SHARED KNOWLEDGE TO IDENTIFY AMERICAN LOBSTER/JAKEJ (*HOMARUS AMERICANUS*) MOVEMENT PATTERNS AND HABITAT USE IN THE BRAS D'OR LAKE/PITU'PAQ

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.

To the Telemetry Fight Club,
which I can't talk about but love dearly.

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ABSTRACT

Natural sciences are dominated by western knowledge and often discount Indigenous knowledge systems. This study uses Two-Eyed Seeing/Etuaptmumk to identify movement patterns and habitat use of American lobster/jakej in the Bras d'Or Lake/Pitu'paq. Lobster productivity within the lake is low and there is a lack of characteristic lobster habitat in the study bay, yet Mi'kmaw knowledge confirms high site fidelity of lobster within this area. Fine-scale movement patterns derived with acoustic telemetry positioning systems were paired with quantitative habitat analysis to perform integrated step selection analyses. Few lobsters exhibited a significant effect of substrate on habitat selection. This can be a result of the life stage of study lobsters or their abundance and distribution within the study site. Adaptive co-management, utilizing a framework that values diverse ways of knowing, can lead to evidence-based management that supports Mi'kmaw self-determination and leads to stronger and more equitable management of lobster.

LIST OF ABBREVIATIONS USED

DFO   Fisheries and Oceans Canada

HPE   horizontal positioning error

HPEm   horizontal positioning error in absolute terms (metres)

iSSFs   integrated step selection functions

km   kilometres

km^2 kilometres squared

LFA   lobster fishing area

OTN   Ocean Tracking Network

ppt   parts per thousand

UINR   Unama'ki Institute of Natural Resources

VPS   VEMCO positioning system

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CHAPTER 1: INTRODUCTION

1.1 THE BRAS D'OR LAKE/PITU'PAQ, CAPE BRETON/UNAMA'KI

The Bras d'Or Lake, in Cape Breton, Nova Scotia/Mi'kma'ki, is a complex estuary comprised of two basins, multiple shallow and deep bays, narrow channels and straits, and a large watershed with a total catchment area of about 3,600 km^2 that provides important habitat for a number of fish and invertebrate species (Lambert, 2002; Tremblay, 2002). Characteristics of the waters throughout the lake vary both temporally and spatially, with the exception of its low amplitude tides that are seen throughout (Parker et al., 2007). The estuary has three outlets to the ocean and receives inputs from six rivers, with resulting salinity in the range of 20 to 26 ppt (Lambert, 2002). Salinity within an estuary can range from 0.5 to 35 ppt, with freshwater having salinity close to 0 ppt and seawater having an average salinity of 35 ppt (National Oceanic and Atmospheric Administration, n.d.). The circulation, salinity, and temperature of the Bras d'Or Lake are heavily influenced by heat exchange between the water and the atmosphere, its freshwater inflow, and its restricted exchange with the Atlantic Ocean (Petrie & Bugden, 2002). The surface flows carry water from the East Bay, through the Barra Strait, into the North Basin and eventually out to the Atlantic Ocean, while the subsurface current moves in the opposite direction, carrying waters from the Atlantic Ocean into the North Basin, through the Barra Strait, and ultimately into the East Bay (Petrie & Bugden, 2002).

The Lake has sustained the Mi'kmaq for thousands of years and is home to five Mi'kmaq communities: Eskasoni, Membertou, Wagmatcook, Potlotek, and We'koqma'q (Hatcher, 2018; D. N. Paul, 2006). It received designation as a United Nations Educational, Scientific and Cultural Organization Biosphere Reserve in 2011, in large part due to Elder Albert Marshall's efforts (Hatcher, 2018). The estuary comprises 31% of the biosphere reserve, while the rest is the watershed (Hatcher, 2018). With a wide range of habitats found throughout the Lake, the waters are home to a variety of marine life (Lambert, 2002; Tremblay, 2002). Generally, the species found within the Lake are representative of the species occurring along the Atlantic coast of Nova Scotia (Lambert,

2002). However, due to the protection provided in many areas of the Lake, it still provides habitat for both arctic and sub-tropical species that arrived during historic events and that still arrive via the Labrador Current and the Gulf Stream, making it a truly unique ecosystem (Hatcher, 2018; Lambert, 2002). The diversity of species composition found within the Bras d'Or Lake is rare outside this estuary (Lambert, 2002).

1.2 STUDY SPECIES: AMERICAN LOBSTER/JAKEJ

The American lobster is an ecologically important species in the Bras d'Or Lake and a culturally and economically important species for the Mi'kmaq (Parker et al., 2007; Tremblay, 2002; Unama'ki Institute of Natural Resources, 2007). American lobster are found both inshore and offshore in the northwest Atlantic Ocean between Labrador and North Carolina (NOAA Fisheries, n.d.; Wahle, Butler, et al., 2013). They are a long-lived species; however, precise age determinations are difficult due to moulting (Fisheries and Oceans Canada, 2018a; NOAA Fisheries, n.d.; Unama'ki Institute of Natural Resources, 2007). American lobster begin life as planktonic larvae that settle to the bottom after three to nine weeks and remain benthic for the rest of their lifetime (Charmantier et al., 2001; Cobb, 1976; Unama'ki Institute of Natural Resources, 2007). For the next six to eight years, they periodically moult and grow until they reach sexual maturity. Once mature, lobsters will mate following the female moult, when her shell is still soft. The male will transfer sperm cells into the female and then protect her for a few days while her new shell hardens. Females can keep the sperm for over a year and she will use it to fertilize her eggs once they are transferred to her tail. Eggs will remain glued to the female for nine months to a year (NOAA Fisheries, n.d.; Unama'ki Institute of Natural Resources, 2007). Once the eggs hatch, they float to the surface and the cycle begins again.

Lobsters are opportunistic feeders, consuming the prey that is most available to them. Thus, their diet varies by region (NOAA Fisheries, n.d.). Stomach content analysis of American lobsters from different locations has found everything from crustacea, fish, algae, molluscs, hydroids, and echinoderms (Cobb, 1976; Ennis, 1973; Himmelman & Steele, 1971; K. H. Mann & Breen, 1972). These stomach contents have been shown to

reflect the relative abundance of prey within the habitat (Cobb, 1976). In the Bras d'Or Lake, adults feed on echinoderms, gastropods, bivalves, worms, hermit crabs, and rock crabs, with rock crabs likely being an important component of their diet (Gendron et al., 2001; Sainte-Marie & Chabot, 2002; Unama'ki Institute of Natural Resources, 2007).

Across their range, adult hard-shell lobsters have few predators, while smaller lobsters are likely preyed upon by bottom-feeding fish. The most significant predator of adult lobsters are humans, making fishing pressures the main threat to the lobster population, and this is the case in the Bras d'Or Lake as well (Cobb, 1976; NOAA Fisheries, n.d.; Tremblay, 2002; Unama'ki Institute of Natural Resources, 2007; Wahle, Butler, et al., 2013). According to an International Union for Conservation of Nature assessment, the scope, severity, and impact of fishing pressures on American lobster are unknown (Wahle, Butler, et al., 2013). Across Canada, approximately 54% of the value generated by the commercial lobster industry comes from Nova Scotia (Fisheries and Oceans Canada, 2020b). Even with management plans in place, commercial lobster landings have been increasing and are at some of the highest levels recorded in the past century (Province of Nova Scotia, 2015). In 2018, over 47,000 metric tonnes of lobster were landed in Nova Scotia, valued at more than $771 million (Fisheries and Oceans Canada, 2020a, 2020c). As a result, the lobster industry is a major driver of Nova Scotia's economy, particularly in rural areas (Ryan, 2019; Thériault et al., 2013).

1.3 RATIONALE

Mi'kmaw knowledge, capture fisheries, and acoustic telemetry all confirm the continued presence of lobster, yet video footage, captured through this research, suggests an apparent lack of characteristic lobster habitat, habitat with boulders and cobble, in the study area (Parker et al., 2007). This work seeks to improve and deepen our collective understanding of lobster movement and habitat use in a culturally and ecologically significant bay where little has previously been known about lobster distribution in relation to bottom habitat (Tremblay et al., 2005). We aim to conduct this research in a way which values different ways of knowing though partnerships with diverse knowledge holders.

1.4 KNOWLEDGE IN THE NATURAL SCIENCES

The natural sciences is an epistemological monoculture which is dominated by western ideologies and beliefs (Alexander et al., 2019; Merriam & Kim, 2008). Western science is used to evaluate the validity of other knowledge systems, resulting in the discounting, or complete dismissal, of the varied and valuable knowledge systems around the world (Howe, 2020; Mazzocchi, 2006; Merriam & Kim, 2008; Nakashima & Roué, 2002; Reid et al., 2020; Thompson et al., 2020). And while decades of scientific advancement appear to demonstrate the success of the western system, it conceals the history and influence of non-western knowledges, as well as the many limitations and harms that come from excluding diverse ways of knowing (Denny & Fanning, 2016a; Elshakry, 2010; Giles et al., 2016). Science tends to be described as "western", "modern", and "universal", but it has not always been this way (Elshakry, 2010; Siegel, 1997). Beginning in the 17th century, as European power and colonization increased, European explorers and missionaries would travel to settled and unsettled lands, where they began to build schools and academies to spread their European styles of learning. This formed the basis of modern science, although it still varied locally and contained both European and traditional knowledge of the region (Basalla, 1967; Elshakry, 2010). The value given to traditional knowledge depended greatly on the European view of those who held it and whether they were deemed 'civilized' or 'primitive' (Basalla, 1967; Fullagar, 2008). Western science, as we know it today, began when scientists stopped appealing to national, philosophical, or religious objectives, and instead began to search for universal truths (Basalla, 1967; Elshakry, 2010). Science became entrenched in positivism, a paradigm based on the assumption that there is one true reality and it can be observed and measured (Park et al., 2020). It was through this new pursuit that science broke away from any traditional knowledges and promoted the separation between 'knowledge' and 'belief'. The notion of western science became one which diminished community knowledge and traditions and reduced them all to a single teleology from the past (Elshakry, 2010; Goduka, 2021; Merriam & Kim, 2008). Since this time, western science has dominated what is considered 'legitimate' knowledge and what is 'inferior' (Akena, 2012; Elshakry, 2010; Latulippe & Klenk, 2020).

The perceived objectivity of western science, and the global power dynamics that maintain western dominance, have allowed western knowledge to delegitimize other ways of knowing (Akena, 2012; Goduka, 2021; Reid et al., 2020). When Europeans travelled to North America/Turtle Island, they viewed the Indigenous peoples as 'primitive' and through colonization and forced assimilation, European education and languages became dominant and resulted in the cognitive imperialism that is still upheld today (Battiste, 2011). Contrary to European thought, Indigenous ways of knowing are incredibly complex; built upon ancestral knowledge and the mutable local context. Indigenous ways of knowing are incredibly varied and often viewed as a bridge between humans and the environment and many have been used since time immemorial to explain phenomena and manage natural resources (Akena, 2012; Battiste, 2011; D. N. Paul, 2006). Indigenous knowledge holders tend to view knowledge gathering as a process that requires a lifetime of observing and living in relationship with the land and its inhabitants, while western knowledge holders tend to view attaining knowledge as an objective pursuit (K. Paul, 2018). As such, western systems tend to hold little space for the processes of Indigenous knowledges and when they are included, it is often through tokenization, misinterpretation, or misappropriation (Chambers & Gillespie, 2001; Latulippe & Klenk, 2020; K. Paul, 2018). The monolith of knowledge that we continue to foster in science, where there is only one 'true' way of knowing and other knowledge can only be used if it fits into the structures of western systems, has created and continues to create and uphold inequity in our society (Battiste, 2011; Chambers & Gillespie, 2001; Latulippe & Klenk, 2020; K. Paul, 2018; Thompson et al., 2020).

In more recent times, Indigenous knowledges and the perspectives of local knowledge holders are increasingly acknowledged as valuable (Nicholas, 2018; Thompson et al., 2020), but only until they challenge western findings. Then they are typically dismissed and deemed imprecise or anecdotal, and so colonial systems and cognitive imperialism continue to be upheld (Battiste, 2011; Latulippe & Klenk, 2020; Mackinson, 2001; Nicholas, 2018; Reid et al., 2020). To truly create equitable space in research, we must first address the history of colonization, recognize prevailing power imbalances, and

relinquish the perceived superiority of western science (TallBear, 2014). Room must be made in the sciences so that Indigenous researchers can create space where their objectives and values can flourish (Peltier, 2018; Thompson et al., 2020). Given the criticisms and limitations of western science, there is a growing desire to transform the way science is conducted. Frameworks that value diverse ways of knowing can contribute to this transformation.

1.5 TWO-EYED SEEING/ETUAPTMUMK

One framework for integrating diverse knowledge systems is Two-Eyed Seeing/Etuaptmumk. Mi'kmaw Elder Albert Marshall and Elder Dr. Murdena Marshall defined Two-Eyed Seeing as "learning to see with the strengths of Indigenous knowledge from one eye and with the strengths of western knowledge from the other eye and using both eyes together in order to benefit all" (Bartlett et al., 2012). As a framework, Two-Eyed Seeing provides a way for research to weave Indigenous and western knowledges by joining those with different worldviews together to conduct research in an environment built on equity and co-learning (Hatcher, 2012; Johnson et al., 2016). These worldviews are core philosophical foundations, built upon a set of basic beliefs; thus they can never be proven, only believed (Guba & Lincoln, 1994; Reid et al., 2020). Despite this, the worldview to which one prescribe will dictate what ways of knowing are accepted, which will influence priorities and choices (Reid et al., 2020). Western scientists are unable to conduct research without the influence of their worldview, making it imperative that they recognize and understand it and foster relationships in research with individuals who hold a differing worldview (Bartlett et al., 2012; Held, 2019; Mertens, 2015).

Examples of successful collaborations built upon a Two-Eyed Seeing framework are rare in the natural sciences, however my thesis work is part of one such collaboration: Apoqnmatulti'k (Mi'kmaw: "we help each other"). Apoqnmatulti'k is a 3-year collaborative study that brings together local knowledge holders, Mi'kmaw rights holders, and individuals from academia and government to weave together local and academic perspectives from Mi'kmaw and western worldviews to enhance aquatic

stewardship. The project focuses on three species of particular value to coastal Mi'kmaw communities and the Government of Canada: Atlantic tomcod/punamu (*Microgadus tomcod*), American eel/katew (*Anguilla rostrate*), and American lobster/jakej (*Homarus americanus*), within two large ecosystems - the Bay of Fundy/Pekwitapa'qek and the Bras d'Or Lake/Pitu'paq. These species were chosen due to their ecological and cultural importance and the resulting management implications, as well as their contribution to food security among coastal communities. Apoqnmatulti'k brings together the strengths of diverse knowledge holders, acknowledging the need for all to meaningfully engage in the work together to wholly integrate these different ways of knowing (Bartlett et al., 2012).

Our project creates space for Mi'kmaw and western knowledge holders from two different perspectives (Table 1.1). In this thesis, the knowledge that comes from an individuals' perspective has been generalized as local or academic, though it must be noted that the perspective of any individual is entirely inimitable, as it comes from their unique set of lived experiences (Reid et al., 2020). By working together and sharing our ways of knowing, all partners add depth to both the research and the relationships among project partners. Two-Eyed Seeing has been used since the inception of the project through co-development of the research plan, study design, tagging methodologies and the development of the research questions specific to this thesis.

Table 1.1   Brief descriptions of western and Mi'kmaw worldviews, as well as the knowledge generated from local and academic perspectives. It is important to note that there are additional qualities associated with the knowledge from each perspective depending on the worldview of the individual. These descriptions only provide a general overview and do not account for the impact that the ecological, political, and social context have on knowledge[1].

Worldview	Mi'kmaq	A worldview based on the belief that all life and objects are kin (Msit no'kmaq: all my relations)[2]. It values holism and is rooted in human interactions with the natural world, as it considers humans to be a part of ecosystems[2,3]. It takes a preventative approach to decision-making[2].
	Western	A worldview based on the belief that humans are superior over all else[2]. It values hierarchy and segregation in its reductionist approach[2,4]. It take a prescriptive approach to decision-making[2].
Perspective	Academic	Knowledge that is passed through repetition and verification[4]. It is reproducible and evidence-based[4,5], developed through prediction and inference[4]. This kind of knowledge relies on transparency and rigorousness[5].
	Local	Knowledge that passed through cultural transmission[6]. It is dynamic and place-based[7], constantly evolving and adapting to the changing environment[5,6,7]. This kind of knowledge is generational and relies on social relationships[5,6].

[1] Warburton & Martin, 1999; [2] Denny & Fanning, 2016; [3] Giles et al., 2016; [4] Nicholas, 2018; [5] Bates, 2019; [6] Berkes, 2003; [7] FAO, n.d.

