for mobilization of the results for wildlife conservation and connectivity planning, particularly for addressing revealed threats to connectivity from forestry practices (clearcutting and herbicide spraying), roads, power lines, wind-energy farms, and increased water intrusion and flooding.

As such, our study has generated spatial and other wildlife data representative of consensus in local tacit knowledge relevant to wildlife connectivity and other conservation planning in the Isthmus region. The process represents a contribution to conservation planning methodologies, in which combinations of scientific data and local tacit knowledge are critically needed, both to provide reliable and locally supported information for planning and to open up the research and planning process to different ways of knowing and to local communities, in the spirit of inclusive knowledge systems. The findings are relevant to on-going decision-making processes and represent important wildlife information for incorporation into local planning initiatives, addressing gaps in existing formal science data and lending validity to the outputs of computer-based modeling of wildlife habitat and movement pathways. The consistency of data obtained from these local people represents an important outcome that demonstrates and supports calls for greater generation and mobilizing of local knowledge in the scholarly fields of conservation planning and participatory mapping.

Our findings contribute to the growing yet nascent body of literature at the intersection of conservation planning and participatory mapping as means of co-production of knowledge and inclusive knowledge systems. Importantly, it also accesses, generates, and makes available local tacit knowledge for conservation planning in practice, particularly for wildlife connectivity in a key linkage area identified as critical at local, national, and international scales. The findings enrich and complement data from formal natural science models, helping to address their gaps and limitations while providing important explanatory context. At the same time, our participatory mapping approach served to build local participants' confidence in their combined experiential knowledge and local support for conservation. It seems to have enhanced our participants capacity to serve as local champions for infusing local perspectives of wildlife and other ecological and social values that warrant consideration in conservation and other planning initiatives, such as for human infrastructural adaptations to climate change. Our study demonstrates a way to help build a more inclusive knowledge system grounded in the people and place. It illustrates an effective approach for representing differences and consensus among participants' spatial indications of wildlife and habitat. It presents a means of co-producing knowledge in participatory mapping for conservation planning. Engagement of local people and their tacit, experiential knowledge of the land and its wildlife provides important insights and means to enrich natural science and foster conservation action for connectivity and human-wildlife co-existence, both of which are key to addressing the twin crises of precipitous biodiversity loss and climate change.

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Chapter 3: Combining Wildlife-Occurrence Data and Local-Experiential Sources of Roadkill Knowledge to Identify Opportunities and Barriers for Wildlife Movement in the Chignecto Isthmus Region

3.1 Introduction

Participatory mapping, or participatory GIS (PGIS), can be used to develop a better understanding of a people and place by creating georeferenced composite maps of people's contributed knowledge of the local environment (Ioki et al., 2019). Geographic information systems (GIS) have the power to combine spatial information from both expert and locally derived data, producing a series of maps that can explore spatial patterns and facilitate information exchange (Ioki et al., 2019). The use of geospatial tools and participatory mapping helps to increase our understanding of the relationships between the physical world and people (Dracott, Trimble, & Jollineau, 2019). Developing this understanding is particularly useful for determining priority areas and areas of conflict for conservation objectives (Dracott et al., 2019).

Participatory mapping approaches utilize location-specific human values, observations, and perceptions, often towards understanding phenomenon related to land use planning and management (Fagerholm et al., 2021), including for conservation purposes (Brown et al., 2015; Fox et al., 2006; Needham et al., 2020; Sieber, 2006). These approaches can help bridge the gap between science and local knowledge by representing diversity and abundance of values, by analyzing spatially referenced data, and allowing for knowledge co-production between local knowledge holders and researchers (Fagerholm et al., 2021; Pédarros, Coetzee, Fritz, & Guerbois, 2020). Furthermore, engaging local knowledge holders through participatory mapping methods can help identify spatial aspects of social and ecological issues, and this combination of local knowledge with spatial information can lead to more effective land-use planning (Cheung et al., 2016; Ioki et al., 2019).

Proposed methodological frameworks for analyzing participatory mapping data in research suggest three analytical phases for the use in land management and planning: (1) *explore*, (2) *explain*, and (3) *predict/model* (Fagerholm et al., 2021). Goals in the *explore* phase seek to explore local knowledge by visualizing spatial patterns and assessing data quality (Fagerholm et al., 2021). In the second chapter of this thesis, our study worked towards this first analytical phase, exploring participatory mapping and local knowledge applications to identify wildlife locations, movement patterns, and connectivity across the Chignecto Isthmus region. This work provided critical insights that complement natural science research in the region while building more inclusive knowledge systems that support connectivity planning (Needham, Beazley, & Papuga, 2020).

Key themes from the *explore* phase of our participatory mapping study revealed several patterns across the landscape, broadly addressing aspects of wildlife connectivity through the Chignecto Isthmus. The mapped data highlighted barriers and opportunities to wildlife movement across the Chignecto Isthmus and found that local knowledge strongly correlates with modeled data for the region, specifically where it identified several key pinch points to connectivity (Needham et al., 2020; Nussey & Noseworthy, 2018). A section of the participatory mapping interviews explored this relationship between wildlife and roads (Appendix A). Questions regarding the impacts of roads were targeted to gain a better understanding of their possible impacts on wildlife in the region and trends or patterns that may be observed by locals that might not be easily picked up through other types of research. Additionally, questions regarding roads asked participants about possible strategies they felt would help reduce wildlife mortality and make roads safer for both humans and wildlife, which allowed us to explore knowledge holders' perspectives for the potential of mitigation strategies in the region. Critical issues which were highlighted and consistently mapped across participants included barriers (e.g., forestry, roads/roadkill, developed areas) and opportunities for movement (e.g., higher elevation regions, key movement corridors, critical habitat for connectivity) (Needham et al., 2020). This initial exploration created a robust baseline from which we could begin to further analyze and explain the data in the next analytical phase.

The next phase in the framework is *to explain*. The *explain* phase seeks to identify spatial patterns that emerge through visual and overlay analyses among mapped features from multiple datasets (Fagerholm et al., 2021). This chapter aims to deepen our understanding of the relationship between participatory GIS, which was revealed in Chapter 2, alongside other geospatial data sources by incorporating occurrence data from field-based surveys and reports of roadkill derived from previous research and monitoring in the region. Previous to our work in the Chignecto Isthmus region, Barnes (2019) examined multiple lines of evidence of wildlife-road interactions to predict where the movement was occurring across the landscape using systematic roadside surveys, vehicle-wildlife collision reports, and trail camera images. This work helped to ground truth or verify a high-probability wildlife movement corridor modeled by NCC (Noseworthy and Nussey 2018) and to identify areas within and beyond the corridor in which to investigate further potential opportunities to improve connectivity and wildlife movement in these locations (Barnes, 2019).

However, roadkill hotspot analyses—areas where there are high mortalities of wildlife along sections of road—based on data from roadside surveys typically fail to include considerations such as species population suppression, road avoidance, and the surrounding habitat when determining areas for improving connectivity and facilitating wildlife crossings (Barnes, 2019; Litvaitis & Tash, 2008; Profile, 2015). Barnes' work and provincial wildlife-vehicle collision reports provide robust data for determining keys areas where wildlife are moving and come into conflict with assessed roads across a portion of the Chignecto Isthmus. A deeper analysis and comparison to local knowledge helps to further explain and identify movement patterns, barriers, and opportunities in this and other areas across the region, addressing critical considerations needed for assessing priority areas for connectivity conservation. Furthermore, the implementation of previous work into our current research builds upon the knowledge in the region to develop a richer picture of patterns while helping to ground-truth and validate results from both sets of studies. Consideration of diverse forms of knowledge may also prove helpful in identifying feasible methods for mitigating barriers and safeguarding or enhancing opportunities for wildlife movement in key areas. The analyses presented in this chapter explain some key movement patterns and explore potential planning and management options associated with them as revealed through local knowledge considered alongside natural-science-based studies.

3.2 Methods

Participatory GIS data collected and assessed as described in Chapter 2 were used in this analysis for an overlay comparison with results from (i) Barnes' (2019) assessment of roadkill based on roadside survey data and (ii) *Provincial Vehicle-Wildlife Collision Report* data from NS and NB, within the Chignecto Isthmus study area. Local knowledge and spatial data from Chapter 2 include thematically mapped data representing (i) roadkill points, road sections, and concentrated observations, (ii) areas of forestry and other activities that limit or influence wildlife movement, and (iii) concentrated movement patterns such as corridors and pinch points.

3.2.1 Overlay Analysis of Local Knowledge with Roadkill Hotspots Based on Roadside Survey Data

Raw data and methods from Barnes (2019) were used for overlay comparison with local knowledge to determine where there may be similarities and differences between local knowledge and on the ground, roadside surveys of roadkill in the Chignecto Isthmus. Barnes (2019) recorded vertebrate mortalities, excluding domestic species and livestock, along 12 road segments that intersect with NCC's modelled high-probability wildlife movement pathway (Nussey and Noseworthy 2018). To conduct the overlay analysis, I selected Barnes' roadkill hotspot results that were generated from data that had removed birds, amphibians, reptiles, raccoons, and small mammals (i.e., mass less than 1 kg.). Consistent with Barnes' rationale, removal of small-bodied mammal and raccoon occurrences from the data makes sense, as it was noted that these species might skew results, and none were species of conservation or human safety concern (Barnes, 2019). The isolation of mammal-only data was considered appropriate for my overlap analysis, as all shared local knowledge (except for one data point) on road crossings and roadkill were for mammals. Barnes (2019) used this subset of roadkill data within Siriema Road Mortality Software V. 2.0 (2014) to conduct a 2D HotSpot Identification analysis. She conducted an analysis for each of the 12 roads selected in her study to evaluate the spatial distribution of roadkill events within a 90% confidence limit at a 1000-m search radius, as recommended by Coelho, Coelho, & Teixeira (2014). The outputs indicate roadkill aggregation intensity for road segments along each of the roads. For further details on the analysis, please refer to Barnes (2019). Throughout this study, road sections where there are significant aggregations of wildlife mortality at the upper 90% confidence limit will be referred to as hotspots.

I overlaid the results from Barnes' hotspot analysis with the local knowledge generated from participants' delineations. Similarities and differences between the results were identified through visual examination. To compare these roadkill results with other wildlife movement patterns, they were then overlaid with (i) local knowledge of movement concentrations and pinch points and (ii) NCC's modelled high-probability wildlife movement pathway across the Chignecto Isthmus.

3.2.2 Overlay Analysis of Local Knowledge with Provincial Vehicle-Wildlife Collision Report Data

I collected and analysed roadkill data from *provincial vehicle-wildlife collision reports* for areas of NS and NB located within the study area. Roadkill data were obtained over nine years (2011-2019) for Wildlife Management Zone 25 in NB (NBDERD, 2020) and for Cumberland County, NS (NSDLF, 2021). Together, these cover the extent of the Chignecto Isthmus study area. Roadkill data were only reported and obtained for three large mammal species: deer, moose, and black bear. Data points that excluded accurate GPS locations or with incomplete information were removed from the data sets. All remaining points were mapped in ArcGIS to determine where overlap occurred with (i) mapped participant data and (ii) roads surveyed by Barnes. Any roads highlighted through participatory mapping or surveyed for roadkill were extracted from the reported vehicle-wildlife collision data for analysis of hotspot occurrences. Six roads were selected for comparison, including three roads in NS (Hwy. 2, Rte. 366, and Rte. 6) and three roads in NB (Hwy 104, Hwy 16, and Hwy 15). Highway 104 (NS) and Highway 2 (NB) form the Trans-Canada Highway, which transverses the Chignecto Isthmus.

