ASSESSING FUNCTIONAL ECOLOGICAL CONNECTIVITY FOR PROTECTED AREA DESIGN FOR SOUTHWEST NOVA SCOTIA

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ABSTRACT

Assessing Functional Ecological Connectivity for Protected Area Design in Southwest Nova Scotia

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Ecological connectivity is vital for maintaining healthy ecosystems, facilitating essential processes such as species dispersal, gene flow, and adaptation to changing environments. However, this connectivity is increasingly threatened by human activities such as road construction, deforestation, and agricultural practices, which fragment landscapes and impede species movement. This study in Southwest Nova Scotia addresses these challenges by aiming to enhance ecological connectivity in fragmented forest landscapes. Through the identification of potential corridors between protected areas and the assessment of species resistance to movement, the research seeks to provide valuable insights into protected area designs aligning with environmental goals. Utilizing habitat suitability modeling and spatial analysis techniques including least cost path modeling and circuit theory analysis, seven species sensitive to fragmentation are analyzed. Major findings highlight the importance of maintaining and restoring ecological corridors, identifying pinchpoints and barriers to species movement, and suggesting areas for restoration to enhance connectivity in fragmented landscapes. By offering insights into landscape-scale connectivity patterns and providing guidance for conservation strategies, this research aims to support ecologists and landscape planners in Nova Scotia in their efforts to balance wildlife conservation with human development needs. Ultimately, the study contributes to the broader goal of preserving interconnected landscapes and safeguarding biodiversity in the face of ongoing environmental challenges.

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CHAPTER 1

Introduction

Ecological connectivity is the degree to which landscapes or ecosystems are interconnected, playing a crucial role in supporting the movement of plants and animals among other associated ecological processes (Taylor et al., 1993). While critical for the health and resilience of ecosystems, connectivity is unfortunately threated by the fragmentation of landscapes, driven by human activities such as road construction, deforestation, and agricultural practices. These processes result in the division of landscapes into smaller, isolated patches, negatively impacting ecological processes like species dispersal, gene flow, and the ability to adapt to changing climates (McRae et al., 2012).

The objective of promoting ecological connectivity is to establish an interconnected network of natural and semi-natural elements that facilitate movement across the landscape. Ecological networks, consisting of core areas, corridors, and stepping stones, emerge as vital conservation strategies in the face of climate change and human development pressures (Baum et al., 2004). Core areas represent large, uninterrupted ecosystems that serve as critical habitats for various species; however, the spaces between these core habitats are increasingly fragmented and altered due to ongoing human activities. To counteract this, ecological corridors, stepping stones, and wildlife crossings have been identified as effective measures to maintain connectivity across fragmented landscapes.

Landscape corridors, essentially unbroken linear strips of habitat between core areas (Parks Canada Agency, 2022), play a key role in ensuring the continuous movement of species.

Stepping stones, small patches strategically connected to larger isolated ecosystems (Baum et al., 2004), contribute to facilitating movement across fragmented landscapes. Additionally, wildlife crossings including bridges, tunnels, and culverts, are human-built infrastructures designed to safely facilitate animal movement across roads and other barriers. Together, these components form an ecological network that supports the movement of species across the landscape, thereby contributing to biodiversity conservation in the face of environmental challenges.

1.1 Research Objectives

The purpose of this study will be to access and enhance ecological connectivity in Southwest Nova Scotia's fragmented forest landscape and provide insights into protected area designs that align with the province's environmental goals. The objectives are to identify potential corridors and connections between established protected areas and to compare the relative resistance to movement for a suite of species between these areas. It also aims to identify pinchpoints and barriers to species movement and areas for restoration, enhancing connectivity in these fragmented landscapes. To analyze functional connectivity a suite of 7 species were chosen for analysis due to their sensitivity to fragmentation: the mainland moose (*Alces alces),* American marten (*Martes americana*), Northern flying squirrel (*Glaucomys sabrinus)*, Black bear (*Ursus americanus*), Wood turtle (*Glyptemys insculpta)*, Eastern wood pewee (*Contopus virens)*, and Black Ash (*Fraxinus nigra*). This research aims to aid ecologist and landscape planners in Nova Scotia to aid in the conservation of wildlife and preserving the interconnected landscape while balancing the needs of the human population by identifying areas in need of protection or restoration.

CHAPTER 2

Literature

2.1 Ecological Connectivity

Ecological connectivity is how much the landscape facilitates the movement of plants, animals, or ecological processes. It can be passive such as the diffusion of organisms by physical processes carrying species seeds or eggs, or it can be active through directed species movement (Arkilanian et al., 2020). Landscape connectivity can be defined and measured through fine or broad scales. At the smaller scale, connectivity focuses on interventions through corridors and crossings to allow species to remain in their natural habitat ranges. While at the broad scale and in the long-term interventions are focused on maintaining interconnected metapopulations and communities across large-scale areas and migrations (Arkilanian et al., 2020).

Additionally, connectivity science can be broken up into structural and functional connectivity. Structural connectivity refers to the physical and spatial structure of the landscape and does not consider the behavioural response of the species to the structure. Functional connectivity refers to how the organism reacts to the landscape and allows for a more species-specific research approach (Cunningham et al., 2020).

2.2 Habitat Fragmentation

2.2.1 Causes of Habitat Fragmentation

One of the leading threats to species is habitat fragmentation, habitat loss, and habitat degradation. Habitat fragmentation occurs when the once-connected natural landscape gets broken up into smaller, isolated patches as a result of barriers to movement (Baum et al., 2004).

Barriers can be a result of anthropogenic disruptions, such as urbanization, agriculture, logging, roads, or fences or through natural processes like wildfires, floods, rivers, or canyons (McRae et al., 2012). They can also be complete and impermeable or partial such as land cover types that impede movement. They can also be linear such as roads or can span large areas such as agricultural fields (McRae et al., 2012).

2.2.2 Impacts of Fragmentation

Habitat loss and fragmentation are some of the leading risks to the biodiversity of species. The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) estimates that 84% of endangered species in Canada are primarily threatened by habitat loss (Venter et al., 2006). This is because fragmentation impedes the natural movement of species and limits their ability to access suitable habitats critical for survival. Jeopardizing their ability to find suitable areas for nesting, feeding, and reproduction. The resulting isolation of populations in fragmented habitats increases the vulnerability of these species, contributing to declines in population size and limiting their overall adaptability. Additionally, fragmentation impacts species' ability to adapt to a changing climate. Fragmented landscapes impede the species' ability to shift their ranges to access more suitable habitats in response to climate change. Barriers create a significant obstacle to species as they try to find resources essential for survival.

Furthermore, connectivity is essential to maintaining genetic diversity by preventing random genetic drift, inbreeding, and reduced gene flow when populations are small and isolated. Genetic diversity, the variation of genes within species, is promoted by the free movement of species and their ability to find potential mates (Nonić & Šijačić-Nikolić, 2020). A loss of genetic variation can create severe threats to population fitness in both the short and long term. In the short term, it can create an increase in homozygosity which is defined as “a state of possessing two identical forms of a particular gene, one inherited from each parent” (Yunis & Arriola, 2013) and can result in the expression of deleterious recessive alleles causing inbreeding depression and reducing individual’s fitness (Schlaepfer et al., 2018). In the long term, decreased genetic diversity reduces a population's ability to adapt to changing environmental conditions, rendering it more susceptible to the environmental stressors associated with climate change. By facilitating movement and the exchange of genetic material between populations, connectivity enhances the adaptive capacity of species, allowing them to evolve and respond effectively to novel environmental stressors linked to climate change.

2.3 Connectivity Analysis Methods

Least cost path modelling is one of the most common methods for modelling landscape connectivity and is used to find the most efficient or cost-effective path for species or entities to move from one location to another within a landscape (Silver, 2021). The premise of least cost path analysis is that every land cover type has a “cost” to the species as they try to move across it and the least cost path calculates the route that minimizes resistance or cost, based on factors like terrain, elevation, or land cover type.

While circuit theory is common in other disciplines it is relatively new in ecological modelling. It employs electrical circuit theory to analyze connectivity in landscapes (Cunningham et al., 2020). Unlike traditional models, circuit theory considers multiple dispersal pathways, using concepts from random walk theory to calculate resistance, current, and voltage across graphs or raster grids (McRae et al., 2008). It can calculate each area's resistance to currents of electrical flow passing through the cells to predict how the landscape is impacted by different features (Silver, 2021). This method offers unique advantages, allowing for a more comprehensive understanding of movement patterns and outcomes of organisms across landscapes.

The key difference between least cost paths and circuit theory is the way that they make assumptions about the movement of species. Circuit theory assumes all pathways between core areas can enhance connectivity while least cost paths calculate and assume that species chose the path of least resistance between patches (Silver, 2021). Linkage mapper is an ArcGIS toolbox extension developed by McRae et al., (2010) that first employs both least cost paths and circuit theory to identify corridors connecting identified core areas through a raster resistance layer then uses circuit theory to identify pinchpoints and compare network designs.

2.4 Nova Scotia

In 2016, at the conference of Atlantic Canadian Premiers and New England Governors Resolution 40-3 was passed which recognizes the significance of the Northern Appalachian-Acadian Forest (Cunningham et al., 2020). The region consists of a complex forest matrix containing the largest remaining area of temperate broadleaf and mixed forest types in the world (Arkilanian et al., 2020). This area contains a rich biodiversity and is home to important migration pathways of many bird and butterfly species.

In a 2020 Nova Scotia connectivity report, the analysis of landscape connectivity and fragmentation across Nova Scotia reveals that the total province experienced an 8.9% reduction in natural ecosystems, with increased fragmentation indicated by decreased median patch size and effective mesh size, and increased edge density and mean perimeter-area ratio (Cunningham et al., 2020). The region's economy is closely linked to its forestry and water resources; however, hazards including climate change, deforestation, expansion of road networks, and the conversion of wetlands and grasslands to agricultural fields create increasing pressure on ecological connectivity and biodiversity (Cunningham et al., 2020). Maintaining and restoring ecological connectivity is vital for the protection of the region's biodiversity, ecosystems, and human communities.