My contribution to Apoqnmatulti'k is focussed on the movements and habitat use of American lobster/jakej in the Bras d'Or Lake/Pitu'paq. Current evolving discussions between First Nations and the Government of Canada are trying to find a path forward for evidence-based lobster management, in addition to management that recognizes and affirms Mi'kmaw rights, including to fish under Treaty rights. Management recommendations, specifically regarding lobster movement between Lobster Fishing Areas (LFAs), were drawn from my research. These recommendations are based on a holistic and sustainable approach to stewardship through the combining of knowledge systems and offers one example of collaboration which demonstrates the power of engaging with and valuing all knowledge holders.

This thesis is built upon the hypothesis that our understanding of lobster movement and habitat use will be deeper due to our use of a Two-Eyed Seeing framework and contributes to the growing body of literature that models the use of diverse knowledge systems in research (*Fish-WIKS* provides an excellent example). All knowledge systems and methodologies have inherent limitations, but the influence of these is reduced in Apoqnmatulti'k, as we use the respective strengths of the different knowledge systems as well as the varied strengths of the knowledge holders within the partnership (Figure 1.1).
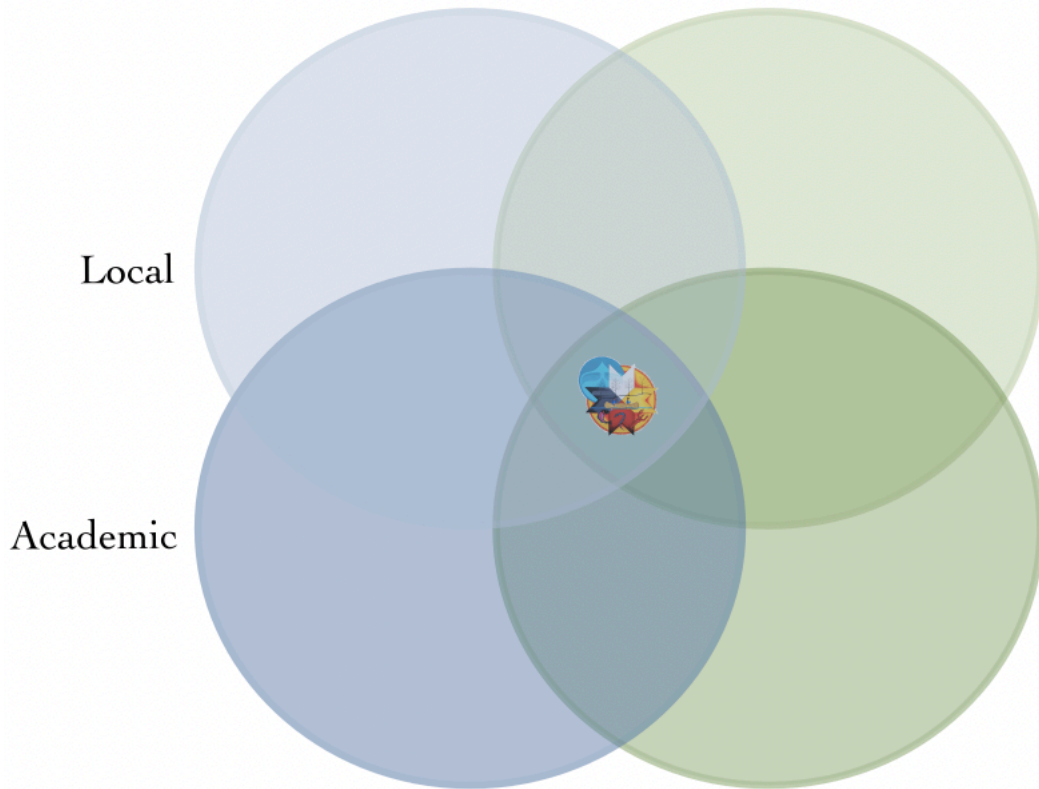
Figure 1.1   This model illustrates the Two-Eyed Seeing/Etuaptmumk framework used in Apoqnmatulti'k. Each worldview (blue for Mi'kmaw and green for western) has been divided into a local (lighter colour) or academic (darker colour) perspective to demonstrate the added value of diverse perspectives within the same worldview. Apoqnmatulti'k, represented by the project logo, is at the centre of these intersecting worldviews and perspectives, and the depth of knowledge we can gather when working together is exemplified by the layering of every circle.

This conceptual model will be evaluated through two research chapters. The first examines the movements of lobster with regards to management implications. The second addresses the habitat use of lobster in an area where little has been known about this habitat. The objectives of this work are to draw conclusions and make recommendations that have been informed by the varied worldviews and perspectives, to demonstrate the value of using a Two-Eyed Seeing framework, and to provide findings that result in stronger and more equitable management of lobsters.

1.6 RESEARCHER POSITIONALITY

I am a white female of European descent, born and raised in Canada, and living in Mi'kma'ki, the ancestral and unceded territory of the Mi'kmaq People. I received my education through the western education system, and I am now a candidate for a Master of Science from Dalhousie University, which sits on the Traditional Territory of the Mi'kmaq. My strong connection to our marine environment has led to my participation in this Master's project.

The following work was completed during my journey as a non-Indigenous student to attempt to transform myself and my research practices through work with local Mi'kmaw communities. Throughout this process, I have strived to engage in Two-Eyed Seeing and to continually question the influence that colonization has on my own practices and beliefs. This is a never-ending process as it necessitates constant self-reflection, listening, and learning and I would not be where I am today without the guidance and support of my project partners. Their willingness to share with me over the past two and a half years will have a lasting impact on the researcher, and the person, that I am.

CHAPTER 2: MANAGEMENT IMPLICATIONS OF AMERICAN LOBSTER/JAKEJ MOVEMENTS IN THE BRAS D'OR LAKE/PITU'PAQ

2.1 INTRODUCTION

The commercial American lobster/jakej (*Homarus americanus*) fishing industry is regulated in Canada by Fisheries and Oceans Canada (DFO) with over 1600 licenses in Lobster Fishing Areas (LFAs) along the Atlantic Coast (Appendix A, Figure A.1) (Fisheries and Oceans Canada, 2018b). Mi'kmaw communities presently access the commercial fishery via communal commercial licenses within an outlined management framework defined through Interim Fisheries Agreements (Unama'ki Institute of Natural Resources, 2007). Moreover, Mi'kmaq have Aboriginal and Treaty rights that were established, in the case of inherent Aboriginal rights, due to being first peoples of the land pre-contact, and in the case of Treaty rights, through negotiations and Peace and Friendship Treaties with the British Crown in the 1700s (R. Francis, personal communication, October 6, 2021).

These treaties remain today, and have been recognized and protected by the Canadian Constitution (K. Coates, 2003; Unama'ki Institute of Natural Resources, 2007; Wiber & Milley, 2007). In 1990, the Supreme Court of Canada reaffirmed the Aboriginal right to fish for Food, Social, and Ceremonial purposes following the *R. v. Sparrow* court case (Salomons & Hanson, 2009). In 1999, in *R. v. Marshall*, the Supreme Court of Canada ruled the Mi'kmaq had a right to fish and hunt to maintain a moderate livelihood (Krause & Ramos, 2015; Unama'ki Institute of Natural Resources, 2007). But shortly after, a second decision, *Marshall II*, was made, in which conservation measures and other compelling public objectives would allow regulation over this Treaty right (Unama'ki Institute of Natural Resources, 2007). Recently, Mi'kmaq in Nova Scotia have been asserting their right to fish for a moderate livelihood through the implementation of Mi'kmaq-led Treaty fisheries for lobster. The government has maintained that these fisheries violate *Marshall II* and deem them illegal, unless they operate within the

commercial season in the area (Doucette, 2021; Fisheries and Oceans Canada, 2021a; Angel Moore, 2021).

The issue of legality surrounding Mi'kmaq-led Treaty fisheries, and the resulting tensions, provide an opportunity for lobster management to implement co-management processes, support Indigenous self-determination, and advance reconciliation (Denny & Fanning, 2016b; Fisheries and Oceans Canada, 2019a, 2021c; Office of the Prime Minister, 2015, 2019). Genuine co-management necessitates sharing both power and responsibility, with the core assumption that doing so will enhance the management of the resource and allow the resource to meet a range of needs (Castro & Nielsen, 2001; Denny & Fanning, 2016b). A management partnership between nations cannot rely on western knowledge and systems alone. The knowledge and values of both nations must be represented and respected. This aim can be supported through a framework of Two-Eyed Seeing/Etuaptmumk, in which all partners learn to use one eye to see with the strengths of Indigenous knowledge and the other eye to see with the strengths of western knowledge and use both eyes together, for the benefit of all (Bartlett et al., 2012).

DFO utilizes prescriptive management in which the organization implements management tools to keep stocks healthy and harvesters safe, with order and predictability for the benefit of managers (Denny & Fanning, 2016b; Fisheries and Oceans Canada, 2021a). Among fisheries, having differing management plans, in particular seasonal closures, is a tool used to reduce interactions between fisheries to keep harvesters safe and make it easier for managers (Fisheries and Oceans Canada, 2021b). Even within fisheries, management plans can differ across regions, as seen by the differences across LFAs (Fisheries and Oceans Canada, 2019b). Thus, when lobster move between LFAs, they may experience increased vulnerability to harvesting based on the timing of their movements. In contrast, Mi'kmaw management is preventative and it is based upon the value of Netukulimk (Denny & Fanning, 2016b). Netukulimk is described as "achieving adequate standards of community nutrition and economic well-being without jeopardizing the integrity, diversity, or productivity of our environment" (Unama'ki Institute of Natural Resources, n.d.). Management that is built upon the

interconnectedness between peoples and their environment encourages self-imposed limits (Berneshawi, 1997; Prosper et al., 2011). In a setting such as the Bras d'Or Lake/Pitu'paq, a large and complex estuary with water characteristics that vary spatially and temporally, the current western management regime lacks the recognition that lobsters within one area, such as a bay, may require very different management than those in another area, such as the larger Bras d'Or Lake or the Atlantic Ocean (Lambert, 2002; Parker et al., 2007). There thus may be a mismatch in regulatory scale.

The primary objective of this study was to provide insights into the movements of lobsters in areas of the Bras d'Or Lake through a Two-Eyed Seeing framework to better understand the implications their movements can have for management. I aimed to answer three key questions: 1) Did lobsters leave the Bras d'Or Lake? 2) Do lobsters move between the study bay and the larger Bras d'Or Lake? and 3) Do lobsters move between LFA 27 and 28? Questions one and two consider movements in relation to ecological boundaries, while question three considers movements in relation to human-designated boundaries. Lobster movements were analyzed relative to time of year to infer seasonal changes in location based on detections from acoustic telemetry. Such information will be crucial as the Mi'kmaq and the Government of Canada navigate their nation-to-nation relationship relative to the Treaty fishery.

2.2 METHODS

2.2.1 Apoqnmatulti'k

This research is part of Apoqnmatulti'k (Mi'kmaw: "we help each other"), a 3-year collaborative study built upon a Two-Eyed Seeing/Etuaptmumk framework. Two-Eyed Seeing was defined by Mi'kmaw Elder Albert Marshall and Elder Dr. Murdena Marshall as "learning to see with the strengths of Indigenous knowledge from one eye and with the strengths of western knowledge from the other eye and using both eyes together in order to benefit all" (Bartlett et al., 2012). Apoqnmatulti'k brings together local knowledge holders, Mi'kmaw rights holders, and individuals from academia and government to weave together local and academic perspectives from Mi'kmaw and western worldviews. This framework is used to join together those with different worldviews in order to

conduct research in an equitable environment that nurtures co-learning (Hatcher, 2012; Johnson et al., 2016).

2.2.2 Study Site

Located within the Bras d'Or Lake/Pitu'paq our study sites were in the Barra Strait/Tewitk (45.960230°, -60.799353°) and the East Bay/Tewitnu'jk (45.888890°, -60.648236°) (Figure 2.1). The Barra Strait is a narrow passage that connects the Bras d'Or Lake to the North Basin and controls the exchange of water between the two (Petrie & Bugden, 2002; Shaw et al., 2006). There are strong, semi-diurnal, tidal currents in the area that can range up to 3 metres/second (Lambert, 2002; Shaw et al., 2006). The Barra Strait is also the dividing line between LFA 27 and 28, with LFA 27 to the north and LFA 28 to the south (Figure 2.1). The East Bay is located within LFA 28, on the eastern side of the lake. It has low densities of lobster and is dominated by soft substrate (Tremblay et al., 2005; Unama'ki Institute of Natural Resources, 2007).
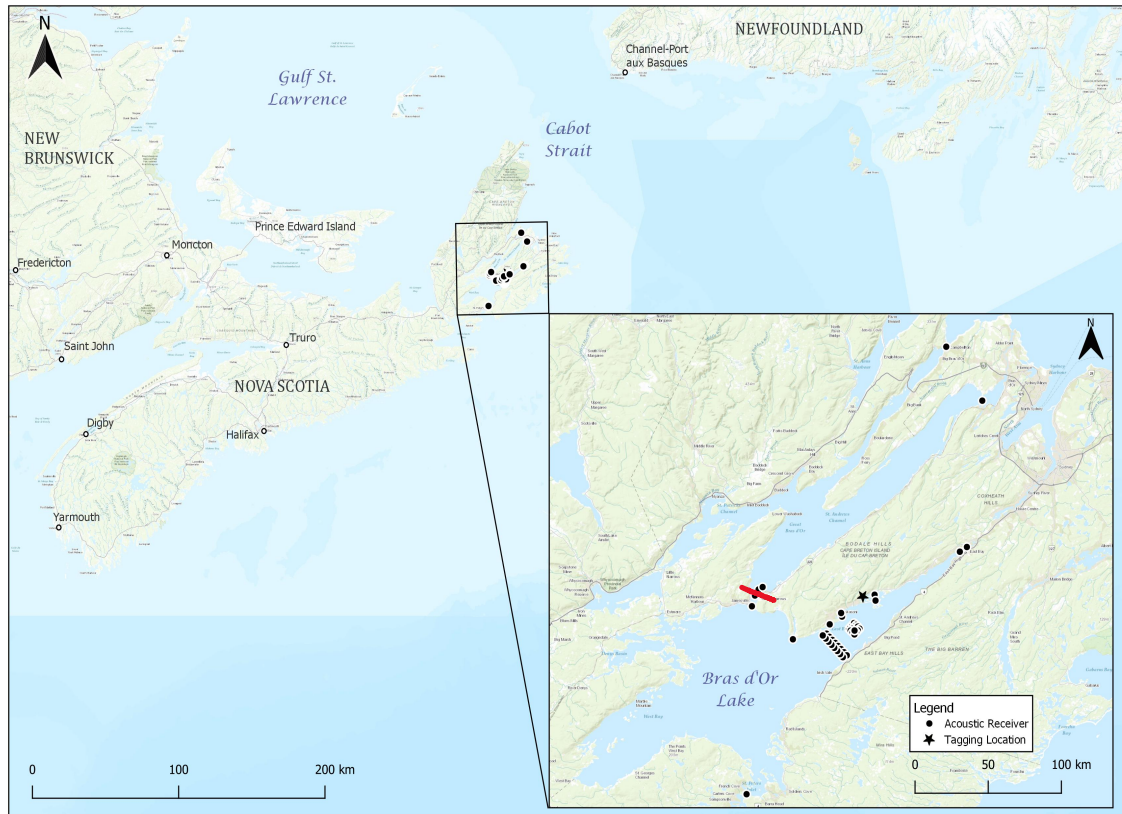
Figure 2.1   Receiver locations (n=47) within the Bras d'Or Lake. Red line indicates the divide between Lobster Fishing Areas 27 (north of line) and 28 (south of line). Map used and adapted with permission from Caelin Murray.

2.2.3 Study Design

Together with the Ocean Tracking Network (OTN) field team and the Unama'ki Institute of Natural Resources (UINR), we deployed a total of 47 acoustic receivers (InnovaSea VR2ARs) from June 2019 until July 2021. Receivers were deployed on both sides of the Barra Strait Bridge (n=4), inside and at the mouth of Barachois ponds in the East Bay (n=8), in the St. Andrews Channel (n=1), the Great Bras d'Or Channel at New Campbellton (n=1), and St. Peters Inlet at Chapel Island (n=1). Sixteen receivers were arranged as a VEMCO Positioning System (VPS) array that functioned as a double gate across the mouth of the East Bay and the remaining 16 were arranged into a VPS array centred in the East Bay (Figure 2.1). The location of this array was selected based on the knowledge of UINR partners. Together, these VPS arrays provided fine-scale movement data with a median position error of 2.4 meters, thus increasing our ability to assess

habitat use and small-scale movements (Smedbol et al., 2014). As a result, 43 receivers were placed in LFA 28 and four were placed in LFA 27.