Following Barnes (2019), I analysed the roadkill data for each of the six roads in Siriema Road Mortality software; a 2D K Ripley statistic within a 90% confidence limit was used to determine the spatial distribution of events along each road segment, followed by a 2D HotSpot Identification analysis to determine the presence of hotspots using a 1000-m search radius. The resulting hotspots were then overlaid with local knowledge to compare similarities and differences between results derived from local knowledge and those from *Provincial Vehicle-Wildlife Collision Reports* across the Chignecto Isthmus region.

3.2.3 Identifying ways to mitigate barriers and enhancing opportunities for wildlife movement in key areas

Additional visual analysis was conducted to examine spatially mapped data regarding forestry concerns in the Chignecto Isthmus which local knowledge holders included in the participatory mapping process. These locations were then overlain with current protected and conserved areas (CPCAD, 2020), the NCC's modelled high-probability wildlife movement pathway, and wildlife movement pathways and pinch points mapped from local knowledge. This was used in tandem with a qualitative textual analysis from interview data to identify concerns expressed by participants for conservation measures across the region. Support for and concerns with potential conservation efforts and mitigation measures were identified through this qualitative analysis to complement mapped spatial data of local knowledge holders.

3.3 Results

3.3.1 Local Knowledge Overlay with Barnes (2019) Roadkill Survey Data

Of the 12 roads surveyed by Barnes (2019), participants identified six roads as areas of roadkill concern in the Chignecto Isthmus. Participants mapped their observations of roadkill (points) and sections/areas where they have noticed increased roadkill or hotspots for roadkill where species frequently cross and move through the region (points, lines, and polygons). These six overlapping roads include Rte. 940 and Hwy 16 on the New Brunswick side, and Rte. 366, Rte. 6, Hwy 204, and Hwy 104 in NS (Figure 3.1). Participants also identified areas of roadkill concern that extended beyond roads surveyed in Barnes' work, which were limited to roads that transect the NCC modeled movement corridor (Nussey & Noseworthy, 2018). Roads that Barnes did not survey but participants identified as areas of concern included sections along the Trans-Canada highway in New Brunswick and northern sections of Highway 16. Five roads identified through roadkill surveys with significant wildlife mortality aggregations that did not overlap with local knowledge occurred further away from the central NS/NB border region, including Rte. 134, Hwy 15, and Rte. 933 in New Brunswick, and Rte. 2 and Rte. 302 in NS.

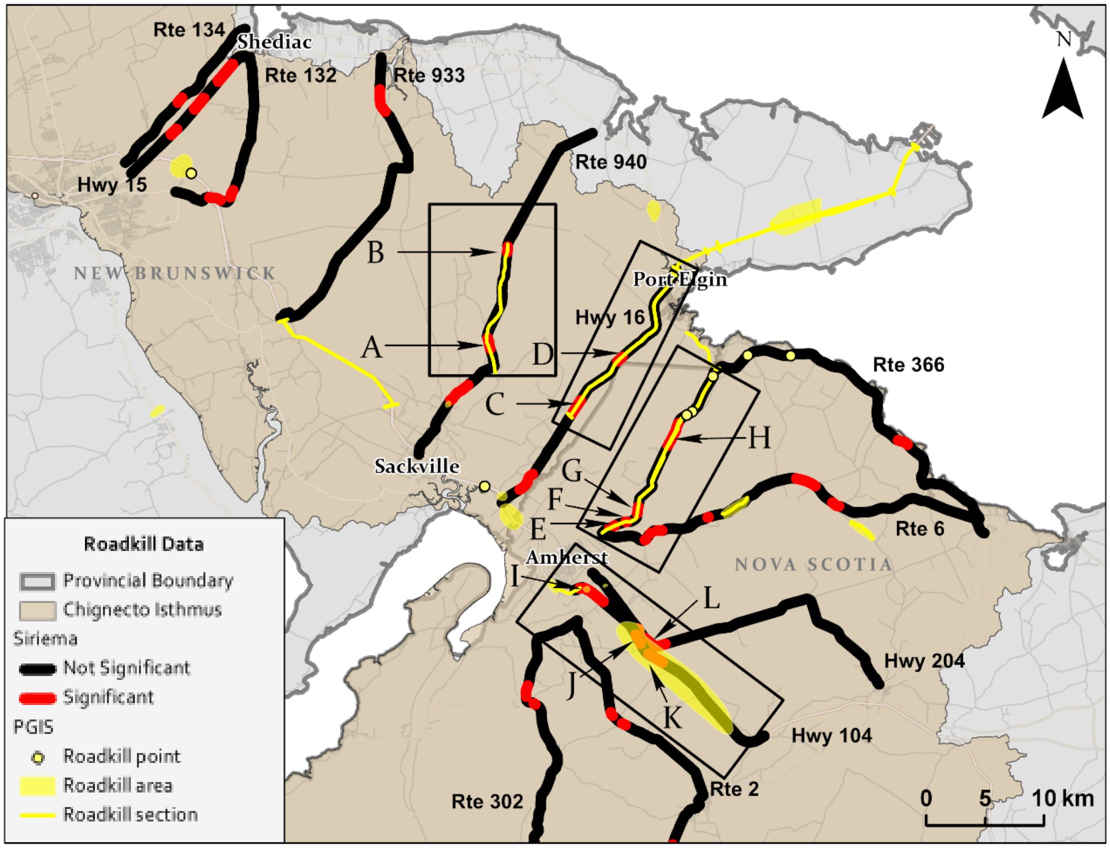

Figure 3.1: Results from Barnes' (2019) Siriema 2D HotSpot Identification analysis showing significant aggregations of wildlife mortality (red) overlaid with local knowledge of roadkill observations (yellow) indicated as points, lines, and polygons in the Chignecto Isthmus. Black boxes highlight road segments with hotspots for both local knowledge and Siriema results. Letters identify specific areas where overlap occurs between identified hotspots, which correspond with letters in Figure 3.2.

Among the six roads for which results overlapped, 12 road sections (Figures 3.1 & 3.2, A-L) along five roads (Rte. 940, Hwy. 16, Rte. 366, Hwy 104, and Hwy. 204) identified by participants as areas of concern were found to directly overlap with roadkill hotspots identified in Barnes' analysis of roadside survey data. Areas in yellow highlight roadkill hotspots identified through local knowledge; and areas in red highlight hotspot segments along roads where aggregations of wildlife mortality occur based on roadkill survey data.

1. NB Route 940 was identified by participants as a hotspot for deer crossings, with increased crossings and roadkill observed during migration seasons when deer are moving to their wintering areas (Figure 3.2 A-B). These areas overlap with two

hotspots identified through roadkill surveys; however, Barnes recorded no roadkill deer occurrences, perhaps because the survey was conducted outside of winter migration season; nine occurrences were noted, consisting of porcupine (4), skunk (3), and snowshoe hare (2). No significant aggregations occurred along this route at the 1000-m scale used for the 2D HotSpot Identification analysis. No significant aggregations suggests that along this road segment at our chosen scale and confidence limit, there are sections along the road that have higher mortality than others (Coelho et al., 2014). This is the only route in our study to not show significant aggregations at the 1000-m scale.

2. Highway 16 (Figure 3.2 C-D), which transects the Isthmus in NB near the border with NS, contained three hotspots identified through the roadside survey data. Two of these overlapped with sections identified by participants as roadkill hotspots for deer. As with Route 940, Barnes recorded no roadkill deer occurrences, noting 21 observations that included porcupine (11), skunk (5), snowshoe hare (2), muskrat (1), and woodchuck (1).
3. NS Route 366 (Figure 3.2 E-H) showed overlap between local knowledge and roadkill survey data. Local knowledge identified multiple areas of crossings and roadkill concern for all species with increased emphasis on coyote and porcupine (Figure 3.2 E-F) and deer (Figure H). Barnes' roadside survey data did not report coyote but included 22 observations in total, consisting of porcupine (12) and deer (1), along with snowshoe hare (4), skunk (4), and red fox (1).
4. Participants identified roadkill hotspots for various species along the NS section of the Trans-Canada Highway 104 (Figure 3.2, I-K), with one section (Fig 3.2, I) being of considerable concern for black bear and deer, both of which were reported as frequently moving across this section of road. Barnes' roadside survey data recorded 28 observations, including black bear (3) and deer (3), as well as porcupine (14), beaver (2), mink (1), skunk (1), snowshoe hare (1), and unknown (3).

5. NS Route 204 contained an area where participants noted high vehicular speeds that often impact deer and bear that overlapped with another significant aggregation of wildlife mortality from roadside survey data (Fig 3.2, L). Barnes reported no roadkill deer or bear occurrences during the roadside surveys but made 8 observations of porcupine (5), skunk (1), and unknown (2).

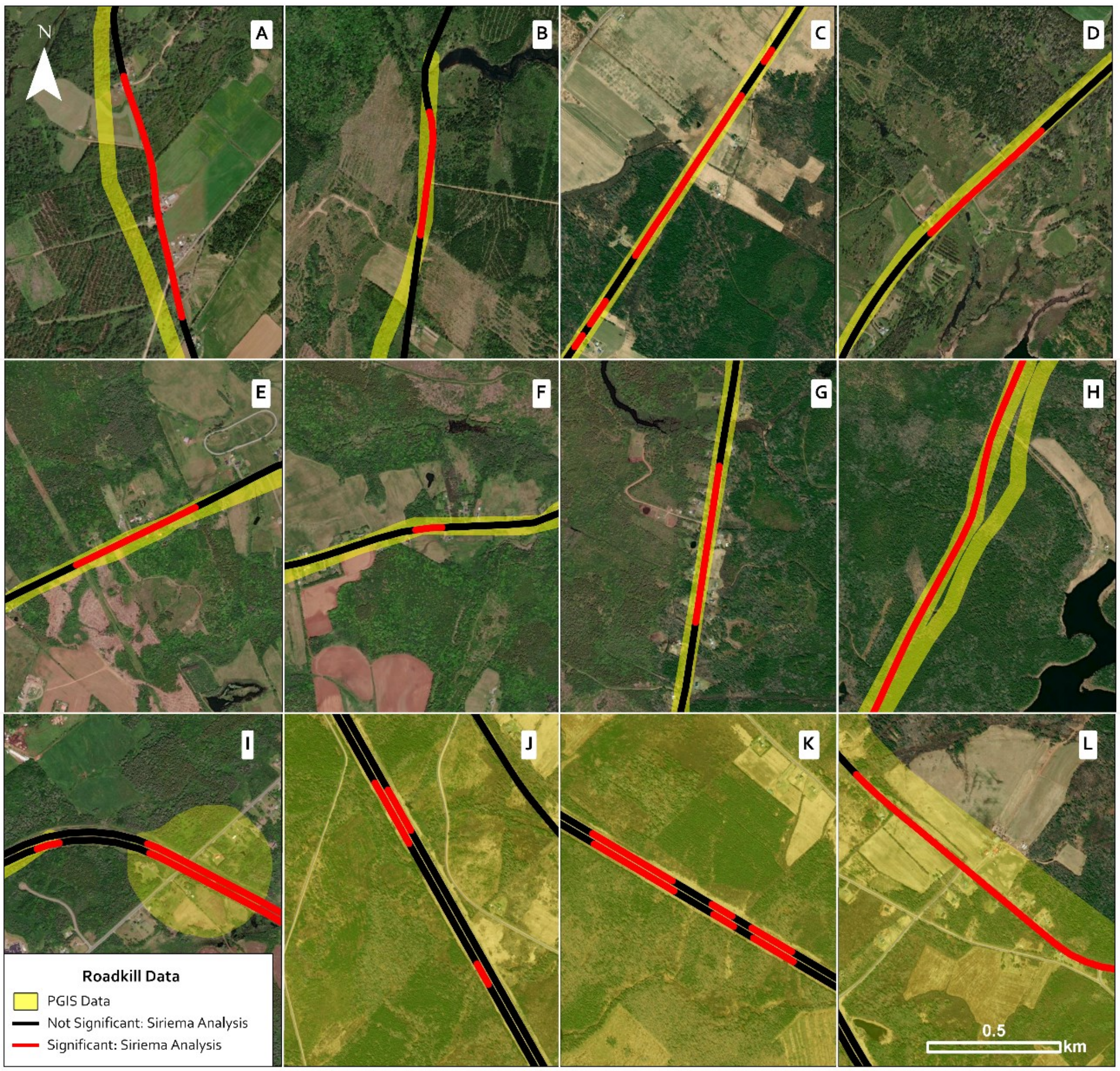

Figure 3.2: Siriema 2D Hotspot Analysis showing significant aggregations of wildlife mortality overlaid with local knowledge data of roadkill observations and hotspots over Aerial Imagery (ESRI,2017). (A-B) Route 940, (C-D) Highway 16, (E-H) Route 366, (I-K) Highway 104, (L) Route 204. Letters (A-L) correspond with Figure 3.1 above which show locations of these road segments within the Chignecto Isthmus.