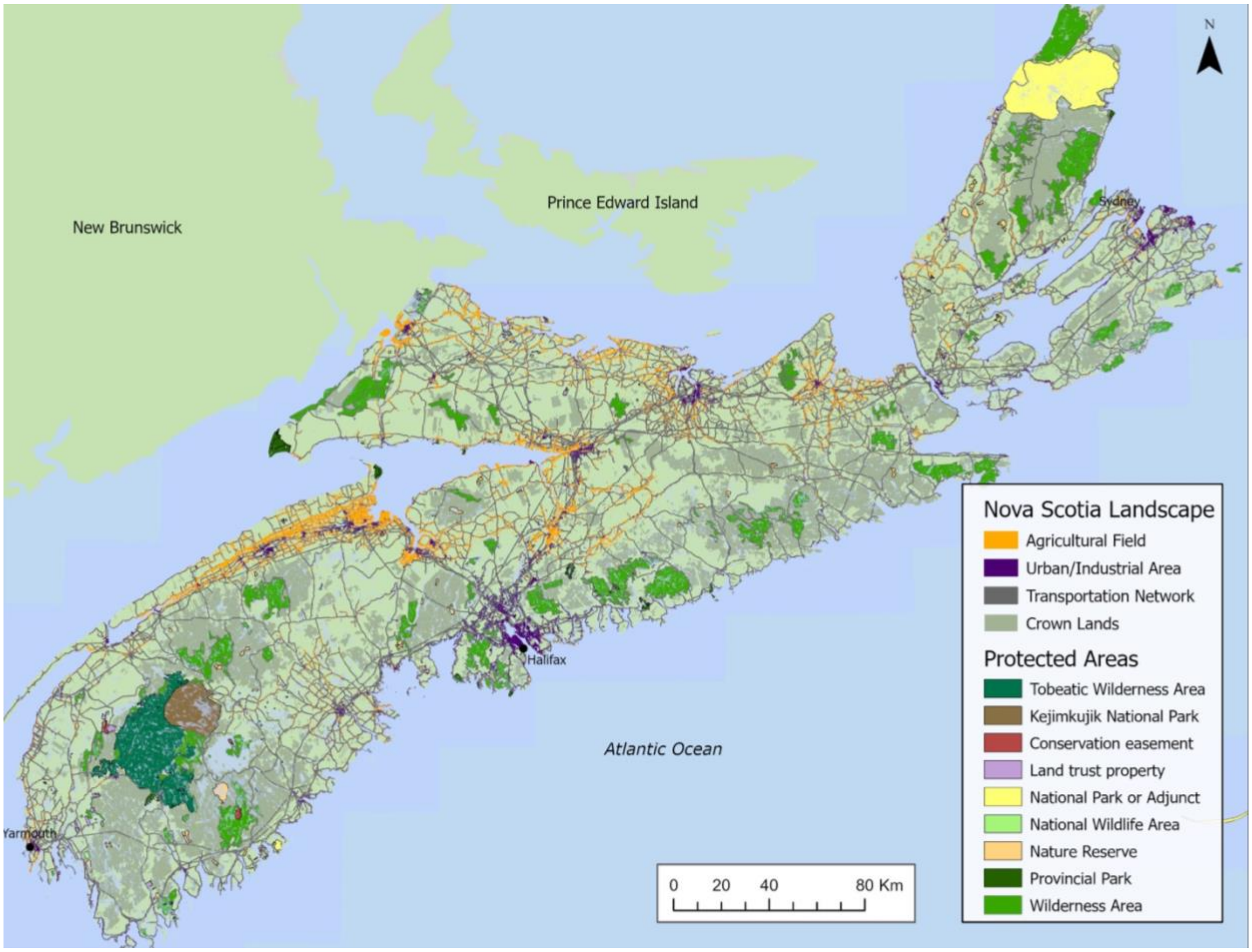

Figure 2.1: Landscape matrix of Nova Scotia depicting anthropogenic disturbances including agricultural fields, urban areas, and transportation networks, alongside protected areas and crown land.

In an effort to protect the health of Nova Scotia's ecosystems, the province announced the Nova Scotia Environmental Goals and Climate Change Reduction Act (2021). In these goals, there is a clear commitment by the provincial government to conserve at least 20% of the total land and water mass as protected areas and effective conservation measures by 2030. However, with about 70% of Nova Scotia's forested area being owned by private landowners (MTRI, n.d.), a strong knowledge of connectivity processes and close working relationships with landowners to protect the integrity of landscapes will be increasingly important as development pressures mount.

2.4.1 Southwest Nova Biosphere Reserve

The Southwest Nova Biosphere Reverse is located in the southwestern region of Nova Scotia and has been a designated a UNESCO Biosphere Reserve since 2001 due to its unique natural and cultural heritage (SWNBR, 2023). Spanning over 1.54 million hectares in five counties including Annapolis, Digby, Queens, Shelburne and Yarmouth (Sollows, 2020), the region has a diverse range of ecosystems, including old-growth forests, wetlands, and coastal habitats supporting a high-level of biodiversity. Key species of conservation concern, such as the Mainland moose, Eastern wood-pewee, and American marten, find a home in this biosphere reserve (Sorrows, 2020).

Ecologically, Southwest Nova represents the natural region of southwestern Nova Scotia, characterized by a diverse range of forest types, including the Acadian Forest. The region supports a unique mix of tree species and harbours diverse wildlife, including species typical of boreal/mixed wood forests. With a population of approximately 100,000 people (Sorrows, 2020), the region has a rich cultural heritage with Acadian settlers and as home to the Mi’kmaq people for thousands of years.

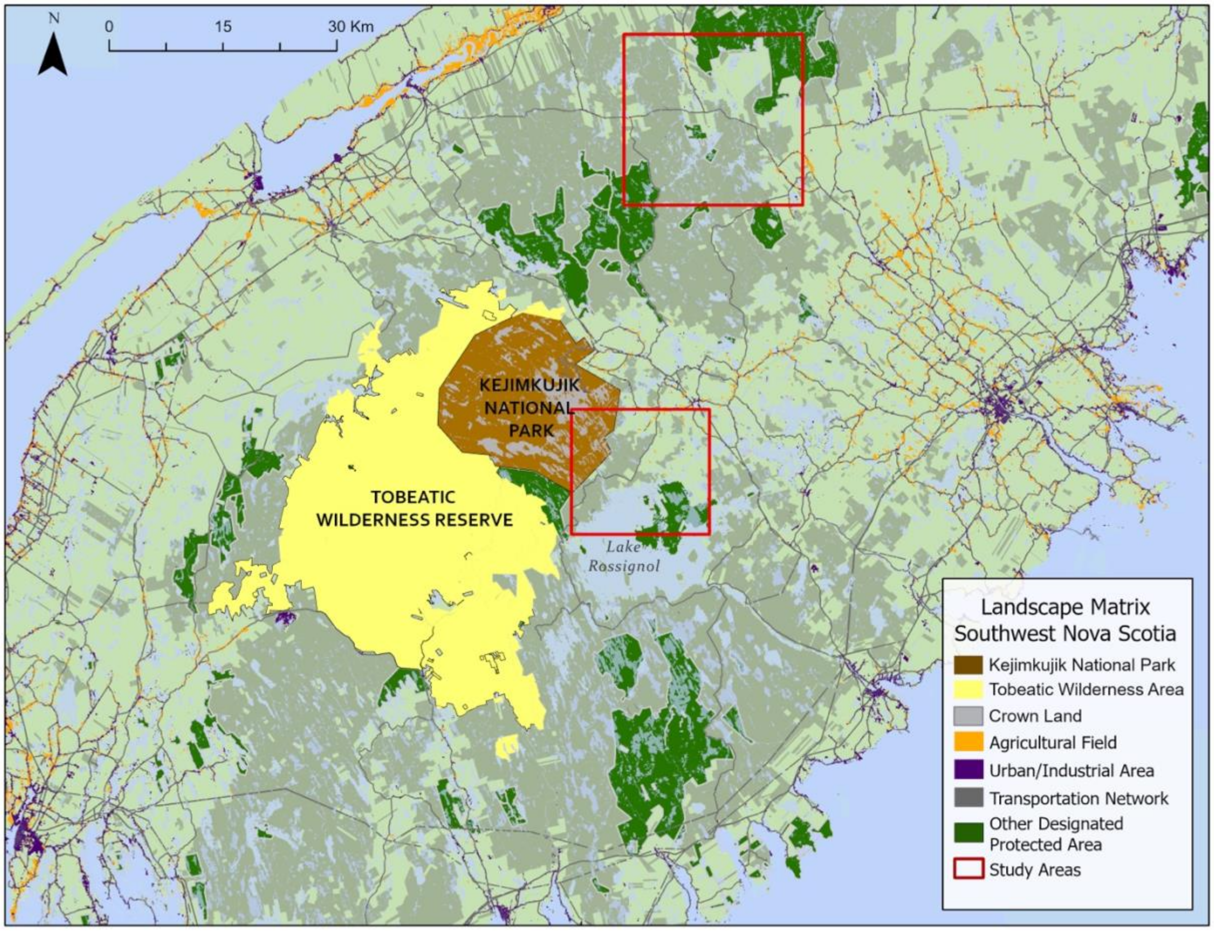

Figure 2.2: Land cover matrix of anthropogenic features, protected area zones and crown land in Southwest Nova Scotia Biosphere Reserve with study areas outlined in red.

Two major protected areas, Kejimkujik National Park, and the Tobeatic Wilderness Area, form the core of the biosphere reserve. However, the region is facing increasing fragmentation due to human activities such as transportation networks, mining, and logging. Effective protected area planning is critical to the preservation and integrity of this region.

2.4.2 Study Regions

As 1 of only 16 designated biosphere reserves in Canada and with a diverse range of ecosystems and biodiversity it is important to keep this region healthy and interconnected. Two study areas connecting two core areas of significant concern have been identified as focuses for conservation.

Study region A is located in the centre of the reserve connecting Kejimkujik National Park and Lake Rossignol wilderness area. At 40400 ha Kejimkujik National Park is an important conservation site providing a unique matrix of freshwater habitats, wetlands, and old growth Acadian Forest (Parks Canada, 2022). Located just south of Kejimkujik is Lake Rossignol Wilderness area, connected by large areas of wetlands and floodplain forests, maintaining the flow of species between these large protected areas will be critical in maintaining the connectivity of wetland dependent species. Study region B is located North-east of region A, connecting Medway Lakes Wilderness Area and Cloud Lake Wilderness Area. With a diverse forest matrix of hardwood and mixed wood forest hills, mature conifer forests, wetlands and numerous old sugar maple, yellow birch, white pine, and hemlock stands in both protected areas, maintaining the connectivity between core areas will be important to the health and resilience of many species that depend on these diverse woodland types for important habitat.

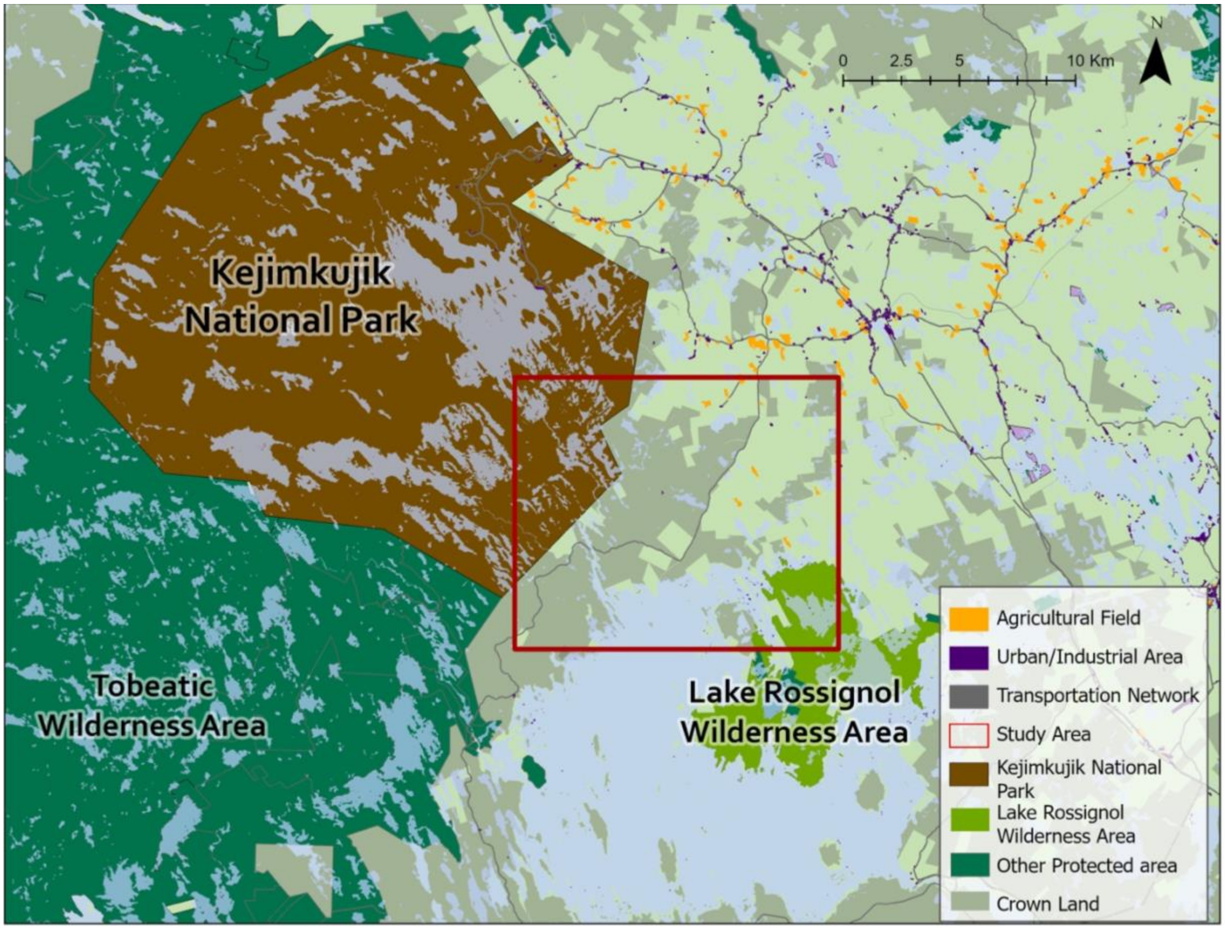

Figure 2.3: Study Area A connecting Kejimkujik National Park and Lake Rossignol Wildness Area