2.2.4 Lobster Capture and Tagging

Between September and December 2019 (n=33) and again from November to December 2020 (n=5), and with the assistance of the project's Community Liason, we tagged lobster caught in partnership with a local harvester in Eskasoni. Thirty-eight individuals were tagged with acoustic transmitters (model V13-1H-069 kHz, Vemco Division, InnovaSea Systems). The tags were 13 mm in diameter with an estimated battery life of 838 days and each unique tag was labeled as "BL #" to represent the individual lobster ID. Tags transmit a unique acoustic signal every 120 to 240 seconds. Criteria for tagging were individuals weighing more than 660g (for tags to be less then 2% of their body weight; Baras & Lagardere, 1995; Jepsen et al., 2002; Scopel et al., 2009) and receiving a shell hardness score of 3 or higher (Appendix B, Figure B.2). Because handling of berried females can contribute to up to 50% egg loss (Unama'ki Institute of Natural Resources, 2007) and the production of lobsters in the Lake is already low (Parker et al., 2007), we avoided handling any berried females in order to mitigate the impact this study could have on the population. Thus, this thesis will not include any data from berried females.

Acoustic transmitters were glued (LePage Ultra Gel Super Glue) directly onto the carapace of the individual lobster, and streamer tags (Floy Tag & Mfg. Inc.) with an ID number and UINR contact information were inserted into the abdomen. Data on carapace length, weight, sex, shell hardness, signs of shell wasting disease, body condition, and antennae truncation were recorded, following protocol outlined by DFO (Appendix B). In total, we tagged 18 individuals collected from the East Bay VPS array (LFA 28), 10 from south of the Barra Strait bridge (LFA 28), and 10 from north of the Barra Strait bridge (LFA 27) (Figure 2.1). This study was reviewed and approved by the Dalhousie Animal Care Committee (protocol I19-17).

2.2.5 Telemetry Data Analysis

2.2.5.1 Data Filtering

Detection data were imported into R using the GLATOS package, which processes, analyses, and visualizes acoustic telemetry data (Holbrook et al., 2019). Detections immediately following release of the individual indicated that the tags were functioning, but detections within 48 hours of release were removed from analyses in case tagging protocols affected animal behaviour (Bowlby et al., 2007; Holbrook et al., 2019; Wickham et al., 2020). The GLATOS false detection function was used to identify and remove potential false detections using a threshold time interval of 3600 seconds (30 times the minimum delay of the tags used). A datum was deemed a potential false detection when the threshold time was exceeded between detection 'A' and the next closest detection of that transmitter (detection 'B') on the same receiver (Binder et al., 2018). Lobster metadata and acoustic receiver data were imported into R and merged with the detection data (Holbrook et al., 2019; R Core Team, 2020).

Fine-scale data from the VPS arrays were imported into R (R Core Team, 2020). Data from lobster detections were removed to determine the horizontal positioning error (HPE) cut-off value using sync tag detections (Meckley et al., 2014). HPE is a relative unitless estimate of error sensitivity and can be used to assess the position quality (F. Smith, 2013). Positions with higher HPE are of a lower quality and likely provide less information about the animals position (F. Smith, 2013). The relationship between HPE and HPEm, the error in absolute terms, was determined separately for each dataset (n=3), separated by their location (East Bay array and gate array) and deployment (2019-2020, 2020-2021) (J. H. Coates et al., 2013). The 2020-2021 deployment of the gate array was disregarded as no lobsters were detected. HPE values were binned and the number of positions within each bin was determined. The lowest HPE bin that retained 95% of the original positions was determined for each dataset and was recorded as a potential HPE cut-off value (Appendix C, Table C.1).

Data were then filtered at each HPE cut-off and the median, 90th, and 95th percentiles of HPEm were calculated, as well as the percent of original positions retained at that cut-off.

The lobster tag data for each dataset were filtered at each potential cut-off value and the percent of original positions retained was determined. The final HPE cut-off value, HPE<25, was selected based on the balance between obtaining higher confidence in animal positions and losing spatial information (J. H. Coates et al., 2013). When all three datasets were combined and filtered at HPE<25, the median HPEm for sync tags was 2.4m and the 90th and 95th percentiles were 8.2m and 11.5m respectively. HPEm values cannot be calculated for animal tags as the 'true' position cannot be known, however HPE is calculated the same way for sync and animal tags, so it is expected that the absolute accuracy (HPEm) of the animal tags would be similar to that of the sync tags (J. H. Coates et al., 2013). Detections within 48 hours of release were removed to account for any effects that tagging may have on animal behaviour and the data were then filtered to include only those animals with over 100 positions fixes (Bowlby et al., 2007; Wickham et al., 2020).

2.2.5.2 Data Analysis

Detection data were filtered using the package *dplyr* to include only the lobsters that were detected on one of more of the receivers placed at narrow channels connecting the Bras d'Or Lake and the Atlantic Ocean (Wickham, 2016).

Using the *sf* package, a polygon was created to encompass the 16 receivers within the double gate array and overlaid on the fine-scale data. A value was assigned to each column denoting whether the detection was from inside the polygon (0) or outside (1) (Pebesma, 2018). Due to the hyperbolic positioning used to obtain VPS positions, the data could be further analyzed to determine whether the position was within the polygon (0, "Gate"), outside the polygon and within the East Bay (1, "EB"), or outside the polygon and within the Bras d'Or Lake (-1, "BDL") (Wickham et al., 2020). Individuals with position fixes classified as "BDL" underwent further analysis. All locations with the position "BDL" were separated out, along with the row above and below them (R Core Team, 2020; Wickham et al., 2020). Time spent in the Bras d'Or Lake was quantified by subtracting the first "Gate" position following a "BDL" position from the first "BDL" position.

The proportion of position fixes within each area (BDL, Gate, and EB) were determined, as well as the time of year of the positions (Wickham et al., 2020). Movements of individuals between the two VPS arrays (East Bay array and gate array) were also determined by filtering out the individuals with positions within both arrays and then performing analyses on each individual (Wickham et al., 2020). First and last positions within each array were used to determine the length of time the lobster was undetected (and assumed to be moving between the arrays) as well as the time of year these movements were occurring (R Core Team, 2020; Wickham et al., 2020). The minimum distance travelled on each trip between arrays was calculated using Google Earth Pro and the latitude and longitude of their last and first position in each array. Individuals that travelled to the gate array and individuals that remained in the East Bay array were grouped together and a Wilcoxon rank-sum test was performed to determine if there was a significant difference between the size (carapace length) of the lobsters that moved to the gate array and those that did not (R Core Team, 2020).

Detection data were filtered to include only those individuals who were caught and released in the Barra Strait study area and then detections were distilled into detection events using the detection_events() function in the GLATOS package (Holbrook et al., 2019). No threshold time was selected; a new event began when there was a detection on a different receiver. Detection events with less than three detections were then filtered out, as that meant the individual had spent less than 10 minutes within range of the receiver and this was deemed insufficient for analysis. The detections on the four receivers in the Barra Strait were plotted to identify movements across the LFA boundary and the time of year these occurred. Lines were added to the plot to visualize movements across the boundary in relation to the opening and closing of the commercial seasons in each LFA (R Core Team, 2020; Wickham, 2016; Wickham et al., 2020). Detections were summed by month, year, and the LFA the receiver was in to determine which months across the study period had the highest detections in each LFA (R Core Team, 2020; Wickham et al., 2020). Detections were then summed just by month and year to determine which months across the study period had the total highest detections.

2.3 RESULTS

Following data filtering, sufficient detections remained for 32 of the 38 tagged lobsters study animals to conduct the desired analysis. No lobsters were detected on any of the three receivers stationed at channels connecting the Bras d'Or Lake and the Atlantic Ocean throughout the study period, September 2019 to July 2021.

2.3.1 Fine-Scale Movements in the East Bay/Tewitnu'jk

Individuals spent much more time in the East Bay array than in the gate array, accounting for 96% of all positions across the study period. Following the filtering of the fine-scale data, positions remained from 10 lobsters within the East Bay and three had positions on both the East Bay array and the gate array (Figure 2.2). Two of the lobsters travelled from the East Bay array to the gate array between the end of October and the beginning of December 2019, one lobster (tag id: BL 027) was undetected for 41.7 days within this period and travelled at least 4.3 km, the other (BL 032) was undetected from its release until its first position within the gate array, a minimum distance of 4.8 km across 8.24 days. Both lobsters maintained positions within the gate array until mid-to-late April 2020, spending 142.23 days (BL 027) and 140.11 days (BL 032) in the area. A total of 15.93 of the days that BL 032 was positioned at the gate array was classified as being spent within the Bras d'Or Lake (Figure 2.3). BL 027 was undetected for 166.7 days after leaving the gate array and travelled at least 4.3 km to return to the East Bay array at the beginning of October 2020. BL 032 was undetected for 56.29 days and travelled a minimum distance of 3.4 km to return to the East Bay array in the middle of June 2020. The third lobster (BL 031) that travelled between both arrays had their last position in the East Bay array at the end of April and first position in the gate array in the beginning of May 2020, remaining undetected for 12.54 days and travelling at least 3.1 km. There was no significant difference (p=1) found between the lengths of those who travelled to the gate array (mean=112mm ± 4.98mm, n=3) and those who did not (mean=114mm ± 15.2mm, n=7).
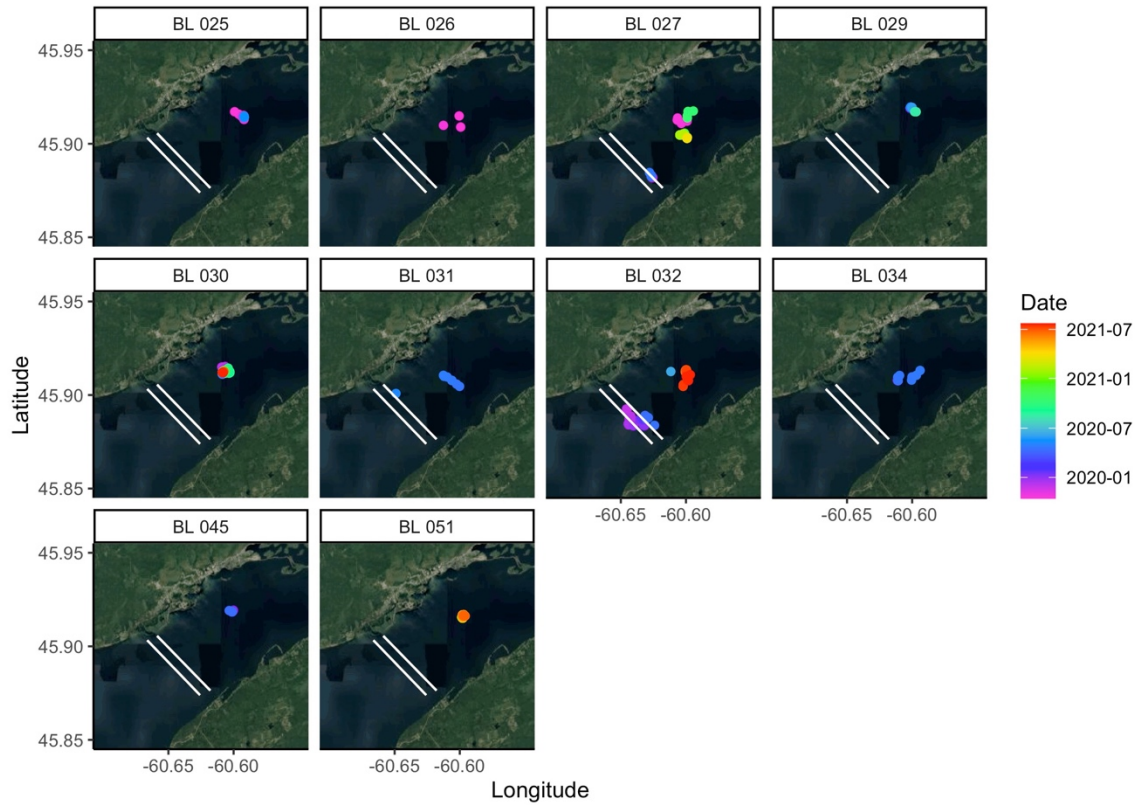
Figure 2.2   Positions of individual lobsters ("BL #") within the East Bay throughout the study period. White lines denote the double gate array and the colour of the points denotes the time period of the position.
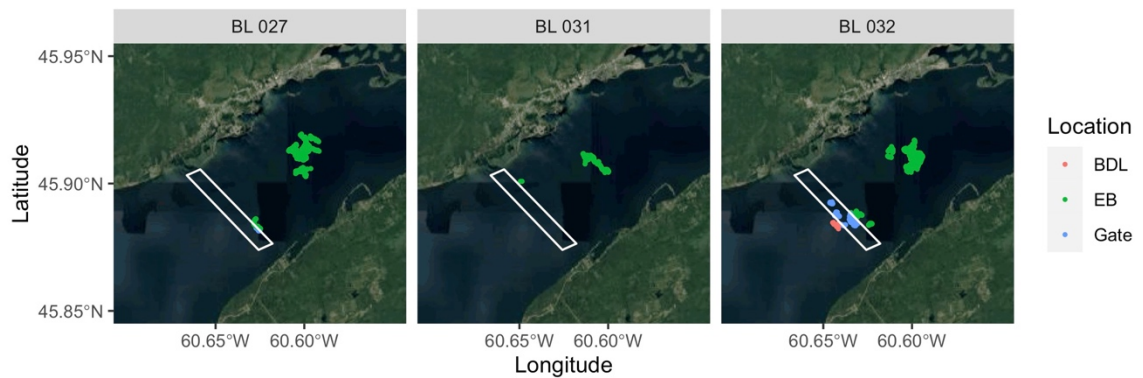
Figure 2.3   Positions of three lobsters that moved from the East Bay array to the gate array. White box denotes the polygon created around the double gate array. Colours denote whether the position was classified as within the gate array (Gate), outside of the gate array and in the East Bay (EB), or outside of the gate array and in the larger Bras d'Or Lake (BDL).

2.3.2 Movements around LFA Boundary

Of the 20 lobsters tagged and released in the Barra Strait area, only 15 were detected on one or more of the four receivers in the area following data filtering and 12 were detected by receivers in both LFA 27 and LFA 28 (Figure 2.4). Detection events indicate lobsters moved consistently between the two management areas, both within and outside of the commercial fishing seasons (Figure 2.4). Five individuals were detected in both LFAs between May and July 2020, when the commercial season was open in at least one management area. The highest number of detection events in LFA 27 was in October 2019 and in May 2020 for LFA 28. When datum from LFAs were combined, October 2019 and May 2020 were still found to be the months with the highest number of events, accounting for 26.2 and 17.3% of total events, respectively.
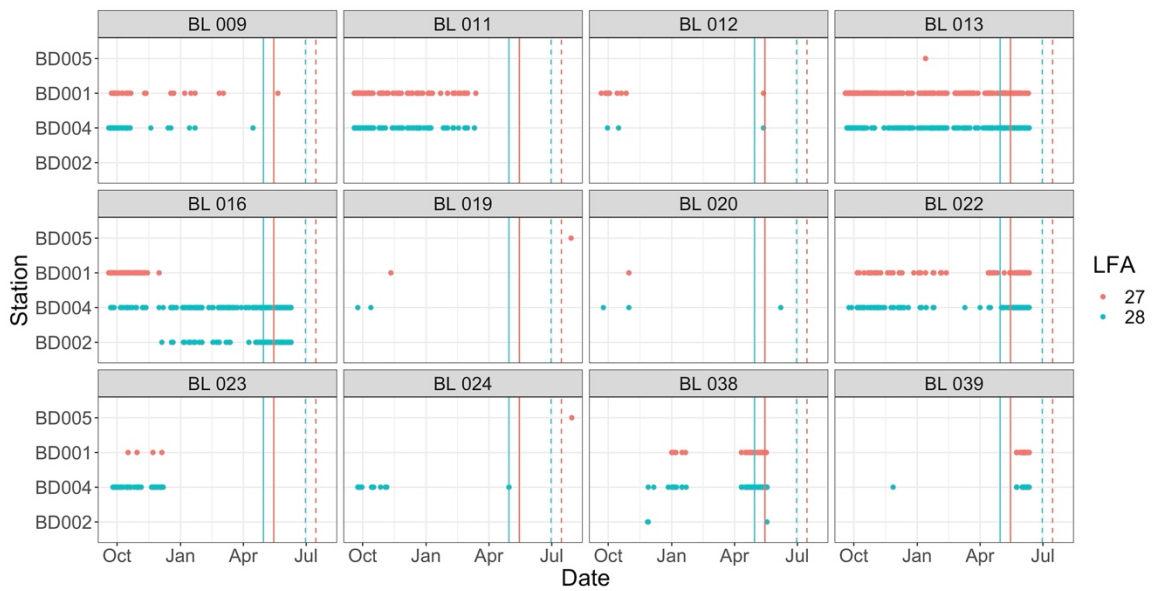
Figure 2.4   Detection events of each individual on receiver stations in both Lobster Fishing Areas (LFAs) from September 2019 to July 2020. Detections on stations in LFA 27 are shown in red and in LFA 28 are shown in blue. The solid lines indicate the opening of the commercial season (LFA 27 in red and LFA 28 in blue), while the dashed lines indicate the closing of the season. The LFA boundary is between the stations "BD004" and "BD001".