3.3.2 Local Knowledge Overlay with Barnes (2019) Roadkill Survey Data and NCC's Modelled Wildlife Movement Pathway

Local knowledge of roadkill locations and wildlife movements and results of Barnes (2019) HotSpot Identification analysis from the roadkill survey data were overlaid with NCC's modelled high-probability wildlife movement pathway across the Chignecto Isthmus (Figure 3.3). Local knowledge identified roadkill points, sections, and areas along roads (yellow), wildlife movement corridors (grey), and movement pinch points (orange). Hotspots of wildlife mortality from Barnes (2019) roadkill survey data are visible in areas of red on black segments of road tracks. NCC's high probability movement corridor shows modeled areas of low-high probability wildlife movement using cool-warm colors. Sections of the corridor where bright red colours occur indicate pinch points along the modelled corridor for wildlife movement. An interesting area of overlap occurs across all three datasets along both Hwy 16 and Route 366, which are major roads that transect the Chignecto Isthmus. Sections of these two roads intersect and border a significant pinch point for species movement identified within NCC's modeled pathway. There is also overlap along sections of Hwy 204 and Hwy 104. Features which overlap include sections of NCC's modelled pathway where a high probability pinch point for wildlife movement occurs, areas identified through local knowledge as sections of road with increased road kills and road crossings, and roadkill hotspots from roadside survey data.

As found in Chapter 2, participants mapped wildlife movement patterns across the region, including crucial corridors (grey) and pinch points (orange) (Figure 3.3). Participants identified corridors as areas where there were increased frequencies of species movement. These areas were identified due to their topographic features such as landcover and elevation, which facilitated species movement across the landscape. Pinch points were identified as areas where species movements were restricted through a narrow area due to landform or land cover or use. These areas were marked by two lines (orange) between which species were forced to move. Participants identified two such pinch points: one across Hwy 15 and Rte. 134, and another across Hwy 16, all in NB.

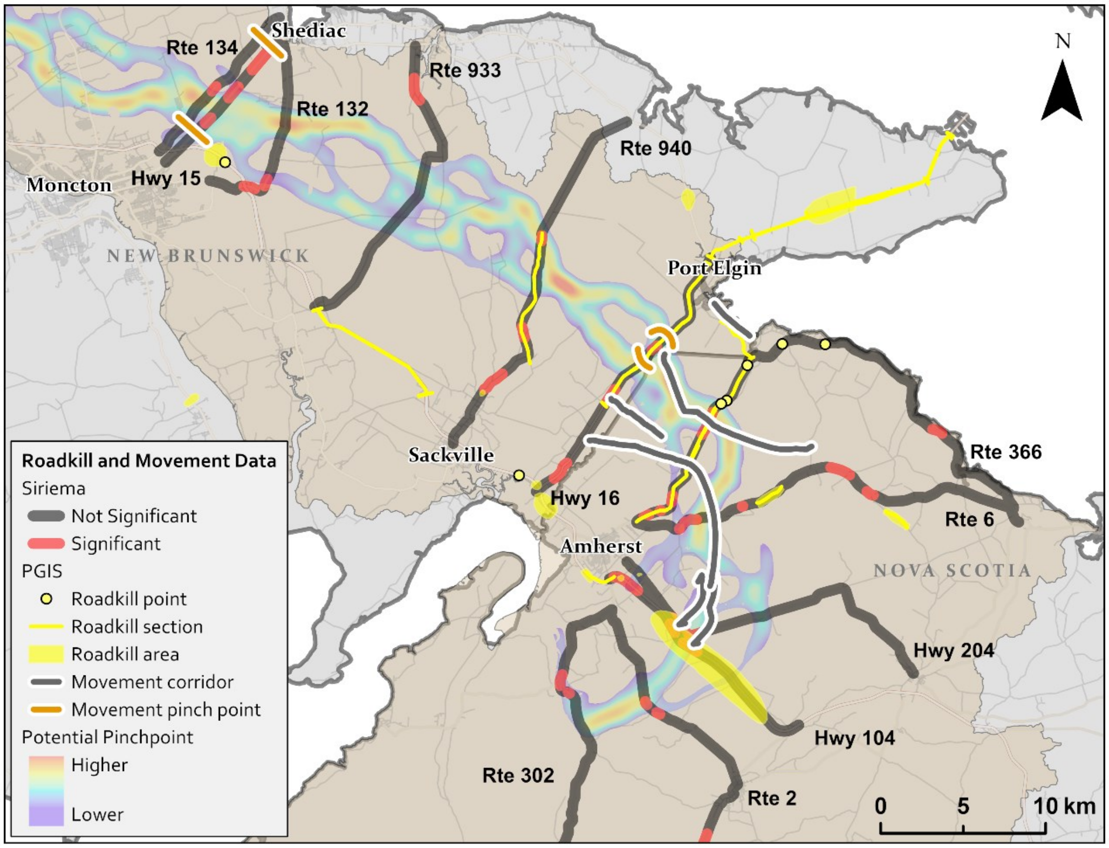

Figure 3.3: Local knowledge data indicating wildlife movement corridors, pinch points, and roadkill locations, overlaid with NCC's high probability movement corridor, and hotspots of roadkill identified from Barnes' (2019) roadside survey data.

Participatory mapping also identified wildlife movement along three corridors between Hwy 16 and Hwy 104, (i) one of which extends from Hwy 16 to Rte. 6; and (ii) one between Hwy 16 and Hwy 104, crossing Rte. 6 and Hwy 204 along the way. These corridors were marked by participants as 'funnels' for wildlife movement through the region and in places align with the NCC's modeled high probability movement pathway for species across the region. The corridors also intersect with major routes and highways participants identified as having significant mortality aggregations. Along the NS/NB border, mapped corridors from local knowledge indicate that movement occurred more frequently between and within the grey lines indicating a movement corridor in Figure 3.3. This movement corridor runs across the centre of the NS/NB border, overlapping with the NCC's high-probability movement corridor where they have identified a major pinch point for movement at the border region. Participants noted that this region is ideal for terrestrial wildlife movement as it is an area of increased elevation with forested land cover. Southwest of this identified corridor, participants indicated that prevalent bogs and salt marshes may be treacherous for terrestrial species to move through; therefore, movement is less frequent.

3.3.3 Provincial Vehicle-Wildlife Collision Report Data

Participants also identified areas of concern regarding roadkill and wildlife movement along roads which fell outside the study area used in both NCC's and Barnes' studies. To further compare results derived from the participants' data to other forms of data available for the broader Chignecto Isthmus region, provincial vehicle-wildlife collision reports were collected and analysed.

Data compiled from the provincial vehicle-wildlife collision reports show that a total of 312 data points were recorded in Cumberland County, NS, for moose, bear, and deer collisions between 2011 and 2019 (Table 1). Deer comprised the most significant portion of records in NS, at 83.4% (260) of the data points, with moose being reported only 2.2% (7) of the time, and bear at 14.4% (45). Alternatively, 983 records were obtained for NB Wildlife Management Zone 25. Deer similarly comprised most data records in NB at 77.8% (765), with more frequent collisions reported for moose (18.1%; 178) in NB than in NS.

Table 3.1: Vehicle-wildlife collision report data for deer, moose, and black bear for Wildlife Management Zone 25 (NB) and Cumberland County (NS) for the years 2011-2019.

NS		**NB**	
Species	**Count (%)**	**Species**	**Count (%)**
Deer	260 (83)	Deer	765 (78)
Moose	7 (2)	Moose	178 (18)
Bear	45 (15)	Bear	40 (4)
Total	312	**Total**	983

There were six road segments with reported vehicle-wildlife collisions from the provincial reports which also overlapped with participant data. Roads included Hwy 16, Hwy. 2, and Hwy 15 in NB, and Hwy 104, 366, and 6 in NS (Table 2). There were only 34 records of vehicle-wildlife incidents for the three road segments in NS, none of which reported any moose-vehicle collisions between 2011 and 2019. Of these 34 records for the three overlapping road segments in NS, deer comprised most record points at 85.2%, with black bear comprising the remanding 14.7% of data points. Of the three overlapping road segments in NB, there were 357 recorded data points, with deer also comprising most records at 71.1%. Reported moose-vehicle collisions made up 22.7% of the records, and black bear comprised 6.2%. Highest counts for all three species in total were on Hwy 16, Hwy 2, and Hwy 15, all in NB (n=138, 117 and 102, respectively).

Table 3.2: Reported vehicle-wildlife collision counts for deer, moose, and black bear between 2011-2019 for road segments which overlapped with local knowledge data and roadkill survey data

Road Name	**Road Length (km)**	**Species Count (%)**			
NB Road Segments		**Deer**	**Moose**	**Bear**	**Total**
Hwy 16	51.9	89 *(65)*	45 *(33)*	4 *(2)*	**138**
Hwy 2	247	86 *(73)*	16 *(14)*	15 *(13)*	**117**
Hwy 15	68.7	79 *(77)*	20 *(20)*	3 *(3)*	**102**
NS Road Segments		**Deer**	**Moose**	**Bear**	**Total**
Rte. 366	47.9	5 *(71)*	0 *(0.0)*	2 *(29)*	**7**
Hwy 104	78.7	17 *(90)*	0 *(0.0)*	2 *(10)*	**19**
Hwy 6	46.7	7 *(88)*	0 *(0.0)*	1 *(12)*	**8**

For the above six road segments, results from my Siriema 2D HotSpot Identification analysis of the provincial vehicle-wildlife collision data highlight areas of significant aggregations of road mortality (in red, Figure 3.4). All road segments apart from Rte. 366 showed significant aggregations at the 1000-m search radius used for the analysis. While Route 366 shows a hotspot along this road segment, it was not significant at the 1000-m search radius. There was no direct overlap between participant data and significant aggregations of vehicle-wildlife collisions along Rte. 6, Rte. 366, and Hwy 15.