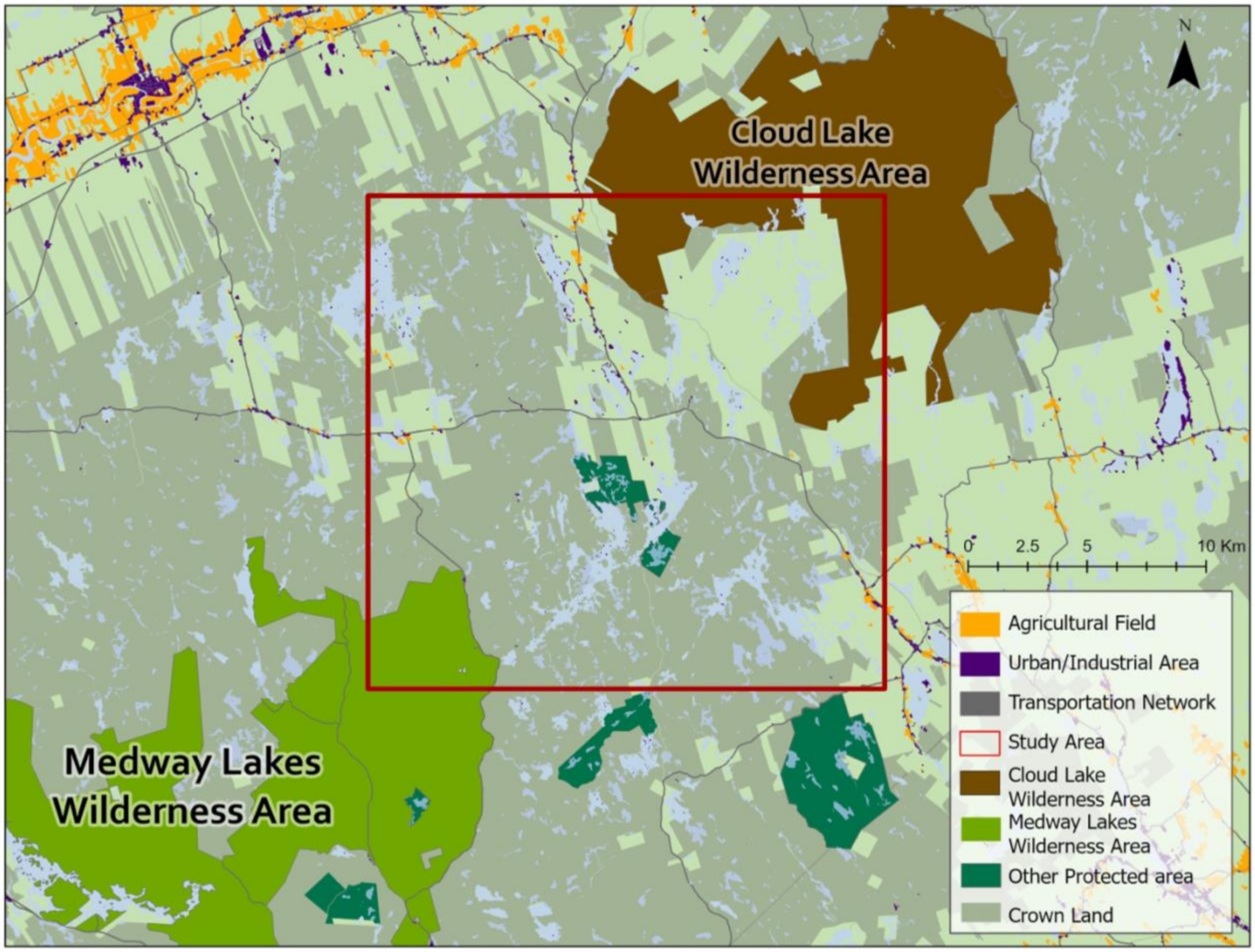

Figure 2.4: Study area B connecting Medway Lakes Wilderness Area and Cloud Lake Wilderness Area

CHAPTER 3

Methods

3.1 Species Identification

Seven species were selected for analysis with the help of experts from the Nova Scotia Department of Natural Resources Biodiversity and Wildlife division. Species were selected because of their sensitivity to fragmentation and of a special concern for connectivity. Also, the species have different habitat requirements and are representative of other species found in Southwest Nova Scotia. The mainland moose (*Alces alces*) prefers a combination of mature forests with high crown cover and regenerating stands. They can be found in a mix of softwood and hardwood dominated stands with a high-water table or close to wetlands and open water (Nova Scotia Department of Natural Resources and Renewables, 2021; Snaith & Beazley, 2004). While the American marten (*Martes americana*) can be found in any mature forest type with trees taller than 9m but show a preference for coniferous to mixedwood stands with old-growth features (Nova Scotia Department of Natural Resources, 2023). They prefer dense forests and will avoid areas with large openings. The Northern flying squirrel *(Glaucomys sabrinus*) is found in stands with old-growth features with high canopy cover and an abundance of standing deadwood (O'Connell et al., 2001; Ritchie et al., 2009). They are common softwood and softwood dominant mixedwood stands and can be found in hardwood but are rarer. Black bear (*Ursus americanus*) habitat choices are more driven by the abundance of food sources such as hard and soft mast, such as acorns, berries, and other fruits. Prefer habitats with broad range of tree species and numerous openings to create a high degree of edge (Costello & Sage, 1997; Rogers & Allan, 1987). The Wood turtle (*Glyptemys insculpta*) is a habitat generalist that has shown preference for riparian habitats and habitats associated with meandering rivers and streams but can be found in a wide range of terrestrial habitats including coniferous forests, mixed forests, agricultural fields, bogs, marshes, and wetlands provided they are near a river or stream (COSEWIC, 2018). The Eastern wood pewee (*Contopus virens*) prefers an older deciduous and mixed forest type with a high canopy, or areas associated with clearings and edges (Nova Scotia Department of Natural Resources and Renewables, 2022). Black Ash (*Fraxinus nigra*) is a habitat specialist predominantly found in areas with a high-water table or wetland habitats such as swamps, floodplains, and fens. Black ash is found to dominate flood-prone environments with moderate to intermediate light requirements and can grow on a variety of soil types and pH conditions but more prominent in alkaline and nutrient rich soils (COSEWIC, 2018; Nova Scotia Department of Natural Resources and Renewables, 2021).

3.2 Habitat Suitability Modeling

Modelling habitat suitability across the region for the seven identified species was done to create resistance layers based on how well each land cover type facilitates or impedes the movement of the species. Land cover types were categorized based on the vegetations types in the Nova Scotia Forest Ecosystem Classification (FEC). Vegetation types are based on overstory trees, soil type and ground vegetation to group land cover types by forest characteristics. Forested areas were then divided into four age classes (establishment, young, mature, old/multi-aged) based on the Nova Scotia Development Classes information (Department of Lands and Forestry, 2019) using the height field of the forest inventory data layer (Table 1). Non-forested and anthropogenic features were categorized based on usage and land cover types. See Appendix for more information on land cover class categorization.

Table 3.1: Forest age class categories and structural requirements. Based on Nova Scotia Development Classes information (2019).

Development Class	Structural Requirements
Establish	< 6m
Young	6-11m
Mature	> 11m
Old/ multi layers	multiple layers, >11m

Once the land cover classes were finalized numerical suitability indicators for each species were assigned to each land class. Landscape types are evaluated based on their suitability to meet habitat requirements for each species and their ability to allow species to move through the landscape. Suitability scores were given from 0-5 (5 being the best available habitat and 0 being absolute non-habitat). Scores were developed based on a literature review of habitat preferences of each species and how conducive the land cover is to the movement of each species (Appendix).

3.3 Spatial Analysis

The spatial analysis was done with ESRI ArcGIS Pro 3.0 with Linkage Mapper toolbox extensions (McRae et al., 2021). The tool utilizes circuit theory and least cost analysis to analyze connectivity and requires a polygon vector dataset of core areas and a raster resistance dataset in GRID format. A shapefile for each of the identified protected core areas was created. Core areas represent the larger land areas where the species are able to live, feed and reproduce. It is presumed that Nova Scotia protected areas provide the necessary features for the suite of species.

Resistance rasters were developed for Southwest Nova Scotia using the “Select by Attributes” tool to extract the critical components of age class and land cover type from the Forest Inventory and Predictive Ecosystem Mapping (PEM) data layers developed by the Nova

Scotia Department of Natural Resources and Renewables that make up each land class type. The “Reclassify” tool in the Spatial Analyst toolbox was used to assign resistance values based on the inverse of the suitability index for each species (Appendix). Then the “Polygon to Raster” tool was used to create a raster resistance grid with a cell size of 100m and the cell value being shown was the resistance.

The “Build Network and Map Linkages” tool from the Linkage Mapper toolbox was then used to create least-cost corridors connecting the core areas through the resistance raster to find the path that has the lowest resistance. The “Pinchpoint Mapper” tool utilizes circuit theory to identify pinchpoints along the least cost path. Pinchpoint Mapper was run with buffers of 1000m and 10,000m around the paths to identify alternative routes between the core areas. “Barrier Mapper” was run to quantify how the barriers impede the quality and location of corridors by analyzing cost weighted distance through the resistance grid using a circular search window to identify areas for restoration and mitigation (McRae et al., 2012).

The location of the corridors and pinchpoints were visually compared and the main values extracted from the analysis were the Cost Weighted Distance (CWD), effective resistance (R̂), CWD to path length ratios, and CWD/R̂ ratios. CWD is the calculated cumulative cost to move across the landscape from one core area to another (McRae et al., 2012). Higher CWD values show a higher resistance to movement than lower values. CWD to path length ratios are useful to account for differences in path length between core areas (Silver, 2021). R̂ considers the quality and width of the corridors and the number of alternative pathways available. A lower effective resistance means a greater potential for flow across the landscape. This potential for flow increases when corridors are wider or there are other high quality alternative pathways available (McRae et al., 2008). The CWD/$\hat{R}$ ratio indicates the redundancy between the number of pathways.

CHAPTER 4

Results

4.1 Mainland Moose

Figures 4.1 and 4.2 shows the resistance raster layers for each study region with barriers along least cost paths showing obstructions to movement and the level of difficulty in which the mainland moose is able to travel the between core areas. Both study regions have areas where restoration could occur, however region B had a larger obstruction to movement south of Medway Lakes. The Build Linkage Pathways analysis tool provides the least cost path with the least resistance to movement between core areas. Study area B provided the lowest cost weighted distance between cores (Table 4.1). However, in both the 1000m and 10,000m circuit theory analysis region A had a lower resistance value and higher CWD/ $\hat{R}$ indicating more higher quality pathways are available (Figure 4.3).