2.4 DISCUSSION

2.4.1 Barriers to Lobster Movements

The low level of movement of lobster across the gate array in the East Bay provides a visualization of the fidelity that individuals have been known to show to the area and suggests that this population is isolated from those in other parts of the Bras d'Or Lake, likely driven by local recruitment (S. Denny, personal communication, May 22, 2019). Lobster tended to remain in and around the East Bay array, and those who did travel to the gate array returned to the East Bay array within months, excepting one individual whose detections ceased shortly after arriving at the gate array. No individuals were found to leave the East Bay entirely, though one lobster was positioned as outside of the gate on the Bras d'Or Lake side for under 16 days, before returning to within gate positions. The lobsters that travelled to the gate array did so in the autumn/early winter (October to early December) and left the area in the spring (April), similar to dispersal patterns seen in the Northumberland Strait as individuals sought appropriate over-wintering habitat (Bowlby et al., 2007). Soft substrate dominates in the East Bay and while some lobsters use soft-substrate burrows in the warmer months, they may leave the area as the water cools to locate a more appropriate winter shelter (Bowlby et al., 2007; Cooper et al., 1975; Tremblay et al., 2005). Understanding these types of movements and the factors that drive them is critical for appropriate management (Le Quesne & Codling, 2009; Pezzack, 1989). The fishing pressures that an isolated population of lobster within a single bay can sustain is different than what lobsters in other parts of the same LFA could sustain, especially considering the variability of the Bras d'Or Lake (Pezzack, 1989; Pittman & McAlpine, 2003; Tremblay et al., 2005).

While there are ecological boundaries affecting lobster movements in the study area, the results from the human-designated management boundary show consistent movement of individuals between the LFAs. Of the detection events on both sides of the management boundary, 17.3% were in May 2020, indicating a higher presence of lobsters in the area at a time when the commercial seasons are opening. LFA 28 opens on April 30, while LFA 27 opens on May 15. The individuals that travel across the management boundary may experience increased vulnerability, as they could be facing fishing pressures for a longer

time period. Not only do the dates of the commercial seasons differ between these LFAs, but so do other measures such as number of traps per license (275 in LFA 27, 250 in LFA 28) and the minimum legal size for harvest (82.5mm in LFA 27, 84mm in LFA 28) (Fisheries and Oceans Canada, 2019b).

Importantly, we cannot control a mobile aquatic species, so we place controls on the harvesters of that species. Despite there being areas within the Lake that act as ecological boundaries for lobster, this management boundary only ensures that harvesters do not cross it, to maintain order and predictability within the fishery (Fisheries and Oceans Canada, 2021a). Area-based management, an initiative within Canada's aquaculture fishery, provides one potential framework for adaptive management that could be applied to the lobster fishery. Within this initiative, management areas are to be determined at a local level, with consideration of First Nations' territories, and are intended to account for varied biophysical, jurisdictional, and socioeconomic considerations (Fisheries and Oceans Canada, 2020d). Area-based management, conducted through a Two-Eyed Seeing framework, could account for these considerations while also strengthening recommendations and relationships by valuing diverse knowledge holders. Strong management must be adaptive in order to reflect the realities of the species being managed, while also providing clear and safe guidelines for harvesters to ensure the stock remains healthy (Denny & Fanning, 2016b).

The movements of individuals around the Barra Strait illustrate their consistency in crossing between LFAs, however the receiver coverage was low, with only two receivers on each side of the boundary. Due to this, we can only know that they were detected on receivers in both, without knowing the time that was being spent within each LFA. Acoustic telemetry provides incredible insights into the movements of aquatic animals, but it is presence only data. The absence of animals is inferred by the absence of detections, which is not true absence (Macleod et al., 2008). The lobsters had external acoustic tags which could fall or be knocked off, thus their absence could be inferred simply due to tag loss (Bowlby et al., 2008). The VPS arrays provided more comprehensive coverage and fine-scale positions of individuals, but could still only

provide information about a limited spatial area (Hussey et al., 2015). With Two-Eyed Seeing, we were able to position our East Bay array in an area known to partners at UINR as suitable lobster habitat. As a result, we had many lobsters that remained within the array for sustained periods of time, allowing for greater collection of individual positions for analysis. This created a bias in our data, as we chose a location for the array that we knew would give us more data than another area in the same bay. However, our key questions are not comparing areas of the bay and this array placement supported our primary objective.

2.4.2 A Path Forward

Evolving discussions between First Nations and the Government of Canada are charting a path forward for evidence-based lobster management, and management that recognizes and affirms Mi'kmaw rights, including to fish under Treaty rights. In 2015, Prime Minister Trudeau mandated the Minister of Fisheries, Oceans and the Canadian Coast Guard to contribute to a renewed relationship with First Nations Peoples, and to ensure that it appropriately reflected our nation-to-nation relationship (Office of the Prime Minister, 2015). In 2019, he restated the importance of advancing reconciliation and supporting self-determination, while also stating they are to do anything in their power to accelerate both (Office of the Prime Minister, 2019). Specific to fisheries management, he states the importance of decision-making using both Indigenous and western knowledge, as well as the need for continued work towards co-management (Office of the Prime Minister, 2019). Despite this, the recent implementation of Treaty fisheries have resulted in conflict and violence (Beswick, 2019; Bundale, 2020; Edwards & Tutton, 2021; Saltwire Network, 2019). Throughout this time, the Government of Canada can be perceived as failing to meet their own mandates and obligations (Fisheries and Oceans Canada, 2019a, 2021c; Office of the Prime Minister, 2015, 2019), by maintaining that the Treaty fishery is "illegal" and seizing Mi'kmaw traps from the water (Beswick, 2021; Fisheries and Oceans Canada, 2021a; A Moore, 2021; Rhodes, 2021).

Future studies should be conducted in the Bras d'Or Lake to understand the nuances of lobster movements in other areas and determine where there are isolated populations so

that management plans can reflect this. Enhanced knowledge of population dynamics and movement patterns within confined areas, such as recruitment and seasonal habitat use, can improve our understanding of the factors affecting lobster productivity and provide managers and harvesters with additional knowledge to inform their decisions. In a system as diverse as the Bras d'Or Lake, management needs to take a more adaptive approach (Denny & Fanning, 2016b; Miller & Breen, 2010; Tremblay et al., 2005). Studies that model how a preventative, basin-level approach can support the realities of lobster movements could further promote management plans that align with the local context. Given that we have two nations sharing the same waters and resources, these future studies must be built upon a framework, such as Two-Eyed Seeing, that engages with and values diverse knowledge holders and addresses questions that are relevant to both the Federal Government and the Mi'kmaw Nation. With co-developed science and shared information, the power dynamics upheld in current decision-making processes can be redistributed to better reflect our nation-to-nation relationship (Castro & Nielsen, 2001; Denny & Fanning, 2016b; Office of the Prime Minister, 2015).

Currently, DFO maintains that Treaty fisheries must follow the rules of the commercial fishery to ensure there is a 'level-playing field', however, the Treaty fishery allows for fewer traps, uses smaller boats, and encourages family-friendly practices (for example, children fish alongside family members) (B. Maloney, personal communication, September 22, 2021; Fisheries and Oceans Canada, 2021b). Additionally, Mi'kmaw harvesters have the right to fish, while western harvesters have only the privilege (S. Denny, personal communication, October 9, 2019; Supreme Court of Canada, 1990, 1999). While co-management, and operationalizing it for lobster in the Bras d'Or Lake, is not the focus of this paper, it is important to note that such a management regime would be one possible pathway forward. Co-management involves the combination of local- and state-level management systems and exists on a spectrum of possibilities (see work of Armitage et al., 2011), though always requires mutual recognition of the strengths within each system (Berkes et al., 1991). Regardless of where lobster might fall on that spectrum, equitable co-management would require the power dynamics between Mi'kmaw and western decision-makers be addressed, rather than the current focus on

Mi'kmaw and non-Mi'kmaw harvesters (Akena, 2012; Armitage et al., 2011; Castro & Nielsen, 2001; TallBear, 2014). Harvesters are managed as a means of managing lobsters, and harvesters should be managed by their own nation, supporting self-determination and reflecting our nation-to-nation relationship (Office of the Prime Minister, 2015, 2019). As seen by the current management differences between LFAs, uniform management is not critical to managing healthy stocks (Fisheries and Oceans Canada, 2019b). What is critical, however, are the relationships between decision-makers and the ability of those involved to engage with their differences in cultural experiences and knowledge (Natcher et al., 2005). The establishment of Treaty fisheries provides an opportunity to engage in meaningful co-management of our lobster fisheries in a manner that values diverse knowledge holders and results in the equitable sharing of lobster.

The results presented here demonstrate the importance of understanding ecological boundaries for lobster (e.g., Figures 2.2 and 2.3), rather than relying on human-designated boundaries for management (e.g., Figure 2.4). When managing a mobile species such as lobster, it is critical to understand what may be restricting their movements and their local recruitment mechanisms, as this can vary between areas within a single LFA (Pezzack, 1989; Tremblay, 2002). With shared knowledge from our partners at UINR, we were able to design this study in a way that honoured the values of all partners while providing enhanced knowledge of lobster movements for western and Mi'kmaw decision-makers as they continue to navigate the Treaty fishery and discover what co-management looks like between the two nations.

CHAPTER 3: HABITAT AND MOVEMENT SELECTION PROCESSES OF AMERICAN LOBSTER/JAKEJ WITHIN A RESTRICTED BAY IN THE BRAS D'OR LAKE/PITU'PAQ

3.1 INTRODUCTION

Lobster densities within the Bras d'Or Lake are low compared to areas with similar habitats immediately outside of the lake, along the Atlantic coast (Parker et al., 2007; Tremblay et al., 2005). Low egg production, limited food, limited habitat, and low salinity are commonly cited as the factors that limit lobster production (Parker et al., 2007). Within the Bras d'Or Lake, studies have not yet been able to confirm or eliminate the impact of any of these factors (Tremblay, 2002). Though limited food and low salinity may inhibit lobster abundances from matching those seen on the outer coast, there is the potential to increase abundance by addressing egg production and habitat availability (Parker et al., 2007; Tremblay et al., 2005). Egg production in the Lake is only thought to be low because of the low density of lobsters. Proportional to the outer coast, the Lake has more female lobsters than male and more of these females are berried (have eggs) (Tremblay et al., 2005). Thus, past studies have focussed on the potential for habitat enhancement to increase lobster abundances in the Lake but much is still unknown (Fisheries and Oceans Canada, 2004; Tremblay, 2002; Tremblay et al., 2005).

Within the Bras d'Or Lake, the majority of the bottom is sandy to silty substrate (low structure), though there are areas with boulder and cobble (medium and high structure) (Parker et al., 2007). Enhancing lobster habitat through man-made additions has been suggested as a possibility in areas of the Bras d'Or Lake that may have less ideal lobster habitat, such as in the East Bay where low structure habitat dominates (Tremblay et al., 2005). Results from the telemetry study (Chapter 2) visualized the high degree of site fidelity that lobsters have been known to show in the East Bay (S. Denny, personal communication, May 22, 2019) and suggests the local lobster population is isolated from those in other parts of Bras d'Or Lake. Detailed knowledge of substrate classes and their distribution within the Bras d'Or Lake is lacking, with data available from multibeam

bathymetry but no comprehensive quantification of the entire area (Shaw et al., 2005, 2006; Tremblay, 2002; Vandermeulen, 2016). Knowledge about habitat is critical due to its role in explaining the distribution and composition of lobster communities as well as its influence on behaviours (Karnofsky et al., 1989b; Skerritt et al., 2015). Substrate has been found to impact lobster movement characteristics, such as step length and turning angle. Low structure, soft substrates favour high speed and high directionality (Skerritt et al., 2015), whereas medium-high structure, hard substrates necessitate slower speeds and lower directionality to navigate (Schippers et al., 1996; Skerritt et al., 2015; Wiens et al., 1997). Behaviours can also be inferred from movement characteristics, with shorter step lengths and lower directionality classified as searching or foraging movements while longer step lengths and higher directionality are classified as exploratory movements (Martin et al., 2009; Skerritt et al., 2015). Enhancing our understanding of lobster movement and habitat selection can contribute to evidence-based management and potential rebuilding in a changing fishery.

First Nations and the Government of Canada are searching for a path towards evidence-based lobster management in the Bras d'Or Lake and beyond, one that recognizes and affirms Mi'kmaw rights, including to fish under Treaty rights. Within Cape Breton/Unama'ki, Potlotek First Nation first launched their Treaty fishery in October 2020 (E. Smith & Chisholm, 2020). With a Treaty fishery comes the potential for increased lobster fishing in areas of the lake generally unfished by commercial harvesters, such as the East Bay/Tewitnu'jk (Parker et al., 2007; Tremblay, 2002; Tremblay & Eagles, 1997). Given this potential of re-establishing fishing in the area, western and Mi'kmaw knowledge holders coming together could identify shared gaps in knowledge and co-develop research programs to address them, so that management decisions can be made that support Mi'kmaw self-determination, contribute to genuine co-management, and address the realities of local lobster movements and habitat use.

This chapter contributes to a collaborative project, Apoqnmatulti'k, which is addressing some of these persistent knowledge gaps, and doing so in a way that respects different knowledge paradigms. As part of Apoqnmatulti'k, benthoscape mapping, which models

substrate and geomorphology, was completed for the entire Bras d'Or Lake (Murray, 2021). This knowledge of the habitat can be used with habitat-selection analyses to provide greater insights into the selection processes of American lobster/jakej (*Homarus americanus*). Traditionally, resource-selection functions have been used to link animal movements to their environment, but these rely on the assumption that the space available to the animal is temporally static, and do not account for repeated measures sampling designs in telemetry data (Signer et al., 2019a; Street et al., 2021). Step-selection functions provide an emerging advance to addressing this problem by allowing for dynamic space-use based on the individuals' own movements, but assume that habitat selection is dependent on movement but movement selection is not dependent on habitat (Signer et al., 2019a). This assumption was addressed with the introduction of integrated step-selection functions (iSSFs), which allow both movement and habitat-selection processes to be modelled simultaneously (Fieberg et al., 2021; Signer et al., 2019a). Pairing the benthoscape map with fine-scale acoustic telemetry provided an ideal setting to perform iSSFs using the *amt* package for R (Murray, 2021; Signer et al., 2011). The primary objective of this work was to test which substrate classes lobster are using in a bay with high site fidelity but low productivity. My aim was to answer two key questions: 1) do lobsters select for specific substrates? and 2) do lobster movements alter based on the substrate?

3.2 METHODS

3.2.1 Apoqnmatulti'k

Built upon a Two-Eyed Seeing/Etuaptmumk framework, Apoqnmatulti'k (Mi'kmaw: "we help each other") is a 3-year collaborative study that joins together those with different worldviews in order to conduct research in an environment built on equity and co-learning (Hatcher, 2012; Johnson et al., 2016). Two-Eyed Seeing was defined by Mi'kmaw Elder Albert Marshall and Elder Dr. Murdena Marshall as "learning to see with the strengths of Indigenous knowledge from one eye and with the strengths of western knowledge from the other eye and using both eyes together in order to benefit all" (Bartlett et al., 2012). Apoqnmatulti'k brings together local knowledge holders, Mi'kmaw

rights holders, and individuals from academia and government to weave together local and academic perspectives from Mi'kmaw and western worldviews.