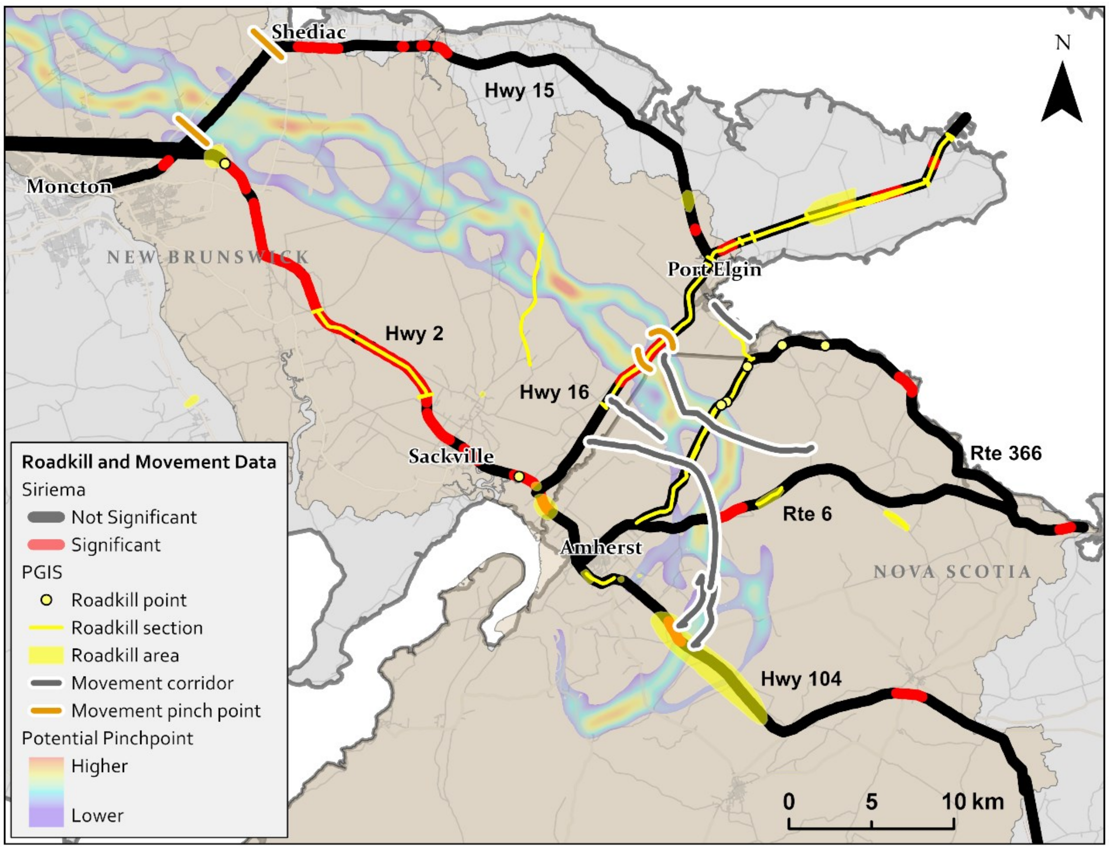

Figure 3.4: Local knowledge data of roadkill observations and hotspots, pinch points, and corridors, overlaid with significant aggregations of wildlife mortality from provincially reported vehicle-wildlife collisions between 2011-2019.

Highway 2 in New Brunswick showed significant aggregations along much of its length between Moncton and Sackville, NB. Reported vehicle-wildlife collisions along this route included deer (73), moose (17), and bear (10). Overlapping this section of Route 2, participant data identified a stretch of increased roadkill for deer and moose. Participants marked this section of road because of forest cover on both sides, reporting high frequency in species crossing along this stretch. Additionally, participants marked an area along Hwy 2 between Amherst and Sackville, highlighting increased deer roadkill and crossings; this overlaps with a hotspot identified from vehicle-wildlife collision reports, in which 66.7% were deer. Highway 104 in NS, which connects with Hwy 2 in NB also shows overlapping data from participants and vehicle-wildlife collision report data, with participants highlighting an area of increased roadkill for deer east of Amherst. Reported vehicle-wildlife collisions for Hwy 104 were mostly comprised of deer (89.5%), with some bear (10.5%), and no moose.

NB Highway 16 showed hotspots of vehicle-wildlife collisions along several sections of the road including deer (64.5%), moose (32.6%), and bear (2.8%). One of these hotspots exists on this highway south of Port Elgin, which overlaps with participants' demarcations of roadkill sections for deer; all reported vehicle-wildlife collisions recorded in this hotspot were also for deer. This hotspot overlaps with a major pinch point identified by participants for wildlife movement across this section of the road. Other hotspots are evident north of Port Elgin along Hwy 16 that overlap with participants' delineations of major road sections and areas with frequent moose-vehicle collisions, concentrated moose movements and crossings, and a high moose population. From the vehicle-wildlife collision data, there were 45 moose-vehicle collisions recorded on Hwy 16, 44 of which occurred along the northern portion of Hwy 16, consistent with locations marked by participants.

3.3.4 Potential for Mitigation and Conservation Efforts

The identification of areas of concern regarding roadkill, wildlife crossings, and wildlife movement often occurred tangentially to conversations about underlying causes and potential mitigation efforts during our interviews with local knowledge holders. Potential for conservation and mitigation efforts included addressing ways to (i) decrease vehicle-wildlife collisions and enhance safe wildlife movement across and around roads, and (ii) foster wildlife connectivity around the regions more generally through integrative forest conservation measures. Local participants described various means of decreasing vehicle-wildlife collisions and enhancing safety for wildlife around roads. These primarily entailed wildlife fencing, signage and speed control measures, and overpasses and underpasses. Each is discussed in turn.

Wildlife fencing - Fencing as an option for roadkill mitigation was often discussed, but with hesitancy. Participants typically feared that fencing might do more harm than good and considered it an expensive mitigation effort with potentially limited effectiveness. In terms of harm, fencing was seen as working against connectivity objectives for species across the region, altering the habitat and acting as a barrier to movement by disrupting the natural movement of species through natural corridors (P1, P8, P9, P10, P16, P32). This disruption of their natural movement raised concerns about limiting gene flow among species population (P10). Fears were also expressed about wildlife becoming trapped between the highway and the fences (P1, P10, P32).

Participants described concerns surrounding the practicality of installing fencing in this region. Many road segments of high concern for roadkill, such as Hwy 16, are not controlled access highways and are surrounded by many parcels of private land which would make fencing as an option difficult to coordinate in these areas with a multitude of intersecting side roads and private access drives along the length of this route (P14, P16, P17, P32). The only time fencing was suggested as an effective mitigation method was in conjunction with underpass and overpass structures. Fencing in such circumstances was perceived as useful for funneling and guiding species towards these structures; fencing in tandem with crossing structures could be successful, as it would not be forming an additional barrier to wildlife (P16, P18).

Overpass/ Underpass - There was some skepticism about the effectiveness of wildlife underpasses and overpasses that have been installed in other parts of Canada, such as the structures in Banff. A few participants reported that few animals use these structures and therefore the cost-benefit potential would not be worth the effort, with one participant noting “I'm not convinced, yet, that if you build it, they will come” (P12). However, other participants did favor the idea of potential underpasses and overpasses in the area. They expressed a need to facilitate movement pathways for larger species through the region, and suggested options such as overpasses and underpasses as methods to safely facilitate this movement (P5, P10, P13, P18).

> There has to be some sort of facilitation, or more than one, probably, to allow the bigger animals, particularly, like the moose, to safely cross the highway without actually being on the highway. Whether that's a green overpass, or I know they've

done in other places, built sort of this overpass and the cars go underneath and it's all green and treed .... It's obviously a tremendously expensive project, but I think this [Chignecto Isthmus] is a particularly important area. Particularly for moose, with the problems in NS, I think it's something that has to be considered (P5).

A general concern was the cost of installing new structures and it was suggested that the best working strategy would be to integrate under/overpasses into new and future developments (P15, P21): if any highway is being expanded and it aligns with a key area for facilitating species movement, then this would be the place and time to implement potential crossing structures. The same was suggested for highways over ravines or stream valleys in the region: if any culvert needs to be replaced, this may offer the opportunity to implement design strategies to make these structures larger and more useable for a wide range of wildlife species in their movement patterns.

Increased signage and speed control measures – Other suggested conservation efforts included signage and speed control measures. Increased signage was thought by some as having potential to warn drivers of increased wildlife hazards along sections of roads that were identified as areas of concern for wildlife crossings and roadkill (P2, P16). However, other participants felt that signs are not an effective option for reducing vehicle-wildlife collisions (P14, P17, P18), as signage already exists in areas that are current hotspots for vehicle-wildlife collisions, and yet people seem to ignore these warnings and often speed through the areas (P17, P18, P20). Speed was another large factor participants saw as being a leading cause of increased vehicle-wildlife incidents (P6, P10, P13, P20). Overall, higher amounts of roadkill were perceived to occur along major routes with higher speed limits, and this corresponds with the speed limits on road segments identified by participants as areas of concern for roadkill: Hwy 16, Hwy 2, Hwy 104, Rte. 366, and Rte. 6 all have speed limits posted at or above 80 km/hr. Reduced speed limits in areas of increased concern for wildlife crossings were suggested as a potential solution to limiting vehicle-wildlife collisions along these major routes (P6, P14, P20). However, enforcing lower speed limits could prove difficult; it was noted by several participants that many people already exceed the current speed limit, with seemingly little regard for existing speed restrictions, along these routes (P10, P17, P18).

Measures for Enhanced Wildlife Connectivity - In describing potential avenues for maintaining and restoring wildlife connectivity in the region more generally, participants largely focused on integrative forest conservation measures. Primarily these measures were related to the need to reform forestry activities in ways that better accommodate wildlife, but in concert with other conservation mechanisms, such as protected areas. A key component of the mapped local knowledge was the spatial area of forestry activity. Participants mapped 22 polygons indicating large areas of intensive forestry practices, including clear-cutting and other silvicultural treatments such as spraying, and direct and indirect associated impacts from forestry activity, including forest roads. Together, these were reported as negatively affecting habitat quality and species distributions and persistence in the region (Figure 3.5).

Participants' mapped forestry-activity data were overlain with (i) their wildlife movement corridors and pinch points, (ii) NCC's high probability movement corridor, and (iii) the boundaries of protected and conserved areas in the region. Large areas of forestry activity identified by participants on both NS and NB sides of the border overlap in places with movement corridors they had identified, as well as with NCC's modeled movement corridor. However, almost no forestry activity was mapped by participants along the NS/NB border, between Hwy 16 and Rte. 366, where there is a concentration of protected and conserved areas and where participants have identified key movement corridors for wildlife.

Some participants viewed changes in the landscape and habitat loss due to past and current forestry activities as a more significant barrier than roads to wildlife persistence and movements (P8, P9, P14, P21). Participants had noticed a correlation between increasing intensity and spatial extent of forestry management practices and changes in moose and deer populations in the region, noting that areas where there was spraying in conjunction with cutting were spatially correlated with areas of decreased abundance of these species (P8, P9, P10, P11). Forestry practices were considered to have reduced the capacity of the land to support ungulates and other species and to provide habitat for previous spatial patterns of species movement in the region. Landscape change due to forestry has resulted in some species being squeezed out of their habitat towards human settlements (P11, P22). The movement of species towards towns has been observed for coyotes and deer due to the loss of critical habitat for food sources (P11, P12).