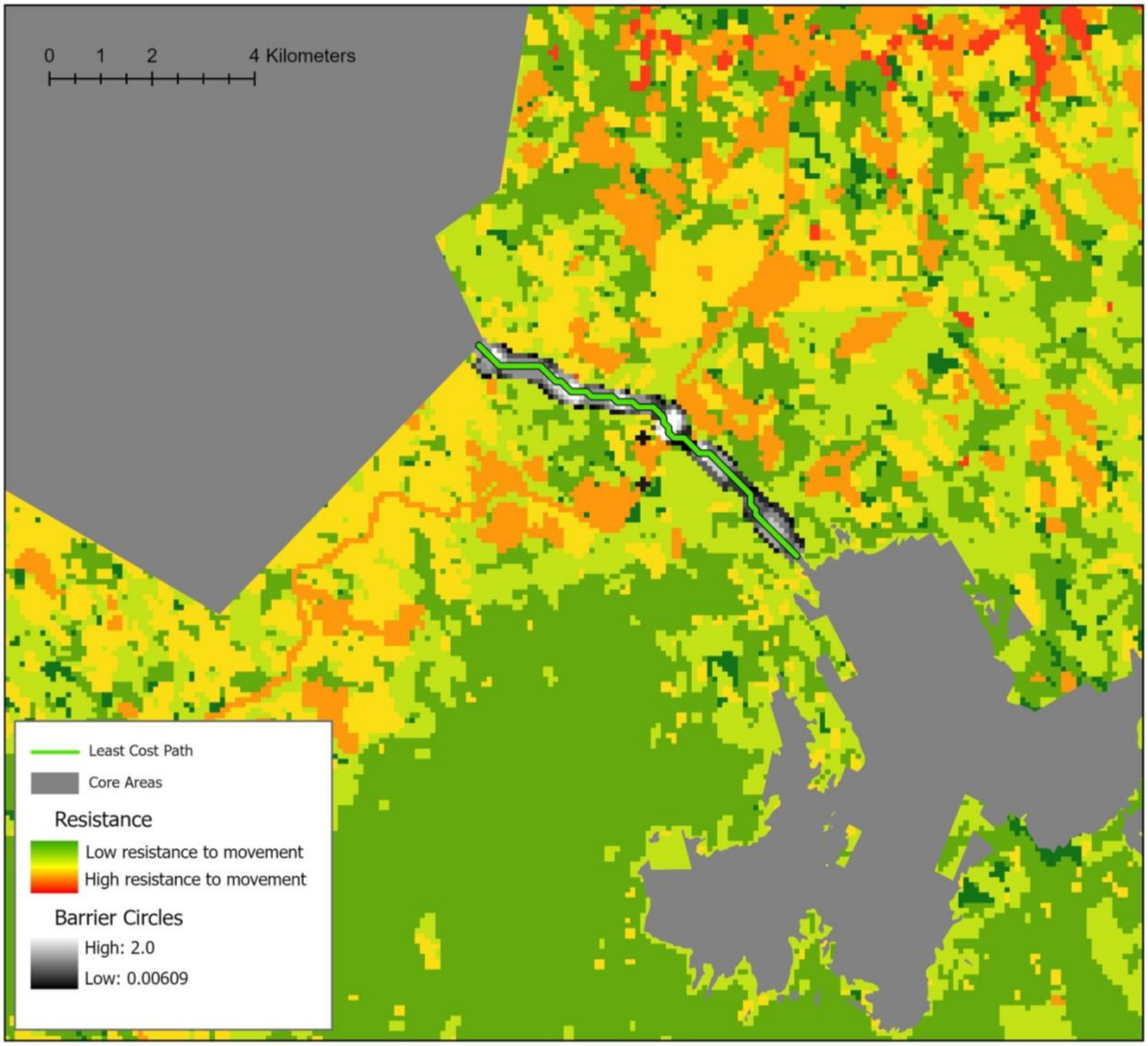

Figure 4.1: Least Cost Paths and Barriers to movement between selected core areas for Mainland Moose between Kejimkujik National Park and Lake Rossignol Wilderness Area.

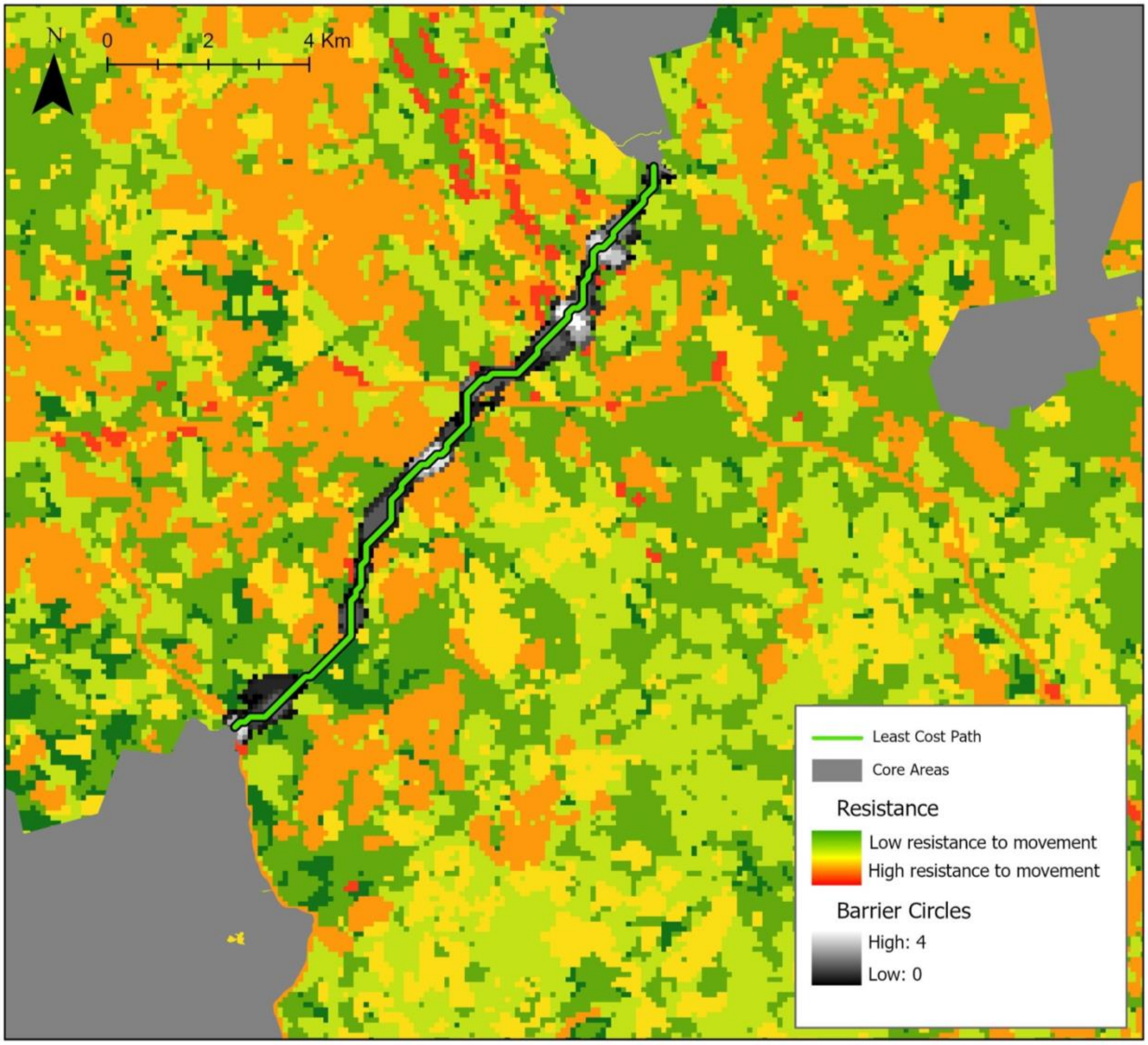

Figure 4.2: Least Cost Paths and Barriers to movement between selected core areas for Mainland Moose between Medway Lakes and Cloud Lakes Wilderness Area

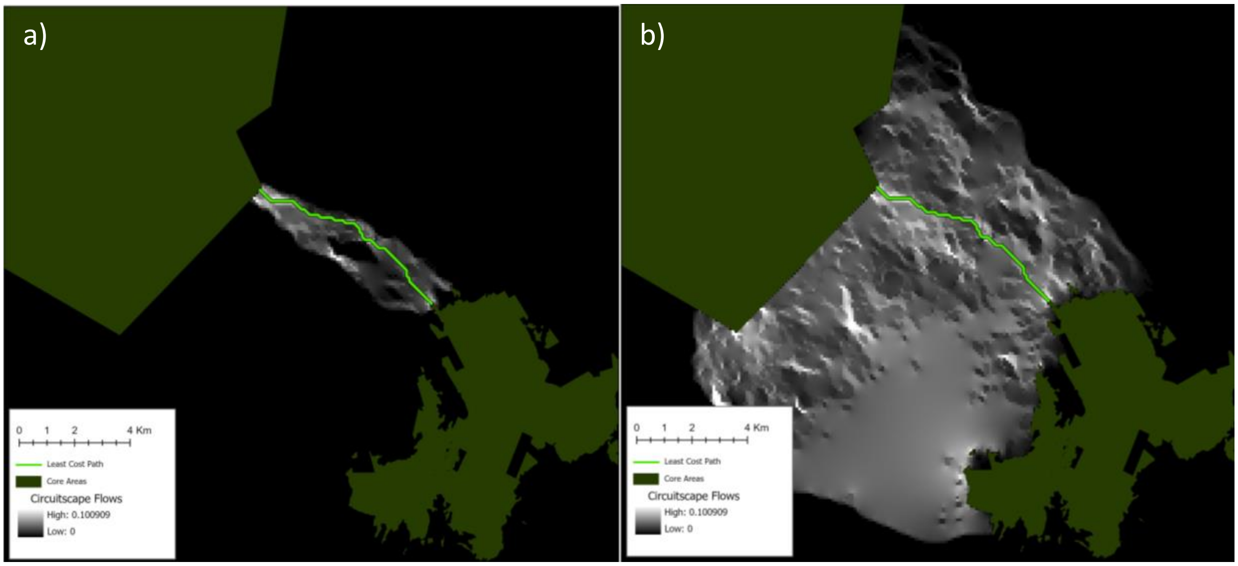

Figure 4.3: Pinchpoints between Kejimkujik National Park and Lake Rossignol Wilderness Area for Mainland Moose at a) 1000m buffer and b) 10,000m buffer

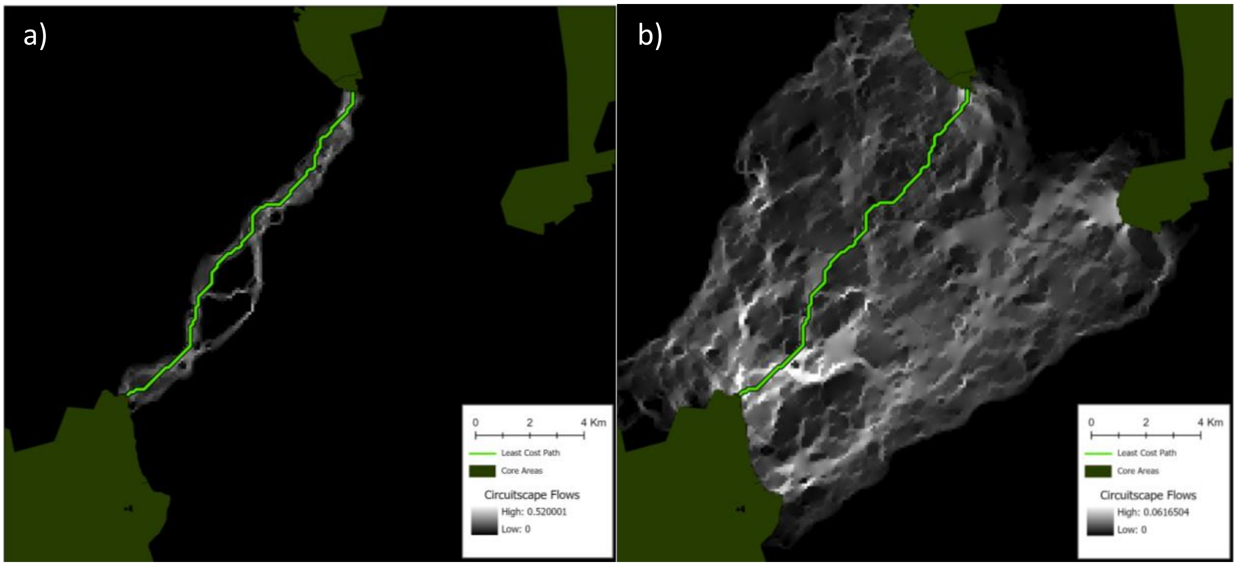

Figure 4.4: Pinchpoints between Medway Lakes and Cloud Lakes Wilderness Area for Mainland Moose at a) 1000m buffer and b) 10,000m buffer

Table 4.1: Linkage Mapper and Pinchpoint Mapper resistance data for Mainland Moose.