3.2.2 Study Site & Design

This study took place within the East Bay/Tewitnu'jk in the Bras d'Or Lake/Pitu'paq (45.888890°, -60.648236°) (Figure 3.1). The East Bay is located within LFA 28, on the eastern side of the lake. It has low densities of lobster and is dominated by soft substrate (Tremblay et al., 2005; Unama'ki Institute of Natural Resources, 2007). Sixteen receivers (InnovaSea VR2ARs) were deployed by the Ocean Tracking Network (OTN) field team and Unama'ki Institute of Natural Resources (UINR) staff from June 2019 until July 2021. These receivers were arranged into a VEMCO Positioning System (VPS) array. VPS arrays increase the ability to assess habitat-use and small-scale movements by providing positions based on triangulation, within the grid array (Smedbol et al., 2014). The median position error was 2.4 meters. The VPS array was located within the centre of the East Bay, in an area known to UINR partners for having higher densities of lobster than other parts of the bay (Figure 3.1).
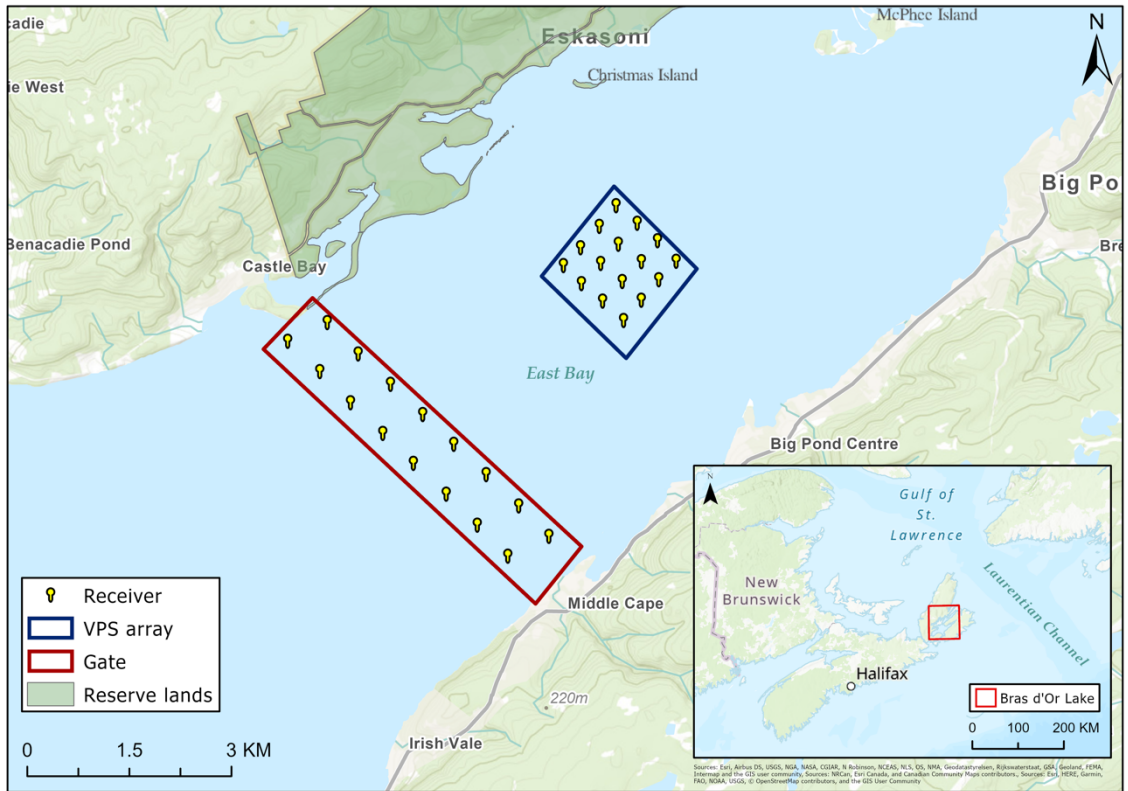
Figure 3.1   Receiver locations (n=32) within the East Bay. The VPS array is within the
              blue. Map used with permission from Caelin Murray.

3.2.3 Lobster Capture and Tagging

Lobsters were tagged between October and December 2019 (n=17) and again in

December 2020 (n=1), with the assistance of the project's Community Liaison and a local

harvester from Eskasoni. Each individual was tagged with a unique acoustic transmitter

(model V13-1H-069 kHz, Vemco Division, InnovaSea Systems). Tagging methodology

is detailed in Chapter 2. Berried females were excluded from this study as the handling of

berried females can contribute to up to 50% egg loss (Unama'ki Institute of Natural

Resources, 2007). Lobster production in the Lake is low (Parker et al., 2007), thus UINR

partners required that we avoided handling any berried females to remain aligned with

study values and mitigate the impact this study could have on the population. This study

was reviewed and approved by the Dalhousie Animal Care Committee (protocol I19-17).

3.2.4 Habitat Quantification

Benthoscape mapping was completed using backscatter and bathymetry data from the Bras d'Or Lake collected through multibeam echosounder surveys conducted by the Canadian Geological Survey and the Canadian Hydrographic Service between 1999 and 2009. These surveys covered approximately 777.6 km^2 of the lake, leaving some areas with no multibeam coverage (Murray, 2021; Shaw et al., 2005). A spatial grid was generated through a principal component analysis to account for at least 95% of the variance between environmental covariate layers, backscatter data, and bathymetry data and then segmentation was performed using an unsupervised object-based image analysis. The final benthoscape classification was developed through ground-truthing with images from Shaw et al. (2006) and newly collected video footage using Remotely Operated Vehicles. The images were classified, using the Wentworth scale (1922) and the Folk (1954) method, into 5 substrate classes from 449 images: 1) till, 2) mud with < 50% pebble/cobble/gravel, 3) coarse sediment with a veneer of mud, 4) deep soft sediment, and 5) soft sediment (Table 3.1). The overall accuracy for the benthoscape is 70.2% with a kappa statistic of 0.42%, indicating moderate agreement (Appendix D; Landis & Koch, 1977; Wilson et al., 2021).

Table 3.1   Names and descriptions of the five substrate classes identified within the Bras d'Or Lake[1].

Class	Name	Description
0	Till	a mixture of fine and coarse sediments, such as sand or sandy pebble gravel
1	Mud with <50% pebble/cobble/gravel	comprised of mud or silty mud with less than 50% pebbles, cobbles, gravel, and occasional boulders
2	Coarse sediment with a veneer of mud	a mixture of course sediments, such as gravel and cobble, with a veneer of mud
3	Deep soft sediment	comprised mainly of silty mud and mud, greater than 50m depth
4	Soft sediment	comprised mainly of silty mud and mud, less than 50 m depth

[1]Murray, 2021

3.2.5 Telemetry Data Analysis

3.2.5.1 Data Filtering

Fine-scale data from the VPS array was imported into R (R Core Team, 2020). The horizontal positioning error (HPE) cut-off value was determined using sync tag detections (Meckley et al., 2014). HPE is an estimate of error sensitivity and is used to assess the position quality. It is unitless and relative, so HPE values are not comparable between studies (F. Smith, 2013). A higher HPE value signifies that a position is of lower quality

and likely providing less information about the position of the animal (F. Smith, 2013). Each deployment (2019-2020, 2020-2021) of the VPS array was treated as an individual dataset and potential HPE cut-off values were determined for each, using the relationship between HPE and HPEm, the error in absolute terms (J. H. Coates et al., 2013). The HPE cut-off value was determined following the methodology outlined in Chapter 2. An HPE cut-off value of <25 was selected, balancing higher confidence in animal positions with the loss of spatial information (J. H. Coates et al., 2013). When the two datasets were combined and filtered at HPE<25, the median HPEm for sync tags was 2.4m and the 90th and 95th percentiles were 8.4m and 11.9m respectively. The 'true' position of animal tags cannot be known, thus HPEm values cannot be calculated. However, HPE calculations are conducted the same way for sync and animal tags so the absolute accuracy (HPEm) of the animal tags is expected to be similar to that of the sync tags (J. H. Coates et al., 2013). To account for tagging effects on animal behaviour, any detections within 48 hours of release were removed and the data then filtered to include only individuals with over 800 positions fixes (Bowlby et al., 2007; Street et al., 2021; Wickham et al., 2020).

3.2.5.2 Data Preparation

Analyses were conducted using the *amt* package and its dependencies (Signer et al., 2011). The *amt* package requires particular data preparation in order to infer habitat and movement selection (Signer et al., 2019a). When running the same analysis on multiple individuals, a uniform sampling rate must be selected to ensure each individual is being analysed on the same temporal scale (Signer et al., 2019a). The make_track() function was applied to the positions of each lobster to create a track, the foundation of the *amt* package, using latitude, longitude, and time. The time intervals between successive positions were then summarized for each individual and the longest sampling rate that contained 75% of positions (q3), 10 minutes, was recorded for future use (Signer et al., 2011, 2019a; Wickham et al., 2020). Preparation of the substrate raster, derived from the benthoscape map (Murray, 2021), included classifying areas with no data into a sixth category for analysis and creating a function to collapse the levels of the raster into appropriate groups (Murray, 2021; Wickham, 2020a; Wickham et al., 2020). This

function combined deep soft sediment and soft sediment substrate classes, because they were only distinguished by depth and depth was not a variable used in these analyses.

Two functions were created, the first to transform VPS data into useable data for the *amt* package (issf function) and the second to bootstrap the results (boot function) (Appendix E; Signer et al., 2019). The first step of the issf function is to classify the positions as tracks, using the make_track() function outlined above. The track then must be resampled using the sampling rate determined above, 10 minutes, and a sampling tolerance. Two minutes was selected as the tolerance of deviations from the sampling rate (Signer et al., 2011). Resampling the data creates regular bursts and, using filter_min_n_burst(), only those bursts with three or more positions were retained because this is the minimum required to calculate a turning angle between successive positions along a path (Signer et al., 2019a). The steps_by_burst() function is used to convert tracks to step representations from point representations and to calculate relative turning angles and step lengths (Signer et al., 2011). Random steps were generated using the random_steps() function, which uses a habitat-selection kernel multiplied by a selection-free movement kernel to determine an availability domain around each observed position and samples the specified number of random locations from within that domain (Fieberg et al., 2021). One hundred steps were selected for this analysis as a higher number of steps increases the computational burden but also reduces the estimation error (Fieberg et al., 2021; Signer et al., 2019a). The substrate class was then extracted from both the beginning and the end of each step (Signer et al., 2011). For one individual, very few positions were recorded on *coarse sediment with a veneer of mud* at the start and end of a step compared to other substrates (e.g., 549 compared to >5,000). For another, very few positions were recorded on the area with no data at the end of a step compared to the other substrates (e.g., 1 compared to >1,300). For a third individual, very few positions were recorded on *coarse sediment with a veneer of mud* and *soft sediment* at the end of a step compared to the other substrates (e.g., 3 and 56 compared to >18,000). Inclusion of these positions prevented model fitting; therefore, they were removed from the analysis. Any infinite log step length values were filtered out, along with any non-computable turning angles (Wickham et al., 2020).

The boot function was used to generate bootstrap replicates (n=1,000) using random sampling with replacement (Wickham, 2020b). The model was:

fit_issf(step ~ ending substrate + log of step length + cosine of turning angle + starting substrate:log of step length + starting substrate:cosine of turning angle + stratified steps)

The model used conditional logistic regression to test how observed steps compared to random simulated steps when assessing habitat and movement selection processes. The response variable represented whether the step was an observed step or a random step. The first predictor variable was used to infer habitat selection processes, while the two predictor variables with interactions were used to infer movement processes (Fieberg et al., 2021; Signer et al., 2019a). The final predictor variable accounted for the stratified steps, which include the observed step and the random steps associated with it (Signer et al., 2019a). The substrate reference level was set to *mud with less than 50% pebble/cobble/gravel*, as this was the most common substrate used. The code required to complete the above is provided in Appendix F.

3.2.5.3 Data Analysis

Filtered lobster positions were plotted on the substrate raster for visual inspection (Murray, 2021; R Core Team, 2020; Wickham, 2016). The boot function was run for each lobster. The mean of the estimate for the substrate at the end of each step and the mean of the 2.5 and 97.5 percentiles of the standard distribution were determined from the bootstrapped data, and plotted for visual inspection of the mean model estimates for each individual (Wickham, 2016; Wickham et al., 2020). The mean estimate for each substrate at the end of a step was then exponentiated as a measure of the relative selection strength. Relative selection strength indicates the probability of a specific substrate class being selected compared to the probability of the reference substrate class, *mud with less than 50% pebble/cobble/gravel*, being selected (Avgar et al., 2017). Throughout this work, this will be referred to as the odds of ending an observed step on one substrate compared to the reference substrate. Odds of 1.0 signify equal probability of selecting a specific substrate compared to the reference substrate, while odds lower than 1.0 signify a

lower probability of choosing that substrate and odds higher than 1.0 signify a higher probability of choosing it compared to the reference class.

The bootstrapped data frames were then analysed to determine the 95% odds ratio distribution. The data were grouped by the terms of the model and the 2.5 and 97.5 percentiles were summarized. If 0 was included within these two percentiles, then the distribution overlapped 0 and this was interpreted to mean that no effect was observed. The code required to complete the above is provided in Appendix G. For interactions between the substrate at the start of the step and the cosine of the turning angle, when the distribution did not overlap 0 and was negative it indicated that the concentration parameter of the von Mises distribution was less concentrated than if a step started on the reference class. Biologically, this was interpreted as indicating lower directionality of the individual (more movements deflecting from a straight path). When positive, it indicated a more concentrated parameter of the von Mises distribution and was interpreted as higher directionality (more movements along a straight path). In the case of the interaction with the log of the step length, a distribution that did not overlap 0 and was negative indicated that the shape parameter of the gamma distribution was more concentrated towards 0 than if a step started on the reference class. Biologically, this was interpreted as indicating shorter step lengths by the individual. When positive, it indicated that the shape parameter of the gamma distribution was more concentrated away from 0 and was interpreted as longer step lengths (Signer et al., 2019a).

3.3 RESULTS

Data from five individuals were used in the analysis, and they ranged in carapace length from 101mm to 138mm with a 4:1 ratio of males to females. Lobster positions were plotted on the substrate raster and indicated an avoidance of *soft sediment* by all study lobsters (Figure 3.2). However, the relative selection strength (Figure 3.3) and the odds ratio distributions (Table 3.2) illustrate individual variability in the selection of substrate classes. No effect was found for the odds of selecting a specific substrate for two of the individuals (BL 027 and BL 034), though substrate did have an effect on the movement selection processes of BL 027 (Table 3.2). This individual displayed shorter observed