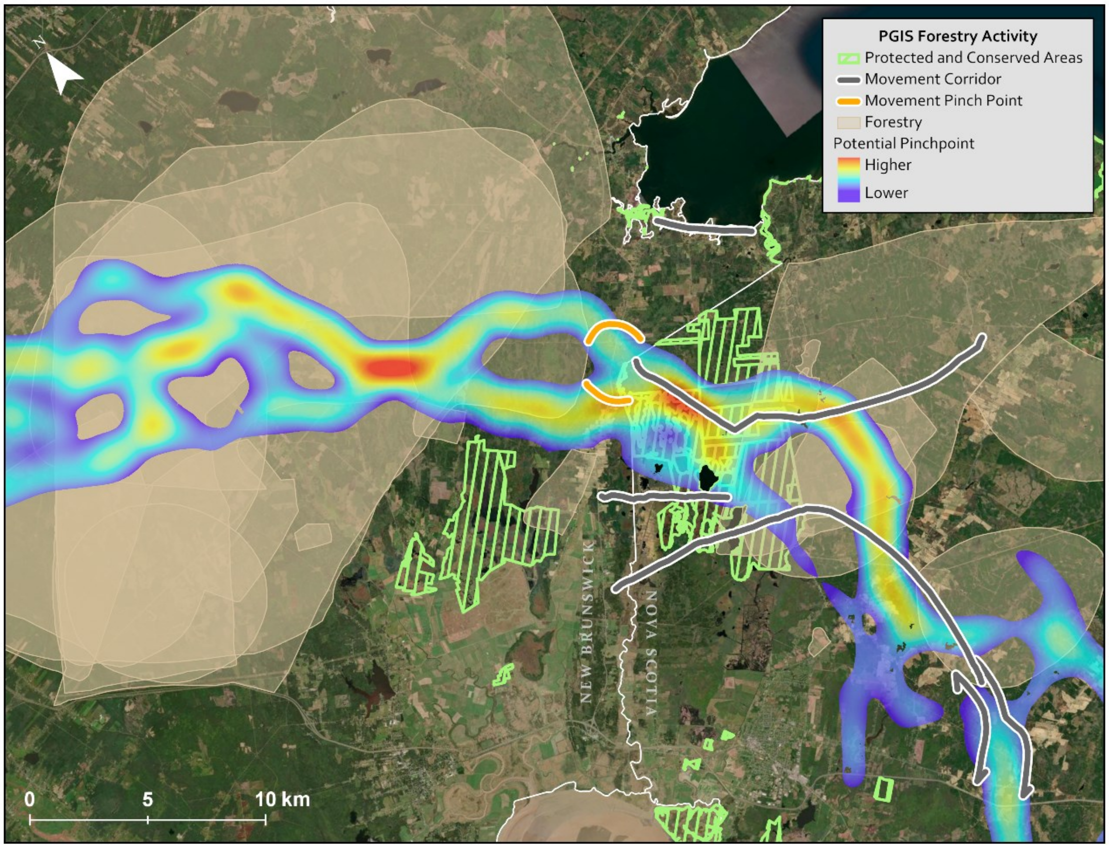

Figure 3.5: Local knowledge data identifying areas of forestry concern, wildlife movement corridors and pinch points overlaid with NCC's high probability movement corridor and the boundaries of Canadian Parks and Protected Areas (2020). Base map provided courtesy of Esri (2017).

Participants stressed that reformed forest and forestry management practices could offer a better solution over other mitigation options for facilitating wildlife presence and movement pathways in the region. There was a range of suggested conservation management practices participants wished to see implemented across the region. Key forest conservation strategies identified by participants included: improved forestry harvest planning and retentions to leave corridors for wildlife (P5, P27, P28); reduced or ceased post-harvest herbicide spraying (P7, P11, P22); and land securements aimed at safeguarding and improving habitat and facilitating connectivity (P12, P14).

3.4 Discussion

This chapter expands our initial analysis of local knowledge in the Chignecto Isthmus to examine different patterns that emerge among spatial trends compared to other studies in the region. Through our initial study, local knowledge was *explored* to identify spatial patterns of wildlife locations and movement pathways across the Chignecto Isthmus, from which key themes and concerns were identified. Understanding how these patterns compare with and complement those found in other studies can provide insight into how and why these patterns emerge and how they might be enhanced or mitigated for improved outcomes for wildlife in the region. Accordingly, the use of local knowledge helps *explain* underlying factors that directly impact wildlife movement pathways and roadkill hotspots, thereby providing explanatory context for spatial patterns revealed both by local participants and in other studies. Additionally, engaging with local knowledge holders allows for *exploring* and *explaining* potential and effective mitigation and conservation strategies, as important precursors to the *predict* phase, to identify conservation priorities.

3.4.1 Generation and Enhancement of Knowledge

Participatory mapping by local knowledge holders can complement knowledge and supplement gaps that arise from limitations in data derived from sources such as roadside surveys and vehicle-wildlife collision reports. For example, during roadside surveys, data was often not collected for large mammals as they were typically removed shortly after a vehicle-wildlife collision and therefore were not on-site during observation periods (Barnes, 2019). Additionally, drivers report vehicle-wildlife collisions to different agencies, and therefore data obtained provincially from NS Lands and Forestry and NB Natural Resource and Energy departments may be missing data that were instead reported to insurance agencies, the Royal Canadian Mounted Police (RCMP), or transportation departments (Barnes, 2019). The introduction of local knowledge helps to identify general areas of concern for roadkill regarding these larger mammals and identify where problem areas exist in the region. Considering local tacit knowledge alongside other sources and forms of data helps to enrich the picture of wildlife movement and barriers to movement, especially around roads, within the Chignecto Isthmus. Additionally, local knowledge provides some explanatory variables as to why these areas may be of greater concern for roadkill potential, along with and heightened concerns for some areas of vehicle-wildlife conflict.

Compared to significant aggregations of wildlife mortality identified by Barnes (2019), the results from participants'data identify several road segments which fall outside of the roads Barnes had surveyed. These include segments along the Trans Canada Hwy (Hwy 2 and Hwy 16) in NB. These road segments do not transect the NCC's high probability wildlife movement corridor but were still identified by participants as areas of concern for wildlife crossings and roadkill. Comparative analysis with results of the vehicle-wildlife collision report data revealed overlap with these sections of road identified through local knowledge. The use of local knowledge, considered alongside vehicle-wildlife collision data, allowed for the identification of other potential areas of concern for wildlife road crossings that fell outside of the road sections surveyed by Barnes, especially for larger mammals.

Along Highway 2, frequent deer and moose crossing and areas of increased roadkill were noted by local knowledge holders. Participants identified this area as having woods along both sides of the road which facilitated wildlife movement and resulted in increased crossings along this stretch of road. Additionally, the hotspot identified along Hwy 16, north of Port Elgin, was identified by participants as a major concern for moose crossings and roadkill, which overlaps with hotspots identified through vehicle-wildlife reports. Participants had heightened concerns along this stretch of road, as it was reported to be a notorious stretch of road for moose-vehicle collisions and deaths in the area. Concerns were expressed over increasing connectivity of wildlife, especially for moose in the region, and the potential this could have on increasing vehicle-moose collisions along this road, endangering both people and moose. While it was recognized that maintaining and improving wildlife connectivity in the region was important, participants stressed that measures need to be taken to consider the potential risks and conflicts associated with road-wildlife mitigation in order to prevent and mitigate any increased dangers associated with moose-vehicle collisions that may arise from facilitating greater connectivity for wildlife across roads.

Local knowledge provided key observations of patterns associated with increased wildlife crossings and roadkill along identified roadkill hotspots which overlapped with data from both Barnes' survey data and vehicle-wildlife collision data. Spatial representation of local knowledge (Figure 3.3) identifies a clear section along Route 940 with frequent deer crossings and roadkill, recognizing that this threat increases during migration seasons when deer are moving to and from their wintering areas. However, hotspot analysis using roadside survey data did not identify a significant hotspot along route 940. Roadside survey data also did not capture any roadkill for larger mammals including deer for this road section. Roadside surveys occurred during the summer months, outside of the migration period participants identified deer to be moving across this route. This could explain why Barnes failed to capture any data on deer for this road during their survey period, and shows how local knowledge can complement temporal patterns which may have been missed during a single, limited season of roadside data collection. Hotspots along this road segment were not revealed through vehicle-wildlife collision data, either; there were insufficient data points to determine potential hotspots along this road. Accordingly, in this and other similar cases, local knowledge provides the only source for identifying and explaining areas of concern for wildlife movements and roadkill.

Along many road sections, however, local knowledge demonstrated areas of concern for roadkill and wildlife crossings which correspond with hotspots identified through roadside survey and provincial vehicle-wildlife collision data reports. Local knowledge of movement patterns and pinch points also reveals a corresponding overlap with those identified in NCC's modeled wildlife movement pathway, both of which also intersect with roadkill hotspots derived from roadside survey data. Thus, there is substantial overlap between these four lines of evidence, which reinforces claims about the validity of each method, including local knowledge, for identifying areas of concern. It also strengthens confidence in the importance of areas identified through all four means as critical conservation priority within the region.

3.4.2 Potential mitigation strategies for connectivity

While work is in progress to protect and conserve areas within the Chignecto Isthmus region, including for connectivity purposes, additional measures are needed to enhance connectivity between protected spaces. As acknowledged in Chapter 2, there are multiple factors impacting ecological connectivity in the Chignecto Isthmus including habitat loss, fragmentation, and climate change. Leading concerns identified through local knowledge for habitat loss and fragmentation in the Chignecto Isthmus region are roads and forestry activities. The impacts of roads and forestry can affect both the quality and quantity of habitat available for species through direct loss and fragmentation (Forman et al., 2003; Glista, DeVault, & DeWoody, 2009; Hilty et al., 2020). Roads and vehicle traffic cause mortality, impacting wildlife populations directly and posing a safety risk to humans (Dion Lester, 2015; Glista et al., 2009; Huijser et al., 2016; Seidler, Green, & Beckmann, 2018). Determining effective mitigation measures for maintaining and restoring ecological connectivity while also reducing wildlife mortality along roadways are critical next steps for conservation planning in the Chignecto Isthmus. However, various social factors influence attitudes and perceptions surrounding mitigation methods for wildlife conservation, including local knowledge holders' familiarity and knowledge of wildlife and wildlife impacts (Dandy et al., 2011).

A breadth of strategies was proposed and discussed throughout our interviews with local knowledge holders with varying degrees of agreeance for which strategies would be the most effective. Participants had conflicting ideas of the effectiveness and feasibility of several mitigation strategies. Despite the implementation and monitoring of overpass and underpass structures across Canada, which have shown species use these structures (Healy & Gunson, 2014; Huijser et al., 2016; McCollister & van Manen, 2010), there were varying perceptions among local knowledge holders of their effectiveness. One participant stated that they do not work, referring to the current underpass installed in Memramcook, which is now only used by ATVs and 4-wheelers (P32). Local folks either perceived these structures as ineffective and did not understand the impact of recreational uses of these spaces on wildlife. The underpass is used as a recreational trail, which can negatively impact species willingness to use it as a means for movement.