	CWD	CWD/Path length Ratio	$\hat{R}^2$ (1K)	$\hat{R}^2$ (10K)	CWD/ $\hat{R}$ (1K)	CWD/ $\hat{R}$ (10K)
Study Region A	18650.1	2.3	1969.1	233.3	9.5	79.9
Study Region B	31314.7	2.0	5712.1	517.5	5.5	60.5

4.2 American Marten

Figures 4.5 and 4.6 display resistance layers for each study region with barriers along least cost paths showing barriers to movement and the level of difficulty in which the American is able to travel across the landscape. There is a substantial barrier north of Lake Rossignol. Least cost corridors are created using the "Linkage Pathways" tool to provide the path with the least resistance to movement between core areas through the resistance layer. Study region A had the lowest CWD and CWD/path length ratio (Table 4.2). Region A also had a lower resistance and higher CWD/ $\hat{R}$ when pinchpoint mapper is run with a buffer zone of 1000m, indicating more alternative high-quality pathways (Figures 4.7, 4.8). However, when pinchpoint mapper is run with a buffer of 10,000m study region B is found to have a lower resistance and higher CWD/ $\hat{R}$. This indicates that when alternative pathways are evaluated on a larger extent there is a higher number of quality pathways between cores.

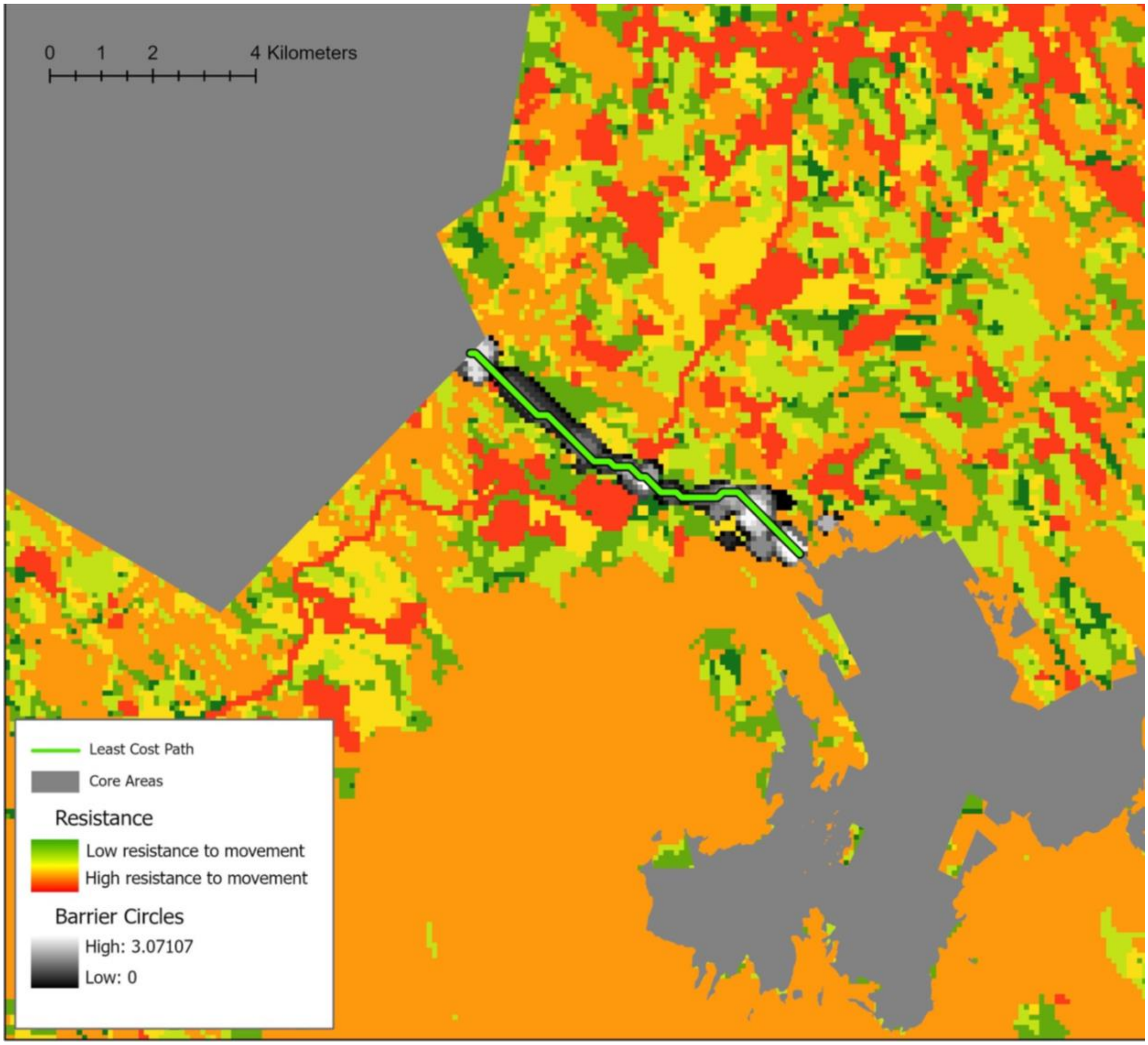

Figure 4.5: Least Cost Paths and Barriers to movement between selected core areas for American Marten between Kejimkujik National Park and Lake Rossignol Wilderness Area.

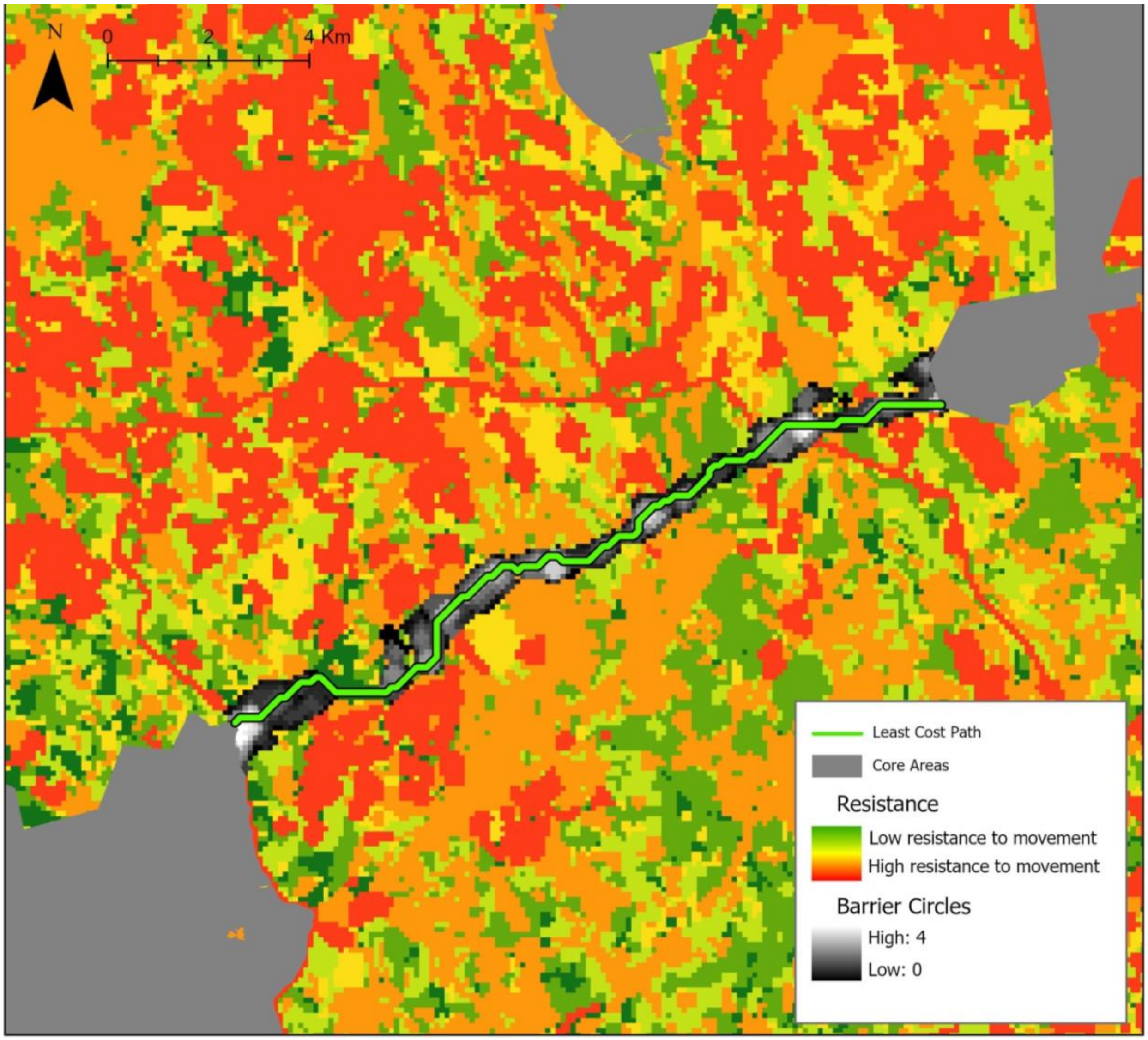

Figure 4.6: Least Cost Paths and Barriers to movement between selected core areas for American Marten between Medway Lakes and Cloud Lakes Wilderness Area

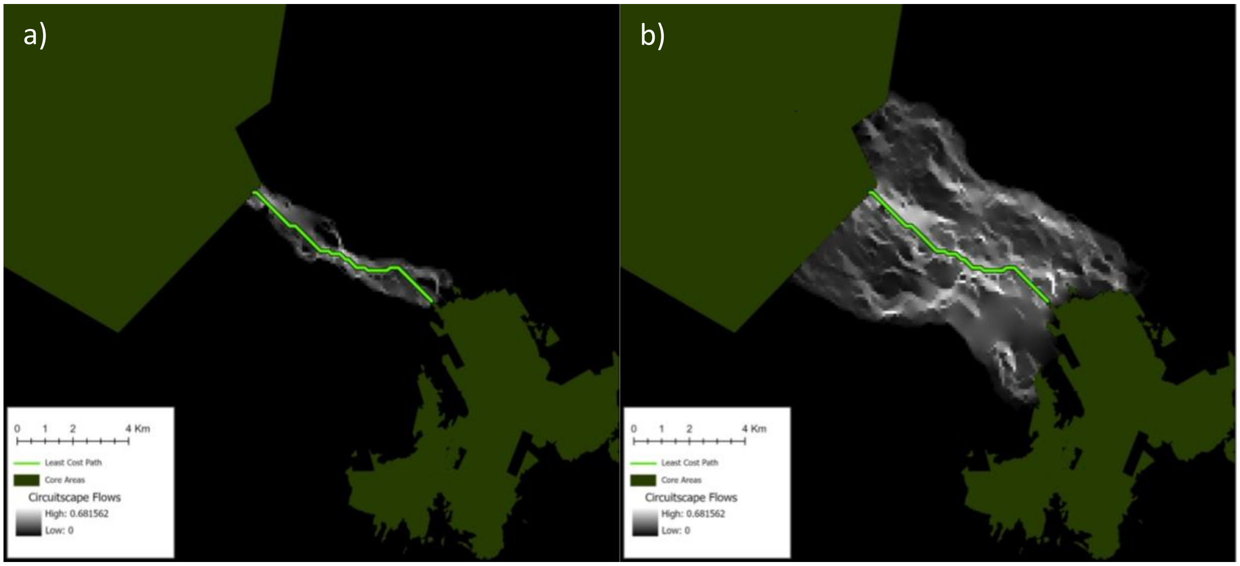

Figure 4.7: Pinchpoints between Kejimkujik National Park and Lake Rossignol Wilderness Area for American Marten at a) 1000m buffer and b) 10,000m buffer