steps with lower directionality when starting on *coarse sediment with a veneer of mud and till* and displayed longer observed steps with higher directionality when starting on the area with no data, when compared to the reference class. When starting on *soft sediment*, the observed steps of BL 027 were more likely to have lower directionality compared to starting on the reference class, but no effect was found for the length of the steps.
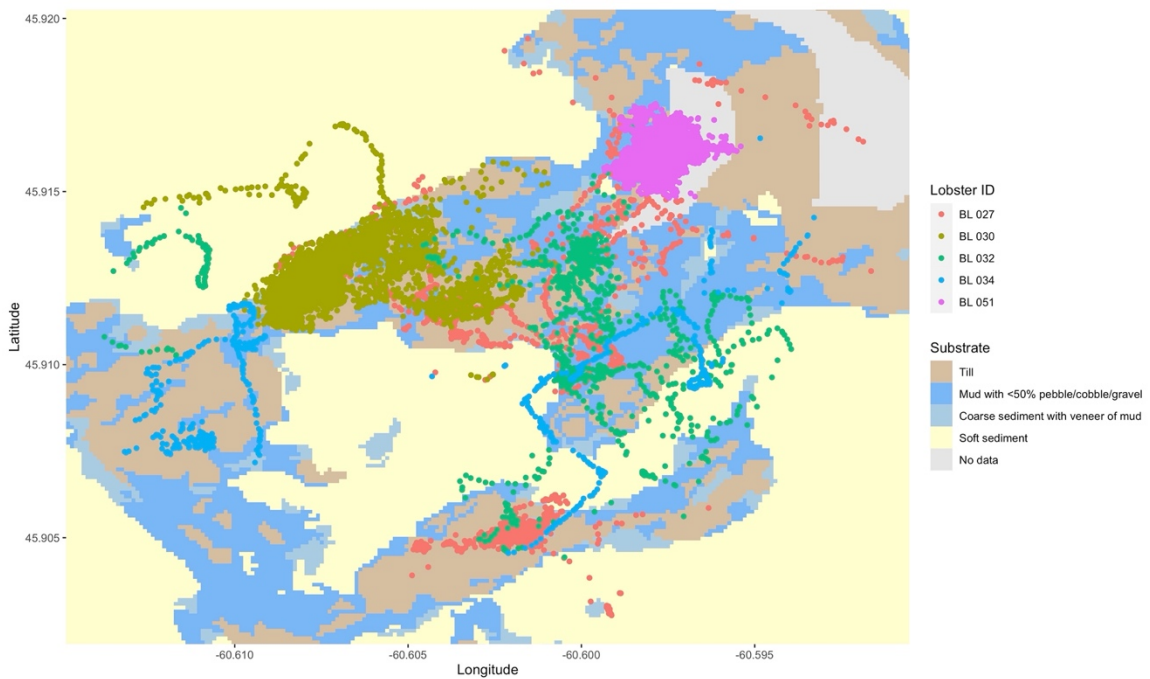
Figure 3.2   Positions of 5 lobsters overlaid on a substrate raster from within the East Bay/Tewitnu'jk in the Bras d'Or Lake/Pitu'paq. Lobster positions were obtained through fine-scale positioning using a VEMCO Positioning System (VPS) array (n=16 receivers).
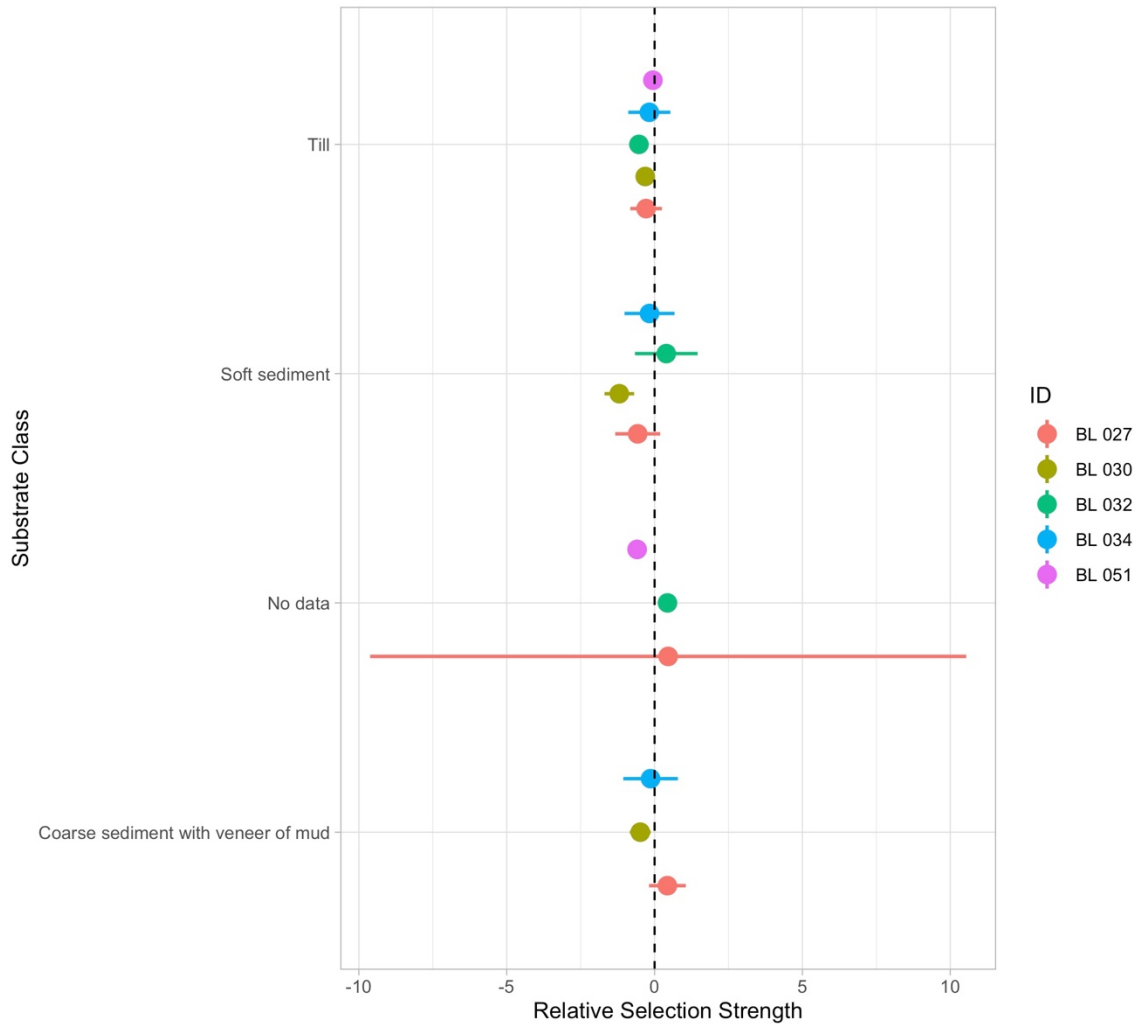
Figure 3.3   Relative selection strength of different substrate classes by five lobsters using point estimates (points) with 95% confidence intervals (horizontal lines) (Avgar et al., 2017; Signer et al., 2019a). No preference relative to the reference class, mud with less than 50% pebble/cobble/gravel, is indicated by intervals crossing the dashed vertical line.

Table 3.2 Model outputs of fitted integrated step selection functions and bootstrapped data for individual lobster. Estimate is the mean beta coefficient from the fitted model and CI is the lower (2.5 percentile) and upper (97.5 percentile) confidence intervals from the bootstrapped data. The effect is classified as significant in relation to the reference substrate class, mud with less than 50% pebble/cobble/gravel, if it does not overlap 0 and is denoted by an asterisk (*). In the Term column, cos_ta_ represents the cosine of the turning angle and log_sl_ represents the log of the step length. sub_start represents the starting substrate while sub_end represents the ending substrate. csed represents *coarse sediment with a veneer of mud*, nd represents the area with no data, and ssed represents *soft sediment*.

| Term	BL 027		BL 030		BL 032		BL 034		BL 051	
	Estimate	CI	Estimate	CI	Estimate	CI	Estimate	CI	Estimate	CI
cos_ta_	0.731	0.41, 1.08 *	0.339	0.11, 0.57 *	-0.420	-0.56, -0.29 *	-0.026	-0.48, 0.51	0.017	-0.06, 0.09
cos_ta_:sub_startcsed	-1.360	-1.80, -0.96 *	-0.319	-0.75, 0.12	NA	NA	-0.530	-1.79, 0.99	NA	NA
cos_ta_:sub_startnd	25.428	5.04, 51.90 *	NA	NA	-0.310	-0.55, -0.07 *	NA	NA	-0.276	-0.42, -0.14 *
cos_ta_:sub_startssed	-1.263	-2.19, -0.45 *	-0.021	-0.48, 0.49	1.490	0.83, 2.40 *	0.065	-0.71, 0.98	NA	NA
cos_ta_:sub_starttill	-0.664	-1.09, -0.27 *	-0.371	-0.61, -0.14 *	0.046	-0.19, 0.30	0.318	-0.42, 1.14	-0.218	-0.51, 0.06
log_sl_	0.326	0.16, 0.51 *	0.778	0.56, 1.01 *	-0.007	-0.05, 0.04	-0.026	-0.16, 0.12	0.021	-0.03, 0.07
log_sl_:sub_startcsed	-0.499	-0.69, -0.33 *	-0.467	-0.81, -0.11 *	NA	NA	-0.164	-0.55, 0.20	NA	NA
log_sl_:sub_startnd	3.823	0.42, 5.98 *	NA	NA	0.002	-0.07, 0.07	NA	NA	0.072	-0.01, 0.16
log_sl_:sub_startssed	-0.204	-0.50, 0.17	-0.377	-0.73, 0.01	1.499	1.01, 2.16 *	0.031	-0.23, 0.33	NA	NA
log_sl_:sub_starttill	-0.288	-0.50, -0.10 *	-0.814	-1.05, -0.59 *	-0.047	-0.12, 0.03	0.109	-0.12, 0.34	-0.128	-0.30, 0.04
sub_endcsed	0.434	-0.16, 1.08	-0.482	-0.85, -0.14 *	NA	NA	-0.134	-1.10, 0.72	NA	NA
sub_endnd	0.461	-1.54, 2.30	NA	NA	0.438	0.23, 0.63 *	NA	NA	-0.589	-0.78, -0.40 *
sub_endssed	-0.571	-1.43, 0.15	-1.192	-1.71, -0.72 *	0.397	-0.72, 1.37	-0.170	-1.01, 0.67	NA	NA
sub_endtill	-0.285	-0.83, 0.28	-0.315	-0.55, -0.08 *	-0.528	-0.88, -0.21 *	-0.176	-0.91, 0.51	-0.055	-0.37, 0.23

Substrate at the end of an observed step was found to have an effect for the remaining three individuals. For BL 030, the odds of ending an observed step on *soft sediment* were 0.30 compared to ending it on the reference class, while the odds of ending on *coarse sediment with a veneer of mud* were 0.62 and *till* were 0.73, indicating a selection preference for *mud with less than 50% pebble/cobble/gravel*. Observed steps that began on *coarse sediment with a veneer of mud* were more likely to be shorter than those started on the reference class, with no effect on directionality found. Observed steps that began on *till* were more likely to be shorter with lower directionality than observed steps starting on the reference class (Table 3.2). For BL 032, no effect was found between the odds of ending an observed step on *soft sediment* compared to the reference class, though the odds of ending an observed step on *till* were 0.59 and the odds of ending on the area with no data were 1.55. Observed steps of BL 032 that began on s*oft sediment* were likely to be longer with higher directionality than those beginning on the reference class. When starting an observed step on the area with no data, both BL 032 and BL 051 were more likely to exhibit lower directionality than when starting a step on the reference class

(Table 3.2). The odds of BL 051 ending an observed step on the area with no data was 0.55 compared to the reference class, while no effect was found between the odds of BL 051 ending an observed step on *till* compared to the reference class.

3.4 DISCUSSION

Data usable for iSSFs were procured from five of the 18 tagged individuals. Despite this limited sample size, notable individual variation was exhibited by the tagged lobsters. iSSFs utilize conditional logistic regression to resample the observed data through the generation of random steps (Signer et al., 2019a). By using conditional logistic regression, the analysis is then conducted on data stratified on its own response variable values, allowing for inferences to be made about the observed habitat and movement selections compared to those individuals could, realistically, have made (Craiu et al., 2008; Fieberg et al., 2021). These results are, to my knowledge, the first use of iSSFs to describe habitat and movement selection processes of an aquatic species in their natural habitat.

Though the strength of substrate preferences varied by individual, only two lobsters favoured other substrates more than the reference class, *mud with less than 50% pebble/cobble/gravel* (Figure 3.3). Lobsters rely on shelters throughout their life and therefore require habitats that meet this need (Selgrath et al., 2007). Certain substrates, those with higher structure from cobbles and boulders, provide superior shelters and foraging areas, though sheltering and foraging can both occur on various substrates (Selgrath et al., 2007; Skerritt et al., 2015). For example, a lobster can create a shelter by burrowing into soft sediment but crevices within cobble or boulder are better (Selgrath et al., 2007). Substrate selection preferences can be a consequence of life stage, as younger lobsters require more protection from predation than larger lobsters, or species abundance and distribution (Boyce et al., 2016; Gaillard et al., 2010; Hovel et al., 2010; Selgrath et al., 2007; Tremblay, 2002). The higher the density of lobsters in an area, the higher the need for shelters and prey. Due to their agonistic nature, some lobsters in high density areas may select for lesser substrates to reduce their interactions with other lobsters in the same area (Selgrath et al., 2007).

Individuals tended to exhibit longer step lengths alongside higher directionality and shorter step lengths alongside lower directionality, aligning with past research on animal movements (Bowlby et al., 2007; Skerritt et al., 2015; Zollner & Lima, 1999). In particular, *till* and *coarse sediment with a veneer of mud* were found to elicit shorter steps with lower directionality than *mud with less than 50% pebble/cobble/gravel*. These movements are recognized as more energetically expensive than longer steps with higher directionality, as exhibited on *soft sediment* (Table 3.2; Skerritt et al., 2015; Zollner & Lima, 1999). Based on previously characterized behaviours, these movement selections can be characterized as searching or foraging movements and exploratory movements, respectively (Martin et al., 2009; Skerritt et al., 2015). When on *till* and *coarse sediment with a veneer of mud*, lobsters exhibit more searching or foraging movements while exploratory movements are seen more on *soft sediment*, in comparison to *mud with less than 50% pebble/cobble/gravel*. The area with no data resulted in lobsters selecting for opposite movements, with one lobster exhibiting higher directionality and two others exhibiting lower directionality than on the reference class, leading to the assumption that this area contained more than one substrate class.

Higher structure habitats, such as those with more cobble and boulder, provide better lobster habitat (Tremblay et al., 2005). The East Bay is known to be dominated by low structure habitats, so of the substrate classes within the bay, those that provide the most structure were *mud with less than 50% pebble/cobble/gravel* and *coarse sediment with a veneer of mud* (Table 3.1; Tremblay et al., 2005). Movement selections made on *till* are more energetically expensive and the low structure leaves lobsters more exposed to predation (Selgrath et al., 2007; Zollner & Lima, 1999). *Soft sediment* favours movements that are the least energetically expensive with potential foraging for fish buried in the sand, but also provides very little protection (Karnofsky et al., 1989a; Skerritt et al., 2015; Zollner & Lima, 1999). While many of these preferences were not found to have a significant effect on habitat selection, they do provide information that can be used to inform future hypotheses.

This study is limited in its sample size, as 72% of the tagged lobsters were removed from the analysis. Some of these lobsters did not meet the requirements of iSSFs, which need high resolution data, while other individuals may have left the VPS array or shed their external tags outside of the array (Bowlby et al., 2008). Many insights into the movements of aquatic animals can be collected using acoustic telemetry, but it provides presence only data. True absence of animals cannot be determined, so inferred absence is used (Macleod et al., 2008). Acoustic telemetry can also only provide insights into lobster movement within the receiver array, resulting in a spatial limitation as any lobster that leaves the array to use another habitat cannot be accounted for (Hussey et al., 2015; Reubens et al., 2019). Two-Eyed Seeing can help reduce some of these limitations, as Mi'kmaq knowledge is not restricted to the receiver locations or the battery life of tags (Bartlett et al., 2012; Brooks et al., 2019; Peltier, 2018). Through our partners at UINR, we were able to position the VPS array in an area with suitable lobster habitat. Consequently, many of the tagged lobsters were detected within the array throughout the study period, though for some of them this was not enough to meet the data requirements of iSSFs. This sharing of knowledge was able to save time, money, and materials when deploying the VPS array.

The use of iSSFs can result in novel findings about animal movement and habitat selection processes, however, it can be challenging to conduct this type of analysis. Obtaining high resolution data on animals over a long period of time is very difficult, resulting in the low sample size seen here. However, low sample sizes with high quality data have been found to be sufficient in resource selection functions in the past, and only six animals were used in the 2019 publication demonstrating the *amt* package (Signer et al., 2019a; Street et al., 2021). Aside from sample size, a model including step length was not able to be fit to the data, and step length may have had an effect on movement processes. When fitting a model that included both step length and the log of the step length, the model outputs contained many infinite values, and this could not be resolved. Finally, the *amt* package does not have a way to assess model fit and other packages with functions to do so were unable to run with this data (R Core Team, 2020; Therneau, 2021). In the absence of credible model validation tools for iSSFs, such as residual

analysis, it will be difficult to assess how well they are able to reflect the true selection strengths shown by individuals.

Some of the challenges presented here may be attributed to the fact that *amt* was developed using data on fishers (*Pekania pennanti*), a forest-dwelling mammal, and that other users of *amt* also tend to use larger, terrestrial animals (Biddlecombe et al., 2020; Fieberg et al., 2021; Meyer et al., 2020; Richter et al., 2020; Signer et al., 2019b). Future studies which are conducted closely with the developers of *amt* may help to address some of these issues and enhance the usability of this package for a greater diversity of research. Studies using iSSFs can also provide insights into selection processes on a seasonal scale, as certain substrates, such as *till* or *soft sediment*, may be selected for during specific seasons, for example, as a result of prey items being found in the area or seasonal migrations. This type of information would be valuable to managers in developing adaptive management plans as discussed in Chapter 2. Finally, UINR is conducting a lobster habitat enhancement project and on October 14, 2021, 104 artificial reef balls were installed within the East Bay (Reynolds, 2021). This provides another ideal setting to use iSSFs, as they could provide fascinating insights into lobster habitat selection processes as habitat availability improves within the area.

Having a variety of substrates accessible to lobsters can allow individuals to exhibit diverse behaviours while remaining close to their shelter (Selgrath et al., 2007). However, availability of substrates may alter the extent to which behaviours are exhibited on substrates less suited to the behaviour (Wahle, Battison, et al., 2013). The availability of substrates also influences distribution, as lobsters do require their own shelters and space, or else they will be displaced through territoriality (Gaillard et al., 2010; Karnofsky et al., 1989b; Selgrath et al., 2007; Wahle, Battison, et al., 2013). The influence of substrate availability on abundance comes out of the different requirements of lobsters at different life stages (Boyce et al., 2016; Cobb, 1971; Werner & Gilliam, 1984). The adult lobsters used in this study have very little risk of predation, thus allowing them to exhibit more exploratory behaviours and reducing their association with substrates that provide shelters (Selgrath et al., 2007; Tremblay, 2002). However, this bay is dependent upon

local recruitment and juvenile lobsters require more from their habitat than adults, due to their higher risk of predation (Cobb, 1976; Hovel et al., 2010; Selgrath et al., 2007; Spanier et al., 1998). Foraging, in particular, presents a much higher risk for juveniles than adult lobsters (Selgrath et al., 2007). If the more ideal substrates in this area have already been filled with adult lobsters, juveniles may not be able to meet their more specialized habitat requirements (Hovel et al., 2010; Selgrath et al., 2007). In a culturally significant area with low lobster productivity, understanding this is critical for enhancing recruitment and fostering evidence-based lobster management that also recognizes and affirms Mi'kmaw rights. With a Two-Eyed Seeing framework, we can co-produce science that identifies shared knowledge gaps and contributes to strong management decisions that supports Mi'kmaw self-determination and addresses the realities of local lobster movements and habitat use.