Perceptions and attitudes towards the implementation of road signs and reduced speeds suggest that most participants believe they may also prove ineffective without understanding and support for these measures, as wildlife mortality will only decrease if the signs are obeyed. Participants had noted that current speed limits are often disregarded and not obeyed, and that subsequent speed control measures along some roads would similarly not be impactful. In order for speed measures to have an effect, there needs to be a shift in current public behavior and perception of risk of potential vehicle-wildlife collisions.

3.4.3 Limitations

That there are differences between hotspots identified by participants and through roadkill data and vehicle-wildlife collision reports does not diminish the validity of these areas as being points of conservation interest or concern. Instead, it may indicate differences in study area boundaries, or areas where ours, or other studies, may have been unsuccessful in capturing relevant date, whether that be through local knowledge, roadside surveys, or vehicle-wildlife collision reports. No data collection method is perfect. For example, there is a decline in the amount of spatial data mapped from local knowledge as we move away from the center of the Chignecto Isthmus around the NS/NB border region, resulting in fewer opportunities to consider local knowledge alongside other lines of evidence and consequently less overlap between results generated from the different data sets. On the other hand, local knowledge generated within the Chignecto Isthmus as defined by local participants' ideas of the extent of the region has resulted in data for areas beyond the boundaries used in other studies, such as outside of the boundaries of NCC's modelled wildlife pathway and those used by Barnes (2019).

While participants have lived parts of their lives within different areas of the Chignecto Isthmus ranging from Moncton, NB to Oxford, NS, most participants live near the NS/NB border region around Sackville, NB, and Amherst, NS, with some scattered around other small towns including Pointe De Bute, Oxford, Baie Verte, and Midgic. Mapped data seemed to reflect proximity to home and the places in which participants spent most of their time, with a concentration of data points mapped and recorded around the central region of the Chignecto Isthmus, clusters near the NS/NB border region, and more dispersed and fewer points mapped at the farther extents of the region. Since mapped data in this chapter primarily focused on wildlife movement, particularly near roads and involving roadkill, it makes sense that observations would be along routes participants would frequent most often, with less knowledge being shared about routes less frequently traveled or further from home. A participant's knowledge of a study area influences the amount of spatial data they provide based on their home perspective (G. G.

Brown, Reed, & Harris, 2002). This can introduce bias resulting from spatial discounting as a participants place of home will influence their contribution to mapped locations (G. Brown & Kyttä, 2014). Future research would benefit from targeting participants in other areas of the region, to capture local knowledge across the geographical region, to represent patterns and trends more broadly.

3.5 Conclusion

While an *exploration* of local knowledge was shown in Chapter 2 to address data gaps in the literature along with validating NCC"s previously modeled data for the Chignecto Isthmus region, this chapter extends the analysis to further *examine* these concepts. This chapter reveals new insights generated through local knowledge when considered alongside other data sources, including NCC's modelled movement pathways, on-the-ground roadside surveys of roadkill, and vehicle-wildlife collision report data, to reveal opportunities and barriers for wildlife movement across the Chignecto Isthmus, particularly around roads. While results from local knowledge bear similarities to those from other forms of knowledge generated through natural-science and model-based studies conducted in the region, they also enlarge, explain, and complement their findings and thereby contribute to a more diverse knowledge system. Local knowledge, alongside and together with other forms of knowledge, can serve to support the identification of potential priority areas of conservation concern and mechanisms for mitigating threats and enhancing maintenance and restoration of wildlife habitat and movement pathways. Through the inclusion of local knowledge, there is an enrichment of knowledge regarding wildlife movement patterns and areas of concern for roadkill and connectivity both at a fine scale or local level and more regionally across the Chignecto Isthmus. While this is an exploratory and explanatory study, the findings further affirm locations described through Barnes' (2019) findings and NCC's modelling, identifying potential areas of concern and mitigation strategies, and offering a richer picture and explanation of patterns observed across multiple lines of evidence.

Chapter 4: Discussion and Conclusion

4.1 Discussion

With a recognized need to protect connectivity across the Chignecto Isthmus, conservation efforts have begun to identify areas where connectivity can be restored and maintained to address environmental and land-use impacts such as climate change, forestry, roads, urban development, and agriculture. Through this research, we explored how local tacit knowledge could be generated to help identify areas of heightened opportunities and barriers to wildlife connectivity to inform biodiversity conservation science and practice in the Chignecto Isthmus region. Local, experiential knowledge can generate data on wildlife species movement and habitat through participatory mapping approaches, along with ideas for enhancing connectivity across the region. The findings were considered alongside those of past formal, natural-science-based studies conducted in the region, including:

1. The NCC's modeled high probability movement pathway;
2. Roadkill hotspot locations modeled from roadside survey data; and,
3. Roadkill hotspot locations modeled provincial records of vehicle-wildlife collisions.

Data and insights gathered through the engagement of local knowledge holders has been shown to enrich existing data and models, as well as provide an opportunity for the coproduction and cogeneration of knowledge. In addition, knowledge generation through this work offered a deeper understanding of factors impacting wildlife patterns across the region. Finally, when combined with data from past studies in the region, local knowledge helped support the need for connectivity planning in the Chignecto Isthmus.

The research conducted through this study supports the perspective that local, tacit knowledge offers valuable information for connectivity planning and management through its identification of species distribution, movement patterns, and external influencing processes on these patterns within the Isthmus. As demonstrated in chapter 2, insights and mapped spatial data from local knowledge holders helped identify areas of concern where external factors directly impacted wildlife movement pathways in negative ways. These factors include habitat fragmentation and degradation from forestry activity, barriers to movement caused by roads, and threats of climate change driving temperature changes and water levels. Spatially referenced locations of wildlife observations, habitat, and movement patterns helped to construct a more robust data set for understanding wildlife distributions and patterns across the region and impacting factors of landscape changes on wildlife over time. Through this research, local knowledge used alongside that from the natural sciences helped to cross-validate previous work conducted to determine priority wildlife habitats and corridors. There was strong consistency among mapped elements by knowledge holders and results from other studies. This overlap helps to verify modeled data for the region. The process also served to foster knowledge transfer within the group of local participants and enhance their confidence in the accuracy and importance of their knowledge.

Additional findings presented in Chapter 3 serve to illustrate that understanding can be enhanced by examining the interrelationships and patterns of humans and wildlife presented through knowledge from diverse sources, such as those revealed in exploring local knowledge in conjunction with those derived from roadside surveys and vehicle-wildlife collision reports. By considering the results of our analysis based on local tacit knowledge alongside those based on other regional studies, key areas of consensus surrounding spatial patterns for wildlife locations, movement, and distributions are highlighted. These areas of consensus offer strengthened evidence for identifying priority areas of conservation. Furthermore, the engagement of knowledge holders through participatory GIS illustrated the value of their insights for conservation decision-making in the Chignecto Isthmus. Their engagement has increased their support for mobilizing local knowledge to address threats to connectivity for wildlife caused by forestry, roads, development, and climate change. As a result, this research has generated valuable spatial data representing shared local views and knowledge of wildlife connectivity and conservation planning for the Chignecto Isthmus region. The compilation of local tacit knowledge helps contribute to the mobilization and accessibility of a more inclusive knowledge system for conservation planning.

4.1.1 Opportunities for Conservation Priority and Road Mitigation

Local Conservation Efforts - Among the four lines of evidence (local knowledge, spatially explicit modeled movement pathways, roadkill survey data, and vehicle-wildlife collision reports), several areas of consensus allow for the identification of potential opportunities for conservation priority and road mitigation strategies. For example, local knowledge identified key movement corridors and pinch points that aligned with NCC's high probability wildlife movement corridor (Figure 3.3). This co-identified movement corridor highlights a potential pathway for connectivity conservation that runs across five significant roads, including Hwy 16, Rte. 366, Rte. 6, Hwy 204, and Hwy 104. On segments of each of these roads contained within the co-identified movement corridor are areas identified as hotspots for roadkill and increased wildlife movement through participatory data models based on roadside survey data (Barnes 2019), and vehicle-wildlife collision data (NSDLF 2020; NBDNRED 2020). This mounting evidence of similarities between multiple forms of data supports the identification of the study area as critical to wildlife movement and therefore represents a priority area for conservation strategies to be developed and implemented.

Outside of this co-identified movement pathway, other areas of concern were identified by participants. These areas also warrant specific attention, as they represent movements that may originate and terminate in areas or patches different from the start and endpoints used in NCC's least-cost path analyses, and they pertain to parts of the region that do not overlap directly with the study area used for the modeled corridor and in Barnes' study. The NCC's work used five major linkage features (i.e., protected areas) to model least-cost paths and a high probability movement pathway across the Chignecto Isthmus. These linkage features were selected specifically because they represented the largest legislatively protected areas in the region (Nussey & Noseworthy, 2018): Canaan Bog (northwest of Moncton, NB) and Cape Chignecto Provincial Park, Kelley River Wilderness Area, Economy River Wilderness, and Portapique Wilderness Area in NS.

Participants noted other key linkage features, beyond the protected areas used by the NCC in their model, that exist and are protected in the central portion of the Isthmus region, offering critical habitat for species and increased permeability for movement across the region. These key linkage features include the Missaguash Marsh Wildlife Management Area, Tintamarre National Wildlife Area, and other key areas of habitat relating to specific species as identified through their individual thematic maps. Local knowledge identified a pinch point at the head of the Missaguash Marsh, a well-known area for the movement of large mammals across Hwy 16, which was the same pinch point identified through NCC's work in the border region. Participants felt these management and wildlife areas were critical for representing core areas of habitat for species movement across the region. These areas offer locations of priority habitat protection for species to move between as they traverse the region. Land securement and other conservation measures around these areas would provide critical forest connectivity central to the Isthmus region.

The pinch point or ‘funnel’ along Hwy 16 identified by local knowledge holders and overlapping with NCC’s pinch point, feeds into the co-identified movement corridor. Current terrestrial protected areas, which are part of the protected and conserved area's network (CPCAD, 2020), represent a partial network of protected lands within the movement corridor near the NS/NB border, contributing to maintaining connectivity and critical habitat for species. However, there are no protected areas around the pinch point, a feature that represents a potential area for high-frequency movement of species. Visual examination of satellite imagery reveals that this pinch point marks an area with significantly less intensive agricultural and forestry activity and developed lands and offers more contiguous forest on either side of the highway. This area, as identified by local knowledge holders as a priority place for land acquisitions and connectivity, represents a good location to focus next steps, including locally focused field research, for road crossing mitigation and land management and securement strategies that work to limit development or agricultural and forestry activity in this area.

Regional Conservation Efforts - As collaborative work across the NAPA ecoregion, the Maritimes, and the Chignecto Isthmus continues to conserve ecological connectivity, strategic conservation approaches to protect priority parcels of land are needed to enhance connectivity across a broader region. While conservation work must continue within pinch points and high-probability movement pathways, local knowledge holders have a growing concern for connectivity in other areas across the Chignecto Isthmus region. Beyond the vicinity of the pinch point located at the border region, many concerns were voiced and spatially illustrated through the mapping of important areas for wildlife movement and threats due to forestry activities across large extents of the Chignecto Isthmus. There is, however, limited current protection of land parcels along potential movement pathways for terrestrial species beyond the immediate vicinity of the NS/NB border.