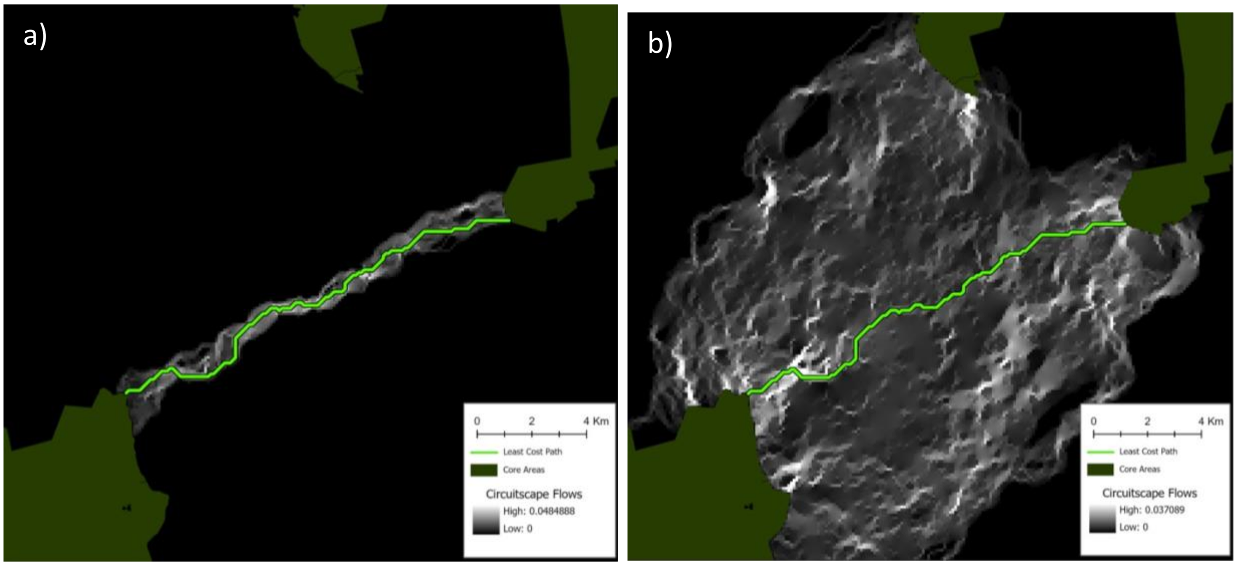

Figure 4.8: Pinchpoints between Medway Lakes and Cloud Lakes Wilderness Area for American Marten at a) 1000m buffer and b) 10,000m buffer

Table 4.2: Linkage Mapper and Pinchpoint Mapper resistance data for American Marten.

	CWD	CWD/Path length Ratio	R̂ ^{2} (1K)	R̂^{2} (10K)	CWD/ R̂ (1K)	CWD/ R̂ (10K)
Study Region A	20494.2	2.8	3416.6	845.5	6.0	24.2
Study Region B	44670.9	3.3	9138.5	767.0	4.9	58.2

4.3 Northern flying squirrel

Figures 4.9 and 4.10 depict the barriers to movement along the least cost pathways between core areas for the Northern flying squirrel. There is a large barrier north of Lake Rossignol. Least Cost Corridors were created using the “Build Linkage Pathways” tool to calculate the path of least resistance through the landscape. Study area A had a large barrier to movement north of Lake Rossignol. Study region B has a lower CWD/Path length ratio indicating lower resistance to movement across the least cost pathways (Table 4.3). Additionally, study area B had a the lowest R̂ and highest CWD/ R̂ at both a buffer zone of 1000m and 10,000m, showing that area B has a lower resistance and more high-quality pathways available for alternative routes of movement.

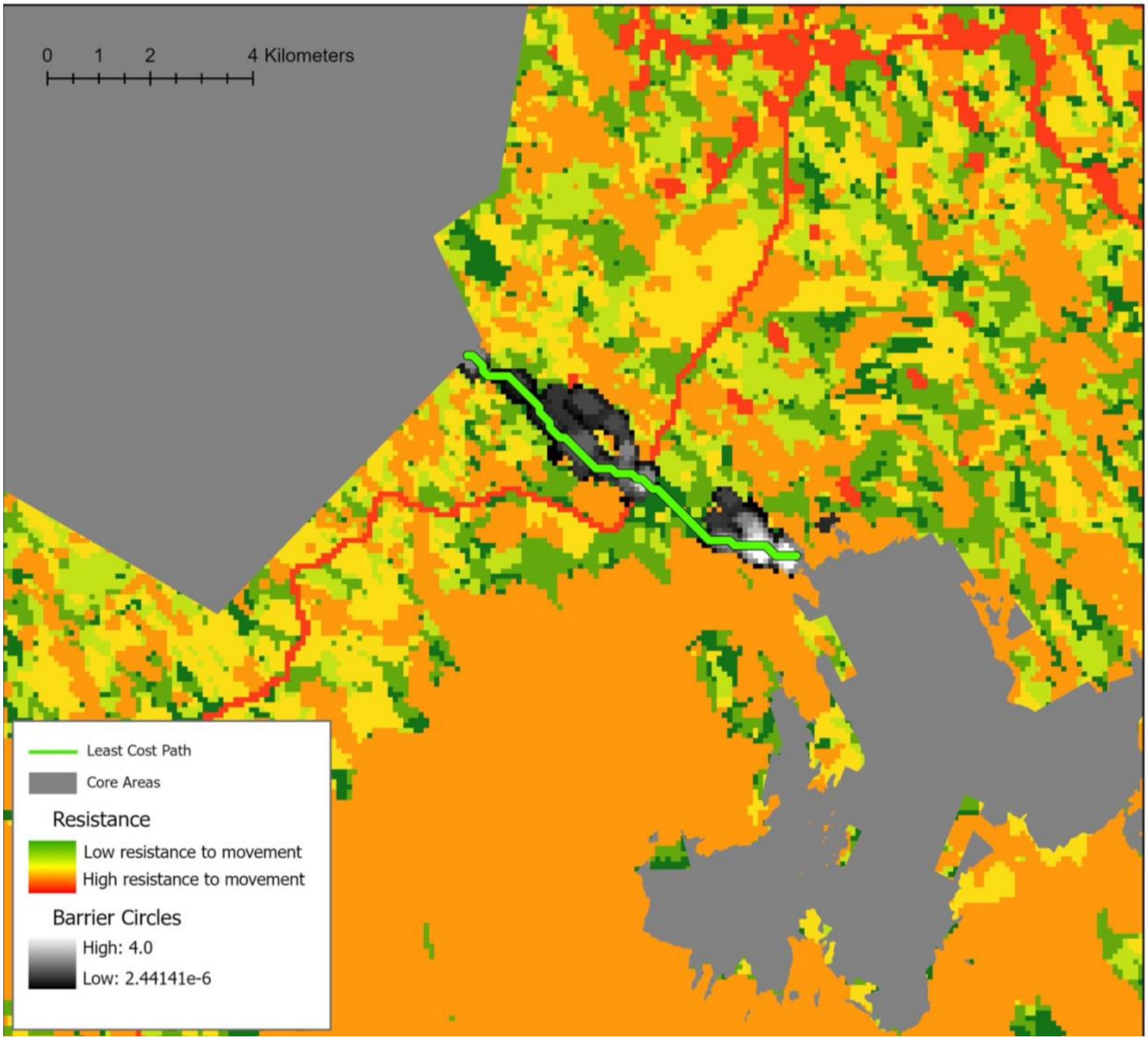

Figure 4.9: Least Cost Paths and Barriers to movement between selected core areas for Northern Flying Squirrel between Kejimkujik National Park and Lake Rossignol Wilderness Area

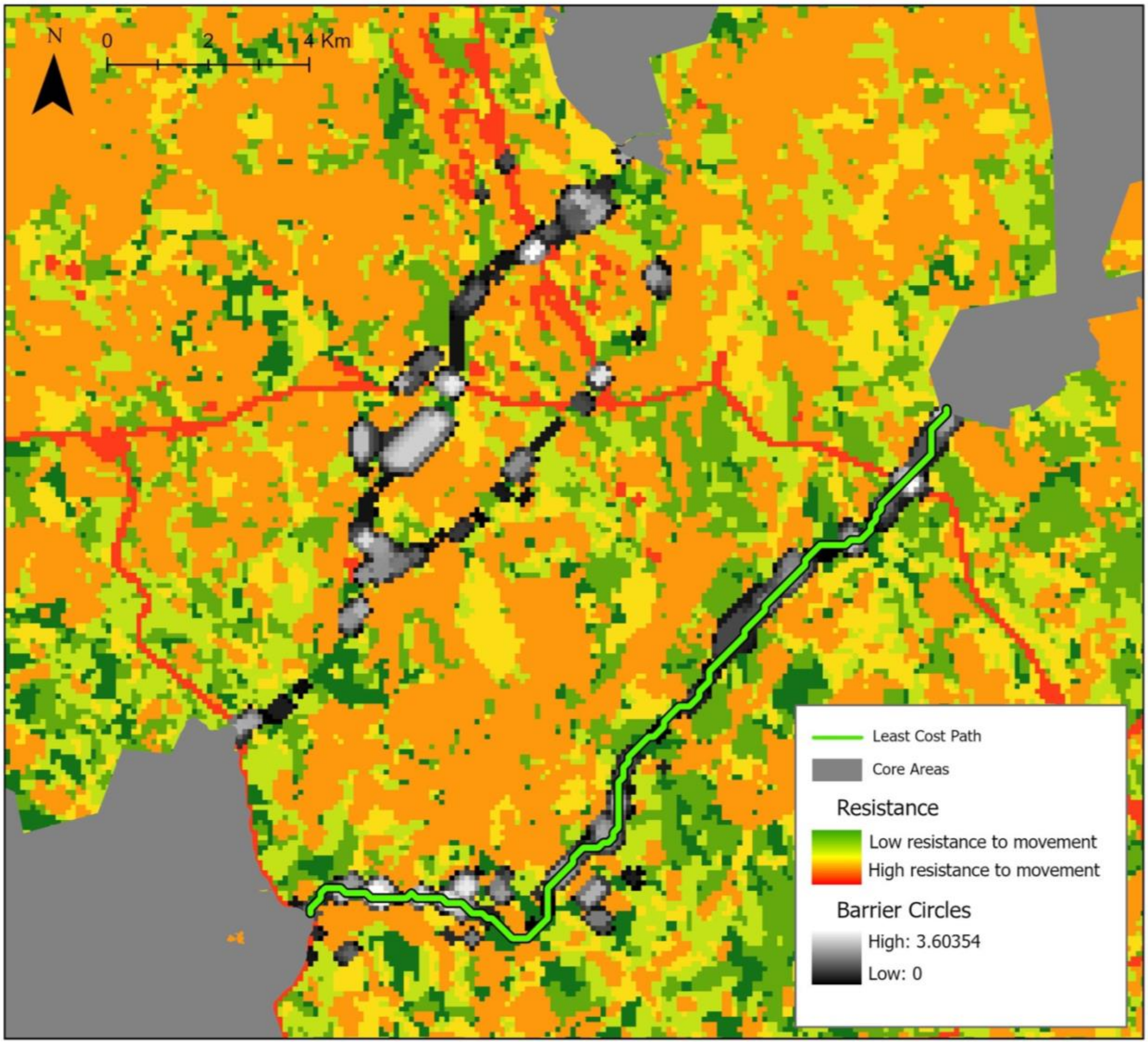

Figure 4.10: Least Cost Paths and Barriers to movement between selected core areas for Northern Flying Squirrel between Medway Lakes and Cloud Lakes Wilderness Area