CHAPTER 4: CONCLUSION

The Bras d'Or Lake, with its unique features and socio-cultural history, was an ideal setting for a study on a highly valued species, American lobster/jakej, and the complexities of the lake embody the complexities of sharing knowledge across knowledge systems (Hatcher, 2018; Parker et al., 2007; D. N. Paul, 2006; Tremblay et al., 2005). Studies on lobster are particularly critical in Nova Scotia, as lobster are not only a part of the collective identity and commercially valuable, but they are currently the focus of significant attention from the Federal government, Mi'kmaw communities, and scientists, as well as the media and the public, due to the recent implementation of Treaty fisheries for lobster (Beswick, 2021; Bundale, 2020; Edwards & Tutton, 2021; Fisheries and Oceans Canada, 2020b; Ryan, 2019; Thériault et al., 2013).

This work identifies lobster movements in relation to current commercial management boundaries, addressing the purpose of current management techniques and how applicable they are to supporting Indigenous self-determination in the fishery. It also provides insights into the habitat and movement selections of lobsters within a restricted bay with low lobster productivity in the Bras d'Or Lake. Within this bay, work is newly being conducted to enhance habitat for lobster with the addition of 104 artificial reef balls (Reynolds, 2021) and the results of this thesis can provide information from before the installation occurred. Aside from providing insights into the selection processes of lobsters, this work also outlines the process of using integrated step selection functions (iSSFs) with aquatic telemetry data.

Lobster management must honour the Peace and Friendship Treaties while identifying and addressing shared knowledge gaps. In Chapter 2, I demonstrated the importance of recognizing ecological boundaries for lobsters when creating management plans, especially in a changing fishery. I also showed how lobsters consistently crossed human-designated management boundaries (Figure 2.4), providing support for the position that it is the harvesters being managed, as a means of managing lobsters. Lobsters were found to remain within the East Bay, exemplifying an ecological boundary and supporting the

known high site fidelity of lobsters to this bay (Figures 2.2 & 2.3). In Chapter 3, I used a benthoscape map created by a project partner (Murray, 2021) to provide novel insights into how the habitat within the East Bay VEMCO Positioning System (VPS) array was used by lobsters. These findings demonstrated the individual variations in lobster movement and habitat selection processes, while also showing that adult lobsters can and will utilize diverse substrates, though this may hinder productivity and impact lobsters differently at different life stages (Figures 3.3 & 3.4).

Within the context of the Bras d'Or Lake, these findings demonstrate the complexities of managing species within such a diverse body of water (Lambert, 2002; Parker et al., 2007). These waters have sustained the Mi'kmaq for thousands of years, and following colonization, became home to the French and the Scots (Hatcher, 2018). The lake also provides a home to many species, including some from the sub-tropics to the arctic (Lambert, 2002). A lake with this degree of diversity, both within its waters and on its shores, calls for a high degree of diversity in its management and the knowledge that informs it. Adaptive co-management that values diverse ways of knowing can benefit not only the species living within the lake, but also the humans living on it.

The specific objectives of each chapter were met, but importantly, the conceptual model for the overall project (Figure 1.1) places an equal focus on the process involved in coming to these conclusions in addition to the findings themselves. Apoqnmatulti'k demonstrates the methodology, results, conclusions, and how lessons were learned, when biology research is undertaken within a Two-Eyed Seeing framework, in which knowledge holders with academic or local perspectives within Mi'kmaw and western worldviews work together to enhance stewardship of ecosystems and the species within them. It is an example of what can be created when there is equal engagement and participation between diverse partners. I believe that this collaboration has been successful because of the relationships built throughout it and the commitment shown by project partners. Partners are currently in discussion about how to carry Apoqnmatulti'k on past the originally agreed upon three years. This desire to continue working together is, for me, a strong indicator of a successful collaborative project and it can likely be

partially attributed to the strong foundation and relationships that have been nurtured over the past years. It is also likely that some of this desire is a result of the fact that this project has not yet met all its original goals, given the relatively short time-frame and conditions (the pandemic) under which we had to work, but there is a belief that if we continue to work together, we can achieve them.

Some of the obstacles yet to be overcome are exhibited by this thesis. The knowledge gained through this thesis came out of a Two-Eyed Seeing framework and was greatly directed by knowledge shared with me throughout my time on the project. However, input from the local community, intended to be gathered through Mi'kmaw Ecological Knowledge workshops, was unable to be obtained due to the COVID-19 pandemic. These workshops were intended to gather knowledge shared by local harvesters and to learn about gaps in knowledge within the community so that the research could address these. Workshops were continually delayed because of the pandemic and this thesis was completed before any were held. Workshops will still be held in the near future, and can provide valuable information that can help direct the future work of Apoqnmatulti'k. But as a result, this thesis lacks input and direction from the community it was meant to serve, and analyses were conducted using only western academic knowledge.

While representation was important in Apoqnmatulti'k, the project was still dominated by western academics and the research outputs completed within western institutions. Within these institutions, high value is placed on timelines and individual work, which contradicts the need to be flexible, adaptive, and inclusive when working with communities or diverse individuals (Gewin et al., 2021; Hill et al., 2020). Western timelines, especially in the natural sciences, do not account for the time it takes to build relationships and to foster those in an ever-changing social context. Meetings for Apoqnmatulti'k were not just a time for discussing science, they also provided a space to build relationships and awareness and to engage in cultural learning on all sides. Conducting meetings with a broader and more adaptable focus is critical for providing opportunities for partners to share unique perspectives and grow together. Western timelines also inhibit the relationship-building required between researchers and

communities, which is an issue when there is a desire and intention to develop research that meets the needs of communities. Within Apoqnmatulti'k, we addressed this through our Community Liaisons, a crucial position in each study site filled by individuals already known to and trusted by the community. Our Community Liaisons were integral to the success of this project thanks to their knowledge, connections to the community, and willingness to share their time and knowledge with project partners. The culmination of a Master's degree is a thesis, which has to be largely the work of one individual. In this thesis, the work has been infused by what others have shared with me, but the writing, data analysis, and conclusions were all completed by myself and through my western academic lens. A thesis is also intended for a western academic setting and not readily accessible to those outside of academia, such as a local community. Fortunately, Apoqnmatulti'k partners are addressing the need to ensure there are a diversity of project outputs and that the findings of this work do not remain solely within a thesis or a peer-reviewed publication.

We have the opportunity to utilize research frameworks that value diverse knowledge systems so we can create a knowledge landscape that is not dominated by a single way of knowing, but has room for natural variation in knowledge and where knowledge holders can grow and thrive alongside each other to create more just, diverse, and healthy systems (Alexander et al., 2019; Ban et al., 2018; Kimmerer, 2012; Reid et al., 2020). While this thesis may result from a project where the aspirations of Two-Eyed Seeing were not fully met, it does demonstrate the use of the framework from the research plan to the study design, tagging methodologies, and development of research questions. It also provides an excellent example of the challenges and successes of work of this nature and shows the value in continuing to remain committed to research that challenges the traditions of natural science. It can provide a strong foundation for further studies that follow the direction of local harvesters to address issues relevant to the local community.

Working within any framework that values diverse knowledge holders is an ever-changing process and each group will build a unique research project together. While there is no 'one size fits all' model for conducting research with Two-Eyed Seeing, there

are some lessons learned through Apoqnmatulti'k that, I believe, would lead to success if implemented by others. Firstly, project partners must do more than just hear what one another have to say, they must genuinely listen to the values and input shared by others. Secondly, time must be set aside to build relationships, knowing that the amount of time this takes cannot be anticipated in advance. Thirdly, and crucially, partners must be willing to sit in discomfort. This is not easy work, and it will be uncomfortable at times. Remaining committed through discomfort not only results in personal growth, but nurtures relationships and creates an environment in which partners feel valued and safe enough to share their perspectives. Apoqnmatulti'k is a success because every person involved wanted it to be a success and was willing to give their time, effort, and emotions to make it one.

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APPENDIX A: MAP OF LOBSTER FISHING AREAS IN NOVA SCOTIA
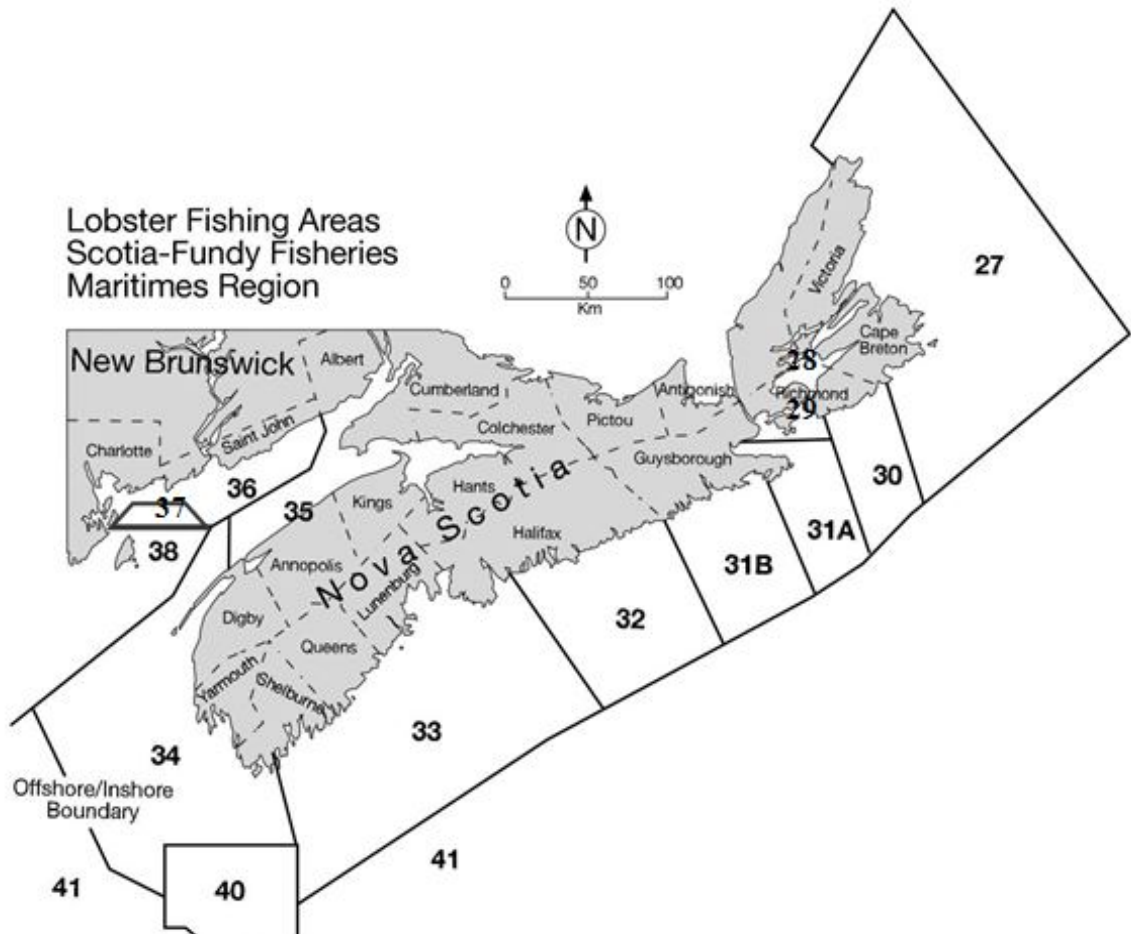

Figure A.1   Lobster fishing areas (LFAs) within Nova Scotia. These areas are designated by Fisheries and Oceans Canada and each area has its own set of rules and regulations. Study sites for this project are within LFA 27 and 28. Image from Fisheries and Oceans Canada, 2011, Retrieved from https://www.dfo-mpo.gc.ca/fisheries-peches/ifmp-gmp/maritimes/inshore-lobster-2011-eng.html#fig-2.

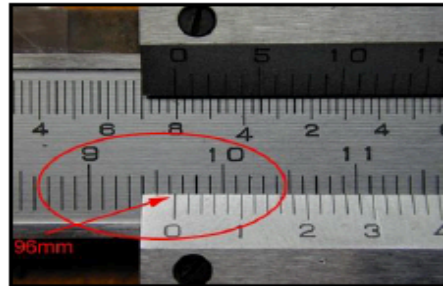# APPENDIX B: FISHERIES AND OCEANS CANADA SAMPLING PROTOCOL

Appendix A: How to measure the carapace length of a lobster

1. Ensure the small screw on the top of the calipers is loosened in order to be able to open and close the jaws of the calipers. Once loose, the jaws should open easily.
2. Place the top end of the caliper at the back of the eye-socket of the lobster. Pull the jaw of the caliper back and gently tighten it to the edge of the carapace (where the shell meets the tail).
3. Check to make sure that the calipers are in a straight line (parallel to the mid-line of the lobster). If they are crooked the measurements will not be accurate (Figures 3a and 3b).
4. Read the caliper where the zero mark on the slider indicates in millimeters the carapace length (not the inside edge of slider; there is a 3mm difference). The bottom of the caliper is marked in centimeters, lines between numbers are millimeters, so that 9||| would be 93, 9|||||| would be 96.
5. Always round down to a whole number, there is no need to estimate fractions of millimeters. For example, halfway between 92 and 93 would be recorded as 92.


Vernier calipers

How to read a caliper

Ensure the calipers are in a straight line in order to get an accurate measurement.

Figure B.1   Fisheries and Oceans Canada protocol for measuring lobster carapace length. Excerpt taken from the At Sea Sampling Protocol developed by the Lobster Unit at the Bedford Institute of Oceanography (Lobster Unit, 2019)

The shell hardness of a lobster is determined by gently squeezing different regions of the carapace. To determine the shell hardness, gently press the areas of the shell indicated; 'A' will harden first in a newly molted lobster, and 'C' will harden last. Be careful not to squeeze the carapace so hard as to puncture a hole through the shell.

A lobster that has just molted will have no shell and will be 'jelly' like to the touch (stage 1); a stage 2 hardness lobster would have a hardening shell but still be very breakable; a stage 3 would have a shell that could be compressed in both areas 'C' and 'B'; a stage 4 would be compressible in only area 'C'; a stage 5 would have a hard shell in all areas, and would not be compressible; a stage 6 would be a hard shelled lobster with epiphytic growth (ex. barnacle growth on the shell); and a stage 7 lobster would have the shell splitting in a straight line down the carapace (starting to molt).
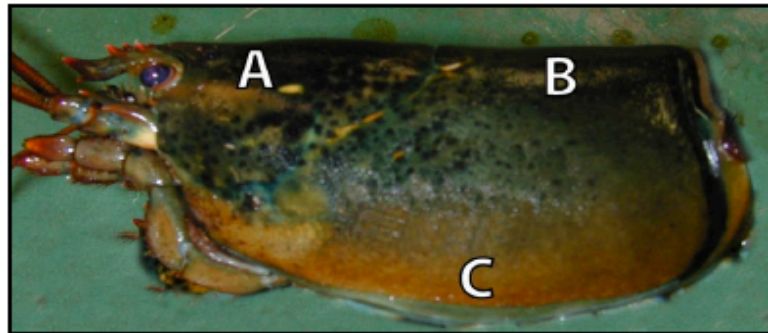
Shell hardness determination - Adapted from Aiken (1980)

Figure B.2   Fisheries and Oceans Canada protocol for determining the shell hardness of a lobster. Excerpt taken from the At Sea Sampling Protocol developed by the Lobster Unit at the Bedford Institute of Oceanography (Lobster Unit, 2019)

Appendix B: How to sex lobster and crab

To identify the sex of the lobster, hold the lobster underside-up so that you can look at the swimmerets. The sex of a lobster is determined by looking at the first set of swimmerets (at the top of the tail). A female lobster's first pair of swimmerets is feathery in appearance and the structures are usually crossed next to the body. A male's swimmerets are more rigid in appearance and are straight, not crossed. Female crabs will have a wider abdomen than the male crabs.

A female lobster.