To be effective, attention should be given to conservation efforts targeting high-priority lands that address concerns supported by both scientific criteria and residents and landowners, as also suggested by Strager & Rosenberger (2006). Coordinated land protection of priority parcels may help facilitate connectivity corridors through forested pathways, but this requires consensus among various interest groups to minimize potential conflict. The local knowledge holders engaged in our study represent a key group that expresses deep concerns for wildlife due to inappropriate forestry activity in the region. Often, these concerns were difficult to geolocate, measure, and represent as discrete spatial objects. Participants' local knowledge of the changes to the landscape and their associated concerns and values cannot easily be quantified spatially. However, these values may be the most important to consider in order to satisfy local knowledge holders' perceived needs and preferences for conservation strategies, as recommend by others, such as Strager & Rosenberger (2006).

With the participatory mapping study design, participants had the opportunity, through map-based interviews and workshops, to convey priority steps for conserving the lands, which complemented their expressed spatial areas of concern. This included areas of conservation priority and concern regarding key wildlife movement corridors and pinchpoints, habitat loss and fragmentation due to forestry, along with potential and effective mitigation efforts for these areas involving forestry management strategies and mitigation for preventing vehicle-wildlife interactions along roads. A deep attachment to the landscape and a growing concern for the loss of wildlife and their habitats through landscape change is a shared sentiment among local knowledge holders. As local knowledge holders, their conservation concerns and suggestions warrant priority attention in decision-making processes within the region. In addition to considerations of protection and conservation, efforts to maintain landscape permeability and protect critical connectivity on a more regional landscape will require that land use planning initiatives engage and consider the insights from local people, including private landowners, partners, and developers, as also recommended by Hilty et al. (2020).

While local knowledge holders talked broadly about ecological connectivity, their spatial and textual data reflect concepts of both structural and functional connectivity. Participants described key landscape features and the relationship between habitat patches which contribute to the structural connectivity for wildlife movement across the Chignecto Isthmus region. Key features include points of higher elevation and areas of forest cover which form corridors for movement between habitat patches of species. Noted features related to landcover include contiguous areas of forest cover which would offer the shortest and most protected corridors for species movement but that also intersect with roads, thereby needing road-mitigation measures for safe wildlife crossing for enhanced connectivity. Structural connectivity is typically easier to identify and model than functional connectivity. Measuring structural connectivity typically requires less data compared to functional metrics, such as how species, genes, gametes or propagules interact and move through the landscape. However, consideration of how a species is moving through the landscape is critical to assessing the success of overall connectivity. Both the participants' indications and the high probability wildlife movement pathway modelled by the NCC primarily represent structural features, however the participants' data also reflect their direct observations of species and their movement patterns.

Importantly, local knowledge can offer insights on functional connectivity which are crucial in their own right, and which can also serve to complement modelled work examining structural connectivity. Local knowledge revealed species movement patterns across the region which helps to explain the permeability of the landscape based on its structural components. For example, we know there is habitat for moose located on either side of the NS/NB border as identified both through local knowledge and modelled breeding and populations patches conducted by the NCC. Additionally, both local participants and the modelled wildlife pathway by the NCC identified a high probability movement corridor across the border region which connect these habitat patches. Finally, great efforts have been put forward to conserve priority areas along this corridor, such as through NCC's 'moose sex' project, to help improve structural connectivity by providing protected areas of habitat, which should support functional connectivity for moose and thereby help to maintain genetic diversity and gene flow amongst populations of moose in NS and NB. However, knowledge on how moose are actually moving through the region and using the landscape is limited. Local knowledge reveals patterns and offers insight into how moose and other species are moving through the region. For moose, participants identified roads as being a barrier to movement, along with warming temperatures which are pushing moose more North to find refuge versus moving into NS. It's also revealed that moose frequently move along the pipeline corridor, which may offer an elevated pathway of least resistance between habitat patches. Local knowledge offers an opportunity to complement modelled data examining structural connectivity with explanatory functional use of these spaces for a breadth of species.

This research builds upon a growing profile of work in a priority conservation area which is critical for maintaining ecological connectivity for terrestrial wildlife species in the region. Through knowledge coproduction, local participants helped to identify key threats to connectivity that deeply impact species movement across the region. Next steps should continue to identify measures to reduce threats to wildlife connectivity while engaging with local people across the region. Local knowledge provides another line of evidence-based data which should help guide future land management and conservation strategies in the region. Not only does local knowledge develop a more robust set of data which can help to inform and identify areas of concern regarding wildlife movement, road crossing, habitat loss, fragmentation, and potential mitigation strategies, but it also represents a shared collective of the values of the landscape and pressing concerns attributed to detrimental impacts of various landscape changes to the Chignecto Isthmus. A proactive approach should be taken to coordinate amongst land planners and developers and industrial forestry activities to examine how compounding regional impacts impact the landscape regarding connectivity and movement as identified through local knowledge and other forms of knowledge. A strategic plan should be created, in consultation with local knowledge holders, stakeholders and rights holders, including the Mi'kmaq. Provincial governments and private forestry interests should work closely with local knowledge holders to develop and implement a management plan to maintain and restore forested corridors within areas of industrial activity where land acquisition may not be possible. Additionally, spatial results generated through this research should be used to inform future land use planning regarding potential rerouting of the Trans Canada highway and other infrastructural adjustments that may arise as proposed mitigation measures in response to sea-level rise and flooding. Key considerations should account for protection of the wildlife movement corridors and pinch points co-identified through local knowledge in this study and additional studies at a more local scale in crucial areas, such as along the NS-NB border.

4.1.2 Limitations

While this research garnered a rich dataset of local knowledge identifying wildlife species, populations, locations, habitat, movement, and threats to species through the Chignecto Isthmus region, there are geographical areas within the study region where no data were gathered. It is unclear whether these areas of no observations are a result of no wildlife being present there (i.e., absence), or instead a knowledge gap or oversight in participants' reporting (i.e., no data). For example, areas in which no roadkill is mapped through local knowledge may not mean that no vehicle-wildlife collisions occur there. Accordingly, the local data we collected may be considered presence only, as opposed to presence-absence, data; location observations are often mapped, however locations with no observations are often not mapped (Brown et al., 2018). A participant's strong familiarity with the entire study area may contribute to more complete mapping results, which may serve as a proxy for improved data quality, but it would likely still be limited by the ambiguity of presence-only data unless questions were carefully structured to ensure it is not simply an area of oversight or no data. Otherwise, the absence of identified locations would not equate to the absence of species presence or movement in a region, as pointed out by Brown et al. (2018). How to determine the status of areas that have no observations recorded through local knowledge in our study becomes ambiguous as this absence of observation could result from gaps in the data and failure to capture local knowledge holders who could speak to regions where there are no spatial data mapped.

Potential gaps in capturing local knowledge data broadly across the entire extent of the Isthmus could be attributed to factors such as geographic location, beliefs, values, experience, and socio-demographic classes of participants who contributed local knowledge to the study, as found by Brown & Kyttä (2014). Participants in our study had diverse backgrounds of places they have lived and how they have spent their time on the land, greatly influencing the information shared during interviews. Backgrounds included fishing, farming, trapping, hunting, naturalizing, conservation, photography, and forestry, with a breadth of time spent living in various parts of the Chignecto Isthmus region in varying capacities. None of these experiences were mutually exclusive to any participant, with multiple viewpoints and lenses contributing to the shared local knowledge throughout the process. The types and amount of spatial data mapped were influenced by their knowledge of the landscape and no doubt by individual characteristics such as age, gender, education, and livelihoods, as also found by Brown & Kyttä (2014). Their knowledge and expressed values were tied to participants' associations with a place and their intimate relationships with wildlife and habitat in the region, as was the case in a study by Brown, Reed, & Harris (2002). Given that the knowledge shared was deeply influenced by the participants' livelihoods, residences, and time spent on the land, the information they choose to share reflects these influences, potentially biasing the results accordingly. These introduced biases in observation, reporting, and geographic location potentially limit the quality of the results, as also suggested by Brown et al. (2018).

The extent of the Chignecto Isthmus region was defined and bound within NCC's and Barnes' studies, but the extent of the study region was never defined when we conducted our PGIS interviews. The exclusion of a defined extent of the region was intentional so that participants could define what they perceived to be the Chignecto Isthmus and identify which areas were of importance to them based on their local expert knowledge. Therefore, the concentration of point locations may reflect what participants consider to be the Chignecto Isthmus region versus a factor of 'spatial discounting'. Spatial discounting is a phenomenon in which a person's familiarity with a place generated through their time spent in these spaces influences their information shared through the PGIS process, as encountered in other studies (e.g., G. Brown & Brabyn, 2012; De Vries et al., 2013). As the distance from their home increases, there is generally a decrease in the spots that will be marked by participants, which may explain the distribution of data generated in our mapped local knowledge.

This research was also limited by the demographics of our participants, especially the lack of engagement with Mi'kmaq people. The majority of our participants (85%) were older men, which may have introduced bias into our results. We did not exclude

Mi'kmaq participants during recruitment, but we did not specifically target them due to the limitations of time and capacity to do so in an ethical way during our study (see Bull et al., 2019). The time frame of the study was insufficient to develop the relationships of trust and Indigenous methodologies necessary to meaningfully engage Mi'kmaq individuals in ways that are culturally appropriate. However, we recognize and respect their Indigenous, Aboriginal and Treaty Rights, including to governance of the land and to their knowledge systems, and uphold the importance and inherent value of their insights and involvement in knowledge co-production (Artelle et al., 2019; M'sɨt No'kmaq et al, 2021). We stress that respecting and advancing their rights and knowledge systems through respectful engagement in ethical space (Ermine, 2007; Indigenous Circle of Experts, 2018) are crucial for next steps towards future research, governance and management practice in the region.

4.1.3 Future Research

Identifying conservation concerns and priority areas are key outcomes of ecological connectivity mapping and modeling through scientific research and public participatory mapping. Collaboration among public agencies and private organizations across the NAPA ecoregion has been a critical first step in efforts to improve and maintain landscape permeability and ecological connectivity, through organizations such as the Nature Conservancy of Canada, Nova Scotia Nature trust, Canadian parks and Wilderness Society, Staying Connected Initiative, and Two Countries One Forest, and initiatives such as the New England Governors and Eastern Canadian Premiers Resolution (40-3) on Ecological Connectivity, Adaptation to Climate Change, and Biodiversity Conservation (2016). However, knowing exactly which areas to target for protection is critical for conservation and land management. There needs to be consideration of how local knowledge can inform which areas will be the most effective to protect, along with local knowledge holder's support for potential strategies and measure for conserving these areas. While this research has generated robust data to inform opportunities and barriers to wildlife connectivity central the Chignecto Isthmus, data is sparse as you move away from the NS-NB border region. Future research should engage with knowledge holders across a greater geographical extent to inform better regional patterns and barriers to wildlife locations, habitat, and movement to account for potential bias in mapping presence-only data and spatial discounting.

Engagement of local people with deep experiential knowledge of the land and wildlife provided essential insights to foster conservation action for connectivity, a critical component to addressing biodiversity loss and climate change. Declines in species abundance and presence, as well as threats from sea-level rise and flooding, were concerns frequently addressed by participants, recognizing the current and future risks imposed by climate change. Participants identified key corridors of priority for species movement in the face of climate change, creating a funneling effect of species movement through areas of higher elevation where impacts of flooding and sea-level rise will be diminished compared to other low-lying regions of the Isthmus. Under current projected climate change conditions in the Chignecto Isthmus, the protection and identification of refugia sites could be considered an increasing priority for conservation strategies, as also suggested by Keppel et al. (2012), along with climate pathways to allow for species movements and range shifts to occur in response to changes. Climate change refugia are areas that will experience the least change to their climate; they are stable, accessible, and facilitate movement between habitats (Mooney, Petter, & Aster, 2014; Reside et al., 2019). The spine of higher elevation land that traverses the Chignecto isthmus represents an example of such a climate refuge and corridor, as it is the most likely pathway to remain as terrestrial habitat in the face of sea-level rise and associated storm surges and flooding. Utilizing climate refugia modeling approaches combined with local knowledge and current scientific data should help to further identify and build a robust and complete portfolio for developing a strategy for wildlife connectivity across the Chignecto Isthmus region. Collaborative, multidimensional approaches will help to ensure a well-connected landscape that will also support conservation goals of protecting biodiversity and species persistence now and into the future.