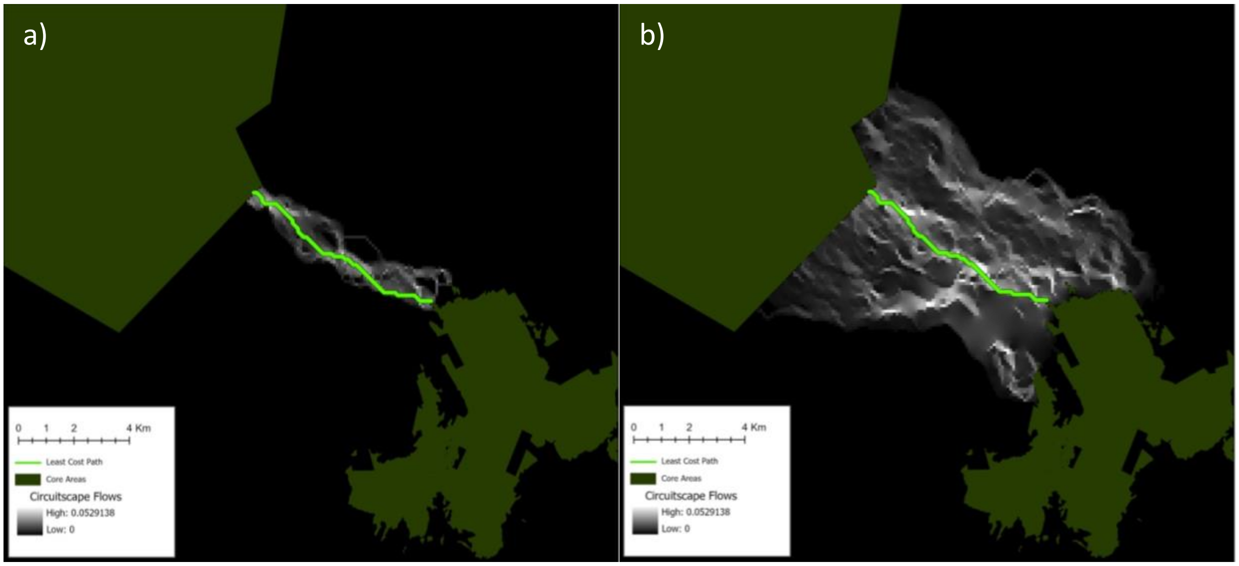

Figure 4.11: Pinchpoints between Kejimkujik National Park and Lake Rossignol Wilderness Area for Northern Flying Squirrel at a) 1000m buffer and b) 10,000m buffer

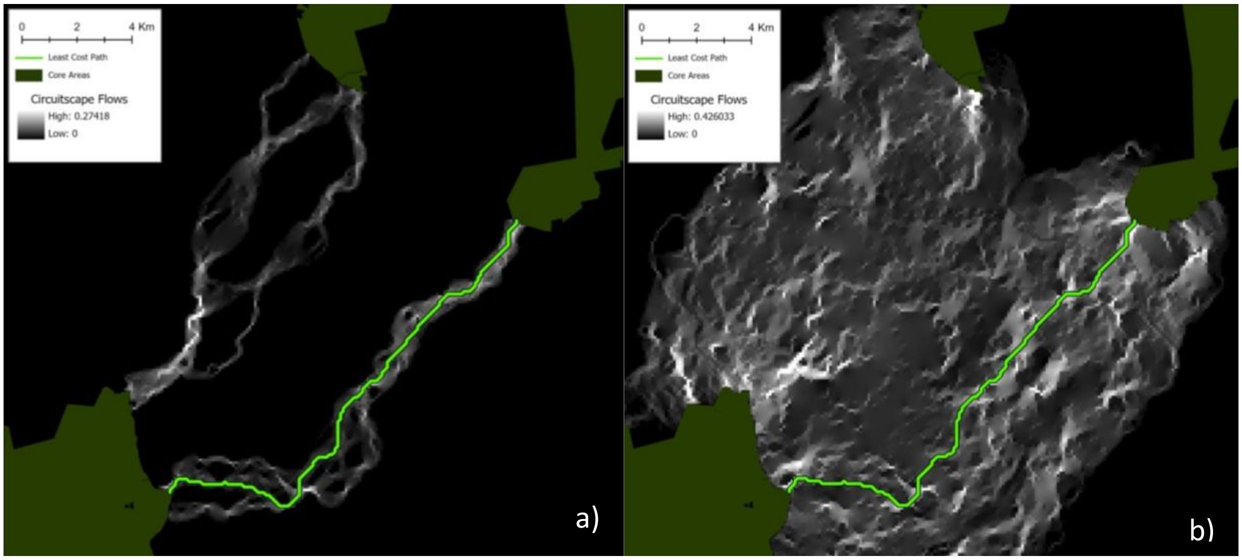

Figure 4.12: Pinchpoints between Medway Lakes and Cloud Lakes Wilderness Area for Northern Flying Squirrel at a) 1000m buffer and b) 10,000m buffer

Table 4.3: Linkage Mapper and Pinchpoint Mapper resistance data for Northern flying squirrel

	CWD	CWD/Path length Ratio	$\hat{R}^2$ (1K)	$\hat{R}^2$ (10K)	CWD/ $\hat{R}$ (1K)	CWD/ $\hat{R}$ (10K)
Study Region A	17663.1	2.2	2646.3	635.5	6.7	27.8
Study Region B	40403.8	2.0	3107.4	546.4	13.0	73.9

4.4 Black bear

As a wide-ranging habitat generalist, the resistance to movement across the landscape between core areas for the Black Bear overlaid by barriers to movement along the least cost pathways are shown in figures 4.13 and 4.13. The raster resistance layer was used along with the build linkage pathways tool to provide least cost paths between core areas for each study region. Region A was found to have a lower CWD and CWD/ path length ratio indicating a lower cost to movement across the landscape. Study region A is also found to have a lower $\hat{R}$ and a lower CWD/ $\hat{R}$ ratio, showing that despite having a lower resistance to movement region A has lower quality pathways and flow is constricted to fewer areas indicating less viable corridors (Table 4.4).

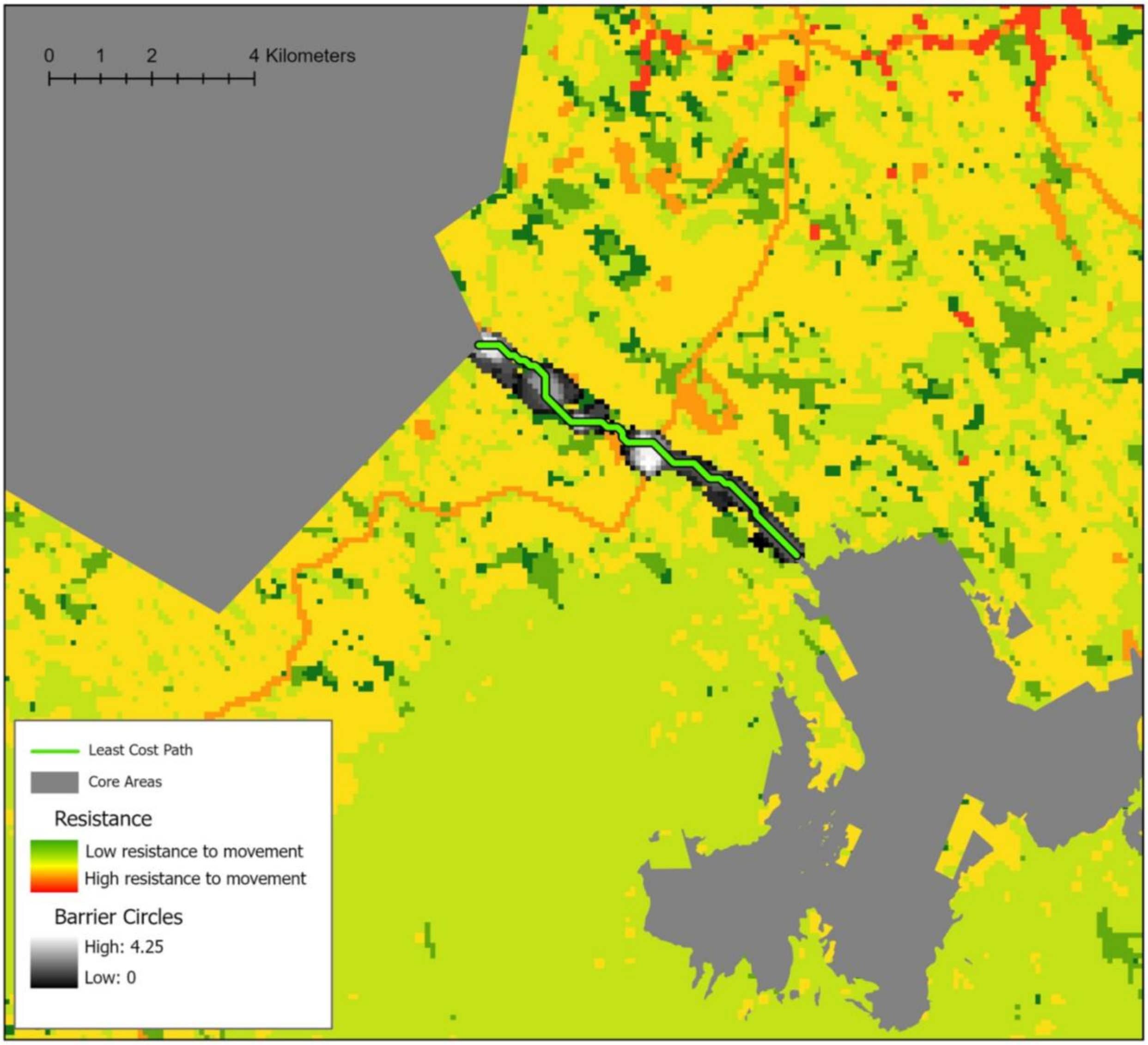

Figure 4.13: Least Cost Paths and Barriers to movement between selected core areas for Black Bear between Kejimkujik National Park and Lake Rossignol Wilderness Area

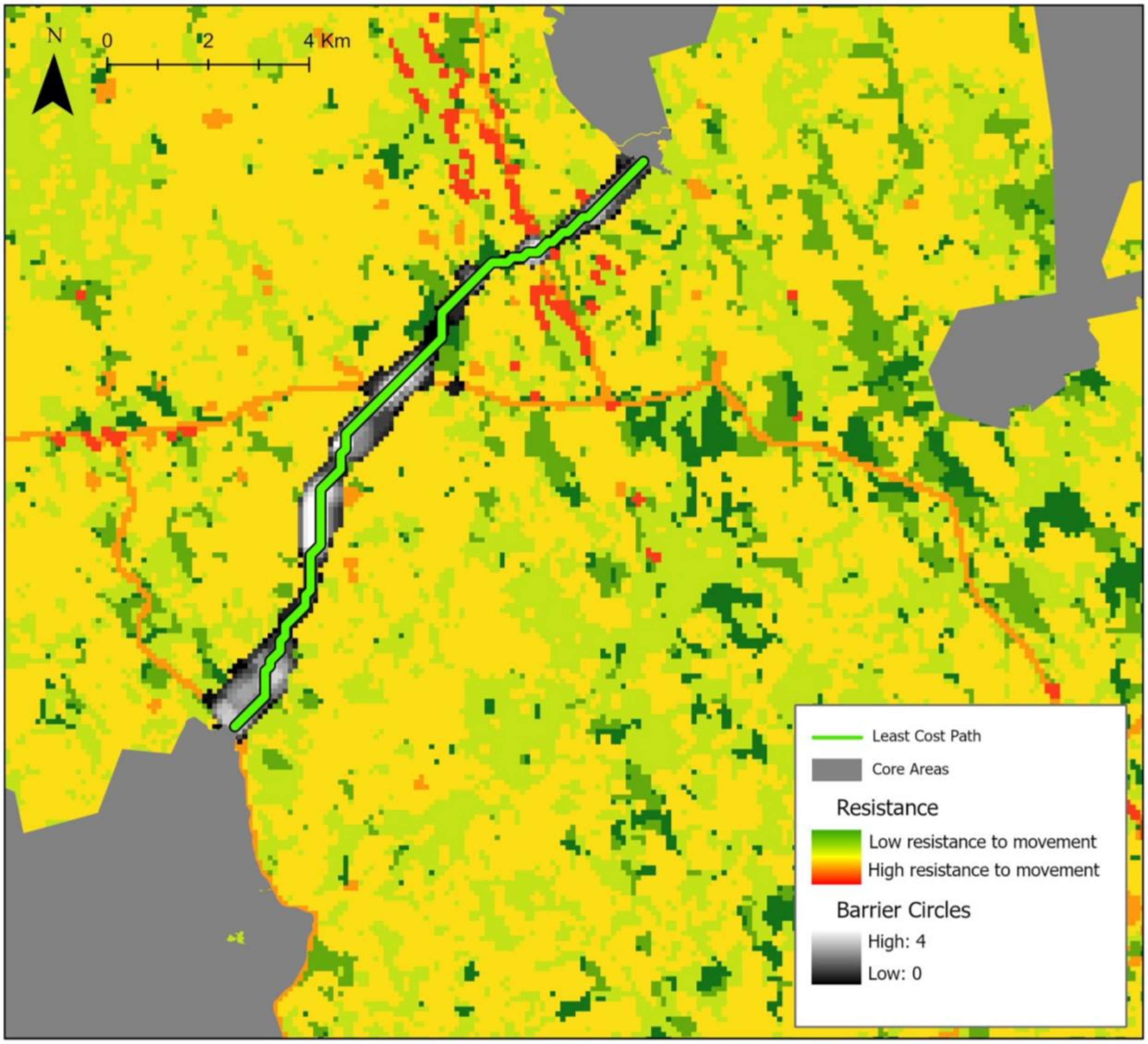

Figure 4.14: Least Cost Paths and Barriers to movement between selected core areas for Black Bear between Medway Lakes and Cloud Lakes Wilderness Area

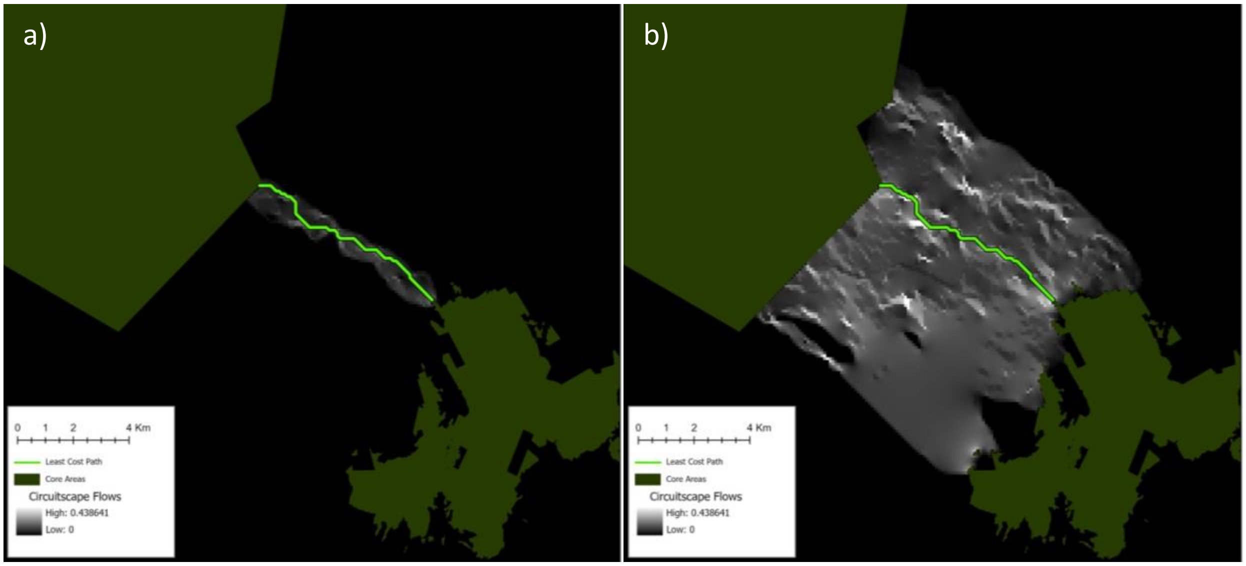

Figure 4.15: Pinchpoints between Kejimkujik National Park and Lake Rossignol Wilderness Area for Black Bear at a) 1000m buffer and b) 10,000m buffer

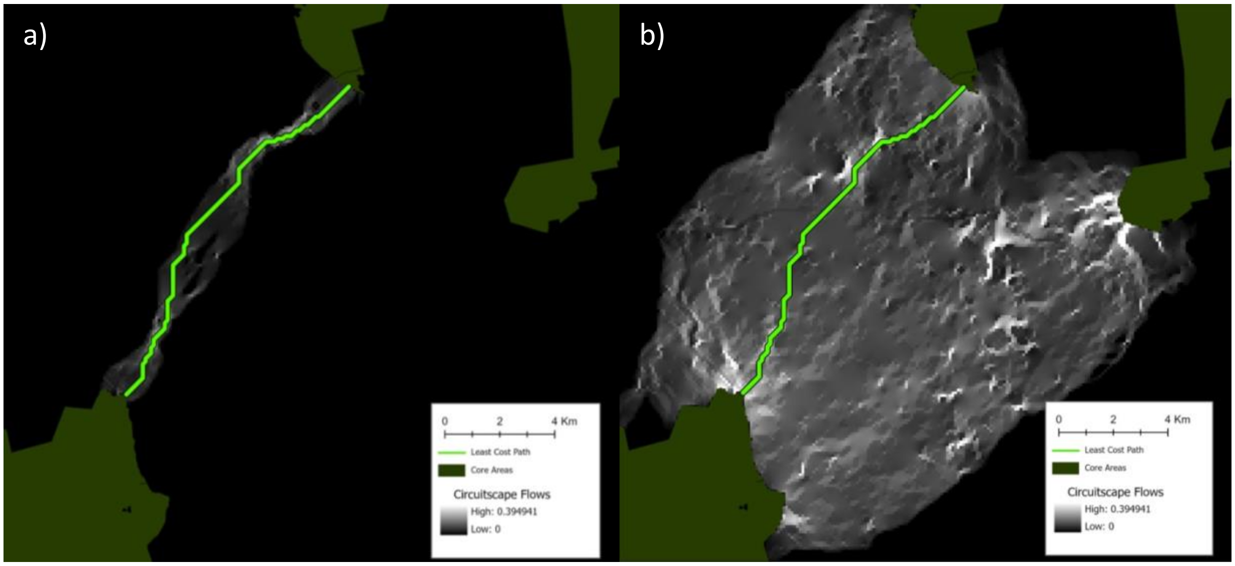

Figure 4.16: Pinchpoints between Medway Lakes and Cloud Lakes Wilderness Area for Black Bear at a) 1000m buffer and b) 10,000m buffer

Table 4.4: Linkage Mapper and Pinchpoint Mapper resistance data for Black bear.

	CWD	CWD/Path length Ratio	CW(1K)	$\hat{R}^2$ (10K)	CWD/ $\hat{R}$ (1K)	CWD/ $\hat{R}$ (10K)
Study Region A	18989.4	2.3	3277.2	412.4	5.8	46.0
Study Region B	40539.3	2.7	6357.1	574.0	6.4	70.6

4.5 Wood turtle

As an opportunity-based habitat generalist the wood turtle can be found in a wide variety of habitats ranging from wetlands to mixed forest to agricultural fields Wood turtles are relatively neutral to most habitat types with no large barriers to movement other than anthropogenic features present (Figure 4.17, 4.18). The “Build linkage pathways” was used to create least cost paths between core areas (Table 4.5). Study area A had a slightly higher CWD/path length ratio. Area A also had a lower $\hat{R}$ but also had the lower CWD/R ratio for both buffer areas indicating that although area A has a lower resistance it also has lower quality pathways and flow was restricted.

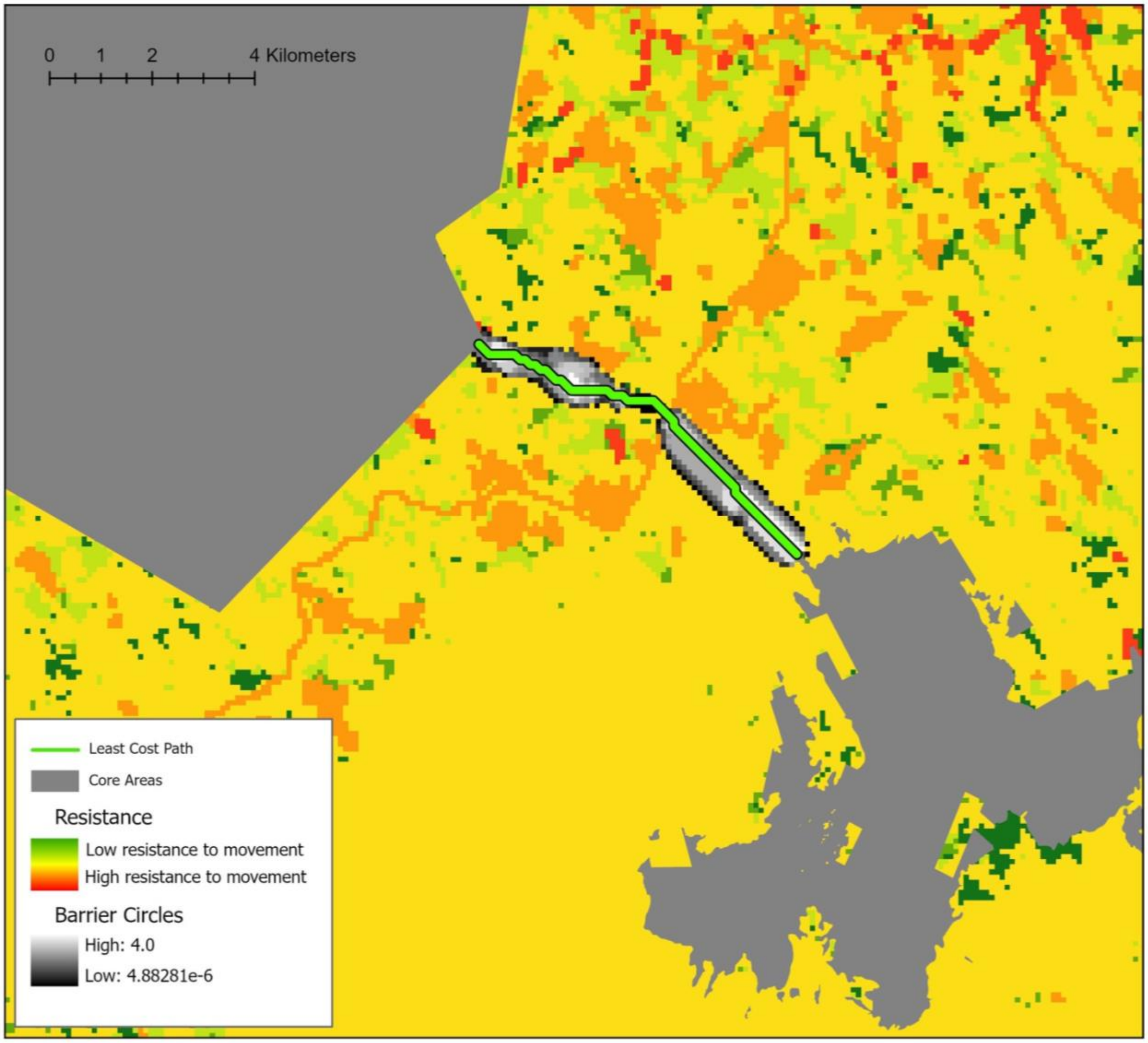

Figure 4.17: Least Cost Paths and Barriers to movement between selected core areas for Wood Turtle between Kejimkujik National Park and Lake Rossignol Wilderness Area