A male lobster.

Code 2526: Snow/Queen Crab (*Chionoecetes opilio*)
Middle photo: male   Bottom photo: female

Code 2520: Toad Crab
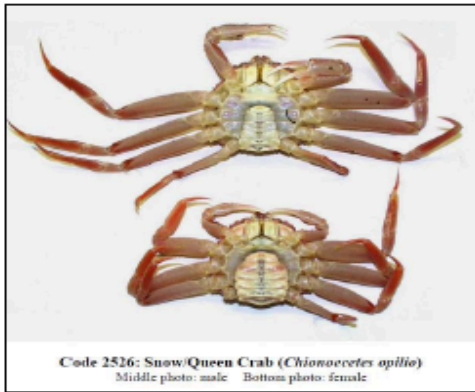Middle photo: male   Bottom photo: female

Figure B.3   Fisheries and Oceans Canada protocol for determining the sex of a lobster. Excerpt taken from the At Sea Sampling Protocol developed by the Lobster Unit at the Bedford Institute of Oceanography (Lobster Unit, 2019)

Shell disease presents itself as degradation to the shell of the lobster (Figures 10a-b). Shell disease is recorded according to the volume of the shell covered in degradation; code '1' is less than 10% of the shell; code '2' is 10-50% of the shell; and code '3' is more than 50% of the shell.

Figure B.4   Fisheries and Oceans Canada protocol for evaluating shell disease on a lobster. Excerpt taken from the At Sea Sampling Protocol developed by the Lobster Unit at the Bedford Institute of Oceanography (Lobster Unit, 2019)

APPENDIX C: HORIZONTAL POSITIONING ERROR (HPE) CUT-OFF VALUE DETERMINATION

Table C.1   Three potential HPE cut-off values were applied to the sync tag positions of three datasets. The median HPE in metres (HPEm), 90th percentile HPEm (90 HPEm), 95th percentile HPEm (95 HPEm), and percent of original positions retained were recorded. The same cut-off values were then applied to the datasets using only animal tag positions and percent of original positions retained was recorded again. A cut-off value of <25 HPE was selected as a balance between increased spatial information and increased confidence in animal positions.

Dataset	HPE cut-off value	Sync Tags				Animal Tags
		Median HPEm	90 HPEm	95 HPEm	positions retained (%)	positions retained (%)
Gate 2020	<18	2.4	6.7	8.6	>95	>88
	<25	2.4	6.8	8.8	>95	>92
	<48	2.5	7.4	10.4	>98	>97
Grid 2020	<18	2.3	7.7	11.1	>79	>79
	<25	2.5	9.9	13.8	>88	>83
	<48	2.7	11.7	16.1	>95	>94
Grid 2021	<18	2.2	6.5	8.9	>86	>93
	<25	2.4	7.7	10.6	>95	>95
	<48	2.5	8.1	11.5	>97	>97

APPENDIX D: BENTHOSCAPE MAPPING

Table D.1   Error matrix for the multibeam sublittoral benthoscape classification. Created by and used with permission from Caelin Murray[1].

Ground-truth (benthoscape) class	Map (IsoCluster) Classes					Row Total (no. of objects)	Producer's Accuracy (%)	Omission Error (%)
	4	1+9	7	5	0+2+3+6+8			
Till	**9**	6	3	0	15	33	90.0	10.0
Coarse sediments (gravel and cobble) with a veneer of mud	1	**3**	5	1	36	46	30.0	70.0
Mud with ≤50% Pebble/cobble/gravel	0	1	**1**	2	10	14	10.0	90.0
Deep soft sediment (≥ 50m)	0	0	0	**78**	48	126	71.6	28.4
Soft sediment (≤ 50m)	0	0	1	28	**279**	308	71.9	28.1
Total objects	10	10	10	109	388	**527**	**Overall Accuracy: 70.2%**	
User's Accuracy (%)	27.3	6.5	7.1	62.0	90.6		**Kappa Statistic: 0.42**	

[1]Murray, 2021

APPENDIX E: FUNCTIONS IN R

ISSF FUNCTION

```
issf <- function(i){
t <- amt::make_track(i, .x = LON, .y = LAT, .t = DATETIME,  crs =
sp::CRS("+init=epsg:4326"))
  r <- track_resample(t, rate = minutes(10), tolerance = minutes(2)) %>%
    filter_min_n_burst(min_n = 3) %>%
    steps_by_burst() %>%
    random_steps(n_control = 100) %>%
    extract_covariates(substrate, where = "both") %>%
    mutate(substrate_start = reclass_substrate(layer_start),
        substrate_end = reclass_substrate(layer_end),
        cos_ta_ = cos(ta_),
        log_sl_ = log(sl_)) %>%
    filter(!is.infinite(log_sl_)) %>%
    filter(!is.na(ta_))
}
```

BOOT FUNCTION

```
boot <- function(i){
  b <- i %>% bootstrap(., 1000)
  a <- b %>% .$strap %>%
    purrr::map( ~ fit_issf(case_ ~ sub_end + sub_start:log_sl_ + sub_start:cos_ta_ +
                strata(step_id_), data = .)) %>%
    map(., first) %>%
    purrr::map(~broom::tidy(.)) %>%
    bind_rows()
}
```

APPENDIX F: R SCRIPT PREPARING DATA FOR AMT PACKAGE

```
#choose a sampling rate and tolerance
dat <- grid_animalshort %>% dplyr::select(x='LON', y='LAT', t='DATETIME',
id='TRANSMITTER')
dat_all <- dat %>% nest(-id)

dat_all <- dat_all %>%
  mutate(trk=map(data, function(d) {
    amt::make_track(d, x, y, t, crs=sp::CRS("+init=epsg:4326"))
  }))
dat_all %>% mutate(sr=lapply(trk, summarize_sampling_rate)) %>% dplyr::select(id, sr)
%>%
  unnest(cols=c(sr))

#reclassify the substrate raster
substrate[is.na(substrate[])] <- 5
reclass_substrate <- function(s) {
  fct_collapse(factor(s),
          till = "0",
          mudL = "1",
          csed = "2",
          ssed = c("3","4"),
          nd = "5")
}

#create function for prepping the data to fit an issf
issf <- function(i){
  t <- amt::make_track(i, .x=LON, .y=LAT, .t=DATETIME,
crs=sp::CRS("+init=epsg:4326"))
  r <- track_resample(t, rate=minutes(10), tolerance=minutes(2)) %>%
    filter_min_n_burst(min_n=3) %>%
    steps_by_burst() %>%
    random_steps(n_control = 100) %>%
    extract_covariates(substrate, where="both") %>%
    mutate(substrate_start = reclass_substrate(layer_start),
        substrate_end = reclass_substrate(layer_end),
        cos_ta_ = cos(ta_),
        log_sl_ = log(sl_)) %>%
    filter(!is.infinite(log_sl_)) %>%
    filter(!is.na(ta_))
}

#create function for bootstrapping
```

```
boot <- function(i){
  b <- i %>% bootstrap(., 1000)
  a <- b %>% .$strap %>%
    purrr::map( ~ fit_issf(case_ ~ sub_end + log_sl_ + cos_ta_ +
                    sub_start:log_sl_ + sub_start:cos_ta_ +
                    strata(step_id_), data = .)) %>%
    map(., first) %>%
    purrr::map(~broom::tidy(.)) %>%
    bind_rows()
}

#run issf function (and adapt it for certain individuals)
issf027 <- issf(grid_animalshort %>% filter(TRANSMITTER=="BL 027"))
issf030 <- issf(grid_animalshort %>% filter(TRANSMITTER=="BL 030"))

issf32 <- function(i){
  t <- amt::make_track(i, .x=LON, .y=LAT, .t=DATETIME,
crs=sp::CRS("+init=epsg:4326"))
  r <- track_resample(t, rate=minutes(10), tolerance=minutes(2)) %>%
    filter_min_n_burst(min_n=3) %>%
    steps_by_burst() %>%
    random_steps(n_control = 100) %>%
    extract_covariates(substrate, where="both") %>%
    filter(layer_end != "2") %>%
    filter(layer_start != "2") %>%
    mutate(substrate_start = reclass_substrate(layer_start),
        substrate_end = reclass_substrate(layer_end),
        cos_ta_ = cos(ta_),
        log_sl_ = log(sl_)) %>%
    filter(!is.infinite(log_sl_)) %>%
    filter(!is.na(ta_))
}
issf032 <- issf32(grid_animalshort %>% filter(TRANSMITTER=="BL 032"))

issf34 <- function(i){
  t <- amt::make_track(i, .x=LON, .y=LAT, .t=DATETIME,
crs=sp::CRS("+init=epsg:4326"))
  r <- track_resample(t, rate=minutes(10), tolerance=minutes(2)) %>%
    filter_min_n_burst(min_n=3) %>%
    steps_by_burst() %>%
    random_steps(n_control = 100) %>%
    extract_covariates(substrate, where="both") %>%
    filter(layer_end != "5") %>%
    mutate(substrate_start = reclass_substrate(layer_start),
        substrate_end = reclass_substrate(layer_end),
        cos_ta_ = cos(ta_),
```

```
      log_sl_ = log(sl_)) %>%
    filter(!is.infinite(log_sl_)) %>%
    filter(!is.na(ta_))
}
issf034 <- issf34(grid_animalshort %>% filter(TRANSMITTER=="BL 034"))

issf51 <- function(i){
  t <- amt::make_track(i, .x=LON, .y=LAT, .t=DATETIME,
crs=sp::CRS("+init=epsg:4326"))
  r <- track_resample(t, rate=minutes(10), tolerance=minutes(2)) %>%
    filter_min_n_burst(min_n=3) %>%
    steps_by_burst() %>%
    random_steps(n_control = 100) %>%
    extract_covariates(substrate, where="both") %>%
    filter(layer_end != "2") %>%
    filter(layer_end != "4") %>%
    mutate(substrate_start = reclass_substrate(layer_start),
        substrate_end = reclass_substrate(layer_end),
        cos_ta_ = cos(ta_),
        log_sl_ = log(sl_)) %>%
    filter(!is.infinite(log_sl_)) %>%
    filter(!is.na(ta_))
}
issf051 <- issf51(grid_animalshort %>% filter(TRANSMITTER=="BL 051"))

#change substrate reference level
issf027 <- mutate(issf027, sub_start = fct_relevel(substrate_start, "mudL"),
          sub_end = fct_relevel(substrate_end, "mudL"))
issf030 <- mutate(issf030, sub_start = fct_relevel(substrate_start, "mudL"),
          sub_end = fct_relevel(substrate_end, "mudL"))
issf032 <- mutate(issf032, sub_start = fct_relevel(substrate_start, "mudL"),
          sub_end = fct_relevel(substrate_end, "mudL"))
issf034 <- mutate(issf034, sub_start = fct_relevel(substrate_start, "mudL"),
          sub_end = fct_relevel(substrate_end, "mudL"))
issf051 <- mutate(issf051, sub_start = fct_relevel(substrate_start, "mudL"),
          sub_end = fct_relevel(substrate_end, "mudL"))
```

APPENDIX G: R SCRIPT ANALYSING DATA WITH AMT PACKAGE

```
#bootstrap prepared data
set.seed(10)
boot027 <- boot(issf027)
boot030 <- boot(issf030)
boot032 <- boot(issf032)
boot034 <- boot(issf034)
boot051 <- boot(issf051)

#plot mean estimates for sub_end
d027 <- boot027 %>% group_by(term) %>%
  summarize(
    mean=mean(estimate, na.rm=T),
    ymin=mean-1.96*sd(estimate, na.rm=T),
    ymax=mean+1.96*sd(estimate, na.rm=T)
  )
d027$ID <- "BL 027"
d030 <- boot030 %>% group_by(term) %>%
  summarize(
    mean=mean(estimate),
    ymin=mean-1.96*sd(estimate),
    ymax=mean+1.96*sd(estimate)
  )
d030$ID <- "BL 030"
d032 <- boot032 %>% group_by(term) %>%
  summarize(
    mean=mean(estimate),
    ymin=mean-1.96*sd(estimate),
    ymax=mean+1.96*sd(estimate)
  )
d032$ID <- "BL 032"
d034 <- boot034 %>% group_by(term) %>%
  summarize(
    mean=mean(estimate),
    ymin=mean-1.96*sd(estimate),
    ymax=mean+1.96*sd(estimate)
  )
d034$ID <- "BL 034"
d051 <- boot051 %>% group_by(term) %>%
  summarize(
    mean=mean(estimate),
    ymin=mean-1.96*sd(estimate),
    ymax=mean+1.96*sd(estimate)
```

```
  )
d051$ID <- "BL 051"

d <- rbind(d027, d030, d032, d034, d051)
d <- d %>% dplyr::filter(grepl("sub_end", term))
d$x <- 1:nrow(d)
p1 <- d %>%
  ggplot(., aes(x = term, y = mean, group = ID, col = ID)) +
  geom_pointrange(aes(ymin = ymin, ymax = ymax),
                  position = position_dodge(width = 0.7), size = 0.8) +
  geom_hline(yintercept = 0, lty = 2) +
  labs(x = "Substrate Class", y = "Relative Selection Strength") +
  theme_light() +
  scale_x_discrete(labels = c("Course sediment with veneer of mud", "No data",
                    "Soft sediment", "Till")) +
  coord_flip()
p1

#determine RSS w bootstrapped data frames
odds27 <- boot027 %>% split(.$term) %>% purrr::map(~mean(.$estimate, na.rm=T))
%>%
  bind_rows() %>% mutate(term="mean") %>% gather(key, value, -term)
csed27 <- exp(0.4342057)  #=1.54
nd27 <- exp(0.4613381)    #=1.59
ssed27 <- exp(-0.5705380) #=0.57
till27 <- exp(-0.2847470) #=0.75

odds30 <- boot030 %>% split(.$term) %>% purrr::map(~mean(.$estimate, na.rm=T))
%>%
  bind_rows() %>% mutate(term="mean") %>% gather(key, value, -term)
csed30 <- exp(-0.48239866) #=0.62
ssed30 <- exp(-1.19245755) #=0.30
till30 <- exp(-0.31462052) #=0.73

odds32 <- boot032 %>% split(.$term) %>% purrr::map(~mean(.$estimate, na.rm=T))
%>%
  bind_rows() %>% mutate(term="mean") %>% gather(key, value, -term)
nd32 <- exp(0.437719122)    #=1.55
ssed32 <- exp(0.397370376)  #=1.49
till32 <- exp(-0.528056974) #=0.59

odds34 <- boot034 %>% split(.$term) %>% purrr::map(~mean(.$estimate, na.rm=T))
%>%
  bind_rows() %>% mutate(term="mean") %>% gather(key, value, -term)
csed34 <- exp(-0.13365194) #=0.87
ssed34 <- exp(-0.16990129) #=0.84
```

```
till34 <- exp(-0.17635593) #=0.84

odds51 <- boot051 %>% split(.$term) %>% purrr::map(~mean(.$estimate, na.rm=T))
%>%
  bind_rows() %>% mutate(term="mean") %>% gather(key, value, -term)
nd51 <- exp(-0.58930798)   #=0.55
till51 <- exp(-0.05511190) #=0.95

#determine 95% odds ratio distribution
boot027 %>% group_by(term) %>%
  summarize(q025=quantile(estimate, probs=0.025, na.rm=TRUE),
        q975=quantile(estimate, probs=0.975, na.rm=TRUE)) %>%
  mutate(sig=case_when(q025 < 0 & q975 > 0 ~ "no",
              TRUE ~ "yes"))

boot030 %>% group_by(term) %>%
  summarize(q025=quantile(estimate, probs=0.025),
        q975=quantile(estimate, probs=0.975)) %>%
  mutate(sig=case_when(q025 < 0 & q975 > 0 ~ "no",
              TRUE ~ "yes"))

boot032 %>% group_by(term) %>%
  summarize(q025=quantile(estimate, probs=0.025, na.rm=TRUE),
        q975=quantile(estimate, probs=0.975, na.rm=TRUE)) %>%
  mutate(sig=case_when(q025 < 0 & q975 > 0 ~ "no",
              TRUE ~ "yes"))

boot034 %>% group_by(term) %>%
  summarize(q025=quantile(estimate, probs=0.025, na.rm=TRUE),
        q975=quantile(estimate, probs=0.975, na.rm=TRUE)) %>%
  mutate(sig=case_when(q025 < 0 & q975 > 0 ~ "no",
              TRUE ~ "yes"))

boot051 %>% group_by(term) %>%
  summarize(q025=quantile(estimate, probs=0.025, na.rm=TRUE),
        q975=quantile(estimate, probs=0.975, na.rm=TRUE)) %>%
  mutate(sig=case_when(q025 < 0 & q975 > 0 ~ "no",
              TRUE ~ "yes"))
```