4.2 Conclusion

Ecological connectivity is a priority concern for the Chignecto Isthmus. As a critical pinch point, it provides the only terrestrial connection between NS and the rest of North America. Maintaining and improving connectivity for wildlife across this region will help protect and conserve biodiversity in NS and NB. Many compounding factors contribute to connectivity challenges across this priority linkage area, and this research helps synthesize and present a robust understanding of opportunities and barriers to wildlife movement across the Chignecto Isthmus region. This thesis explores and explains how local knowledge plays a vital role in informing key processes, challenges, and conservation concerns and provides an exploratory means for generating invaluable ways of knowing through a participatory mapping process.

As threats of habitat loss and climate change accelerate connectivity concerns across the region, this research occurs in a timely way to help inform future land management and conservation planning initiatives. The impacts of climate change are already apparent within the Chignecto Isthmus, and future threats include disruptions to key transportation and trade corridors in the region, from sea-level rise, flooding, and increased storm surges. As adaptation research and planning are underway for solutions to potential disruption to the Trans Canada Highway and the Canadian National Rail through the Chignecto Isthmus region, there must also be precautionary planning for protecting vital corridors for wildlife movement in areas where there may be future conflicts with infrastructural developments and realignments. Select areas, such as portions of the Isthmus that are higher in elevation, would provide an excellent opportunity for maintaining and restoring a critical movement pathway for terrestrial wildlife. With only a predicted five-kilometer pinch point for species movements across the border region as modeled by the NCC and reaffirmed through local knowledge, it is critical to maintain connectivity through this region and take collaborative action to protect these spaces. Unfortunately, it may also represent an area for rerouting the highway to avoid flooding potential. As such, the areas' crucial role for wildlife must be understood in diverse planning and management contexts.

Development and conservation planning cannot occur in isolation. Instead, collaboration across conservation agencies and those in influencing sectors, such as transportation, forestry, agriculture, and land planning and development, is crucial. To be effective, such collaborations should engage with local knowledge holders and other stakeholders to generate the best possible information available to inform the decision-making process and build buy-in and support. This research, conducted partly in tandem with Victoria Papuga's (2021) MES thesis research, represents an exploratory and explanatory step in capturing local knowledge surrounding wildlife and the landscape, co-generating important insights for maintaining ecological connectivity across the region. Findings reflect local values and concerns surrounding wildlife and their movement pathways and habitats and expressions of support for its conservation from several local leaders in the community in terms of strong tacit and experiential spatial knowledge of the region and its wildlife. The findings can help inform future land use planning as a baseline for capturing local perspectives and providing information complementary to existing natural science-based research both locally in the Chignecto Isthmus and more broadly for conservation science research and planning. It is recommended that local knowledge holders and their insights be engaged in future conservation and land use planning in the region, as their intimate experiences of the land, wildlife movements and habitat, and changes to the landscape reflect rich patterns and processes that reach beyond and help inform information derived from the natural sciences alone.

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Appendix A

Interview Guide (1-2 hours) [July & August, 2019]

Victoria P. Papuga, Karen F. Beazley and Jessica L. Needham
Dalhousie University
School for Resource and Environmental Studies
P.O Box 15000, Halifax, NS, B3H 4R2, Canada

The research assistant and field assistant will introduce themselves and thank the participant for meeting them for an interview.

The interviewers will give the participant time to settle in, offering a few minutes if meeting at a coffee shop or other space offering refreshments for the participant to make any purchase and feel comfortable. Once both interviewers and interviewee are settled in, the researchers will re-summarize the study and data collection methods, review the informed consent form, answer any questions, and seek consent, obtained by signing the consent form. With the participant's permission, the audio recording device will then be switched on.

Key questions for the semi-structured interview are provided in the template, below. These questions are meant as prompts to be used if the topics do not naturally arise in conversation. They will not necessarily be asked in any order in particular or asked at all if the participant leads the conversation toward the topic(s) themselves. The base maps will be displayed between participant and researchers (if there is a table or other object; if not, the researcher will invite the participant to look at the maps before beginning the interview and proceed to either hold the maps or allow the participant to hold the maps for the duration of the interview portion, depending on participant preference). The researcher will use the base study maps of the Chignecto Isthmus region to help the participant visualize the region(s) being spoken of during the interview by pointing to regions identified by the participant and asking questions, if deemed necessary or beneficial by the researcher.

Before launching into core topics pertinent to the study, contextual and rapport-building questions will be asked. The researchers will ask the participant about themselves, such as where the participant lives, how they came to live in the area, how long they have lived there, where they have traveled to within the region, and in which kinds of activities they participate on the land (Topic 1). Researchers will keep track of which of the topic areas and questions arise and are addressed naturally, and then prompt around those not yet addressed prior to ending the interview. Researchers should use the following template to keep track of what is addressed, and to make any other relevant notations, such as key words or phrases, observations or interpretations, clarifications needed, etc.

The conversation, questioning and participatory mapping will take place together, with notations being made on the map as spatially relevant topics arise.

To begin: *Just to be clear, there are no right or wrong answers to any of my questions. I am looking to understand your experience and views. If there is any question you don't want to answer, that is OK, just let me know and we can move on….*

Topic 1: Time and types of experience in the Chignecto Isthmus region	
Pointing to the map: *Let's begin by speaking about which area would you refer to as being the Chignecto isthmus and your experiences in this region.* • How far does it extend, based on your own personal experience? What parts of this region are you familiar with? Most familiar with? How do you spend your time on the land in the Chignecto Isthmus region? • How often do you find yourself spending time out on the land, in nature, in the Chignecto Isthmus region? • Are there specific seasons during which you spend more or less time out on the land? If so, what are they and why? **If participant indicates they live in the area**: Have you always lived in the region/ how long have you lived here? How did you come to live in the area? **If participant indicates they do not live in the area**: What prompts you to travel to this region specifically? Where do you usually travel to in the region?	

<table>
<tr><td>How often, and for how long? How long have you been doing this?

For all:

Where have you traveled [how extensively] within the region?

What kinds of activities do you do out on the land? [hunt, fish, trap, hike, snowmobile, etc]. Tell me more about these activities; would you say these activities are more of a necessity or more recreational [more fun] for you?

• How long have you been participating in these activities? Do you participate in them often?
• Do you tend to participate in these activities individually or in a group?</td><td></td></tr>
<tr><td colspan="2">Topic 2: Participatory mapping

Note: Mapping is not to be conceived as a separate topic or portion of the interview, but rather as an integral part of the interview, as a means of recording their responses in a spatial and geo-referenced way.</td></tr>
<tr><td>Let’s take another look at the maps we have brought. One is larger, showing the entire region. The second one focuses on the border area between Nova Scotia and New Brunswick. Which map or maps would you feel most comfortable using to talk about where you see wildlife?

…Is there a reason you are most comfortable with the chosen map(s)?

I’d like you to draw on the maps areas where you have seen various species of wildlife. You can use whichever colours you like.

As you are making these markings on the map(s), I would like you to speak your thoughts out loud so we can understand what you are showing us.

There are no right or wrong answers, we are interested in seeing your experiences visualized on this/these map(s).</td><td></td></tr>
</table>

<table>
<tr><td>Where you have seen various species of wildlife? Which species? (Wildlife includes animals, birds, fish, etc.)

Are there particular areas where you see wildlife moving, from place to place? Where are they? Which species?

• Are there wildlife movement ‘pathways’ or trails that you are aware of?

We are interested in hearing about any wildlife you have seen or interacted with in the region, but we also have an interest in specific species that live in the region.

Do you ever see … (name the 12 species for which NCC modeled movement corridors)? Where?

Do you think there is more wildlife present in these areas that you have marked than in other areas? Why/why not?</td><td></td></tr>
<tr><td colspan="2">Topic 3: Wildlife in the Chignecto Isthmus Region

[There is overlap among these topics and those addressed in the mapping. Responses will be noted spatially/geographically on the map, and other relevant responses will be noted here.]</td></tr>
<tr><td>While spending time in the region, have you come across many species of wildlife?

What species have you noticed the most during your time spent in this/these region(s)?

• Are there some species that stand out or are more important to you than others? Why?

In which areas do you most often notice these species, or the lack of them?

• Have you noticed the same species in multiple areas of the Chignecto Isthmus? Where?
• Why do you think you notice these species? (Do you think this has anything to do with the activity you participate in)?</td><td></td></tr>
</table>

<table>
<tr><td>Over the time you have spent in this region, have you noticed any difference in how often or how much of this species you’ve seen?

Are there any thoughts you have as to why there might be these differences?

During your time in this/these region(s), have you noticed any wildlife mortality (death)?
Do you notice this dead wildlife in any specific areas you have come across? Are there areas where you have noticed more of this dead wildlife?
Where have you noticed dead wildlife, such as road kill? Are there areas where you see more roadkill? What species? Are there particular times of year when you see more roadkill?</td><td></td></tr>
<tr><td colspan="2">Topic 4: Conversations around conservation [and wildlife-road mitigation]</td></tr>
<tr><td>I’d like to move the conversation now to ideas around conserving wildlife.

Can you think of/Do you think there are any specific things that are happening in this region that may be interfering with the ability of wildlife individuals to thrive?
What about the ability to support healthy populations of wildlife?
What things might be contributing to the death or injury of wildlife, not including hunting, trapping, fishing, etc?

Have you noticed injured or dead wildlife on or around roads in the regions? Where? Which species?</td><td></td></tr>
</table>

<table>
<tr><td>Have you noticed any species avoiding roads (e.g., coming up to a road but then moving away)?
Or not being able to get across roads or other barriers (e.g., fish at roads, culverts, dams, etc; wildlife at fences)?
Are there [specific] areas where you think animals (including fish) would like to move but can’t, or where it is harder for them to move because of human activities or developments? What about roads? Dams?
Can you think of any strategies for reducing the death of wildlife on or around roads?
Any ideas for how to make roads safer for wildlife passage (and people)?
[Researcher may prompt by speaking about the idea of underpasses and overpasses, as an example, if there is confusion/hesitation when referring to strategies]
Do you think the reduction of wildlife injury and death due to vehicle collisions would be beneficial to you and others who use this region?
Why or why not?</td><td></td></tr>
<tr><td>Topic 5: Other/conclusion

Is there anything else we did not cover that you’d like to share or elaborate on?</td><td></td></tr>
</table>

The participatory mapping will conclude when the participant makes it clear that they are finished plotting data onto the provided map(s). The concluding discussion between researcher and participant will include speaking about how the participant felt about the experience and if they were comfortable marking on the provided map(s).

The researcher will ask if they have any final questions or concerns.

The research assistant will reiterate that the participant may contact them or Dr. Karen Beazley at any point with any questions or concerns through the provided contact information in the consent form.

At the conclusion of the interview (or when the participant chooses to end the session) the participant will be given a $25 gas or grocery card (their choice) as a token of appreciation for their time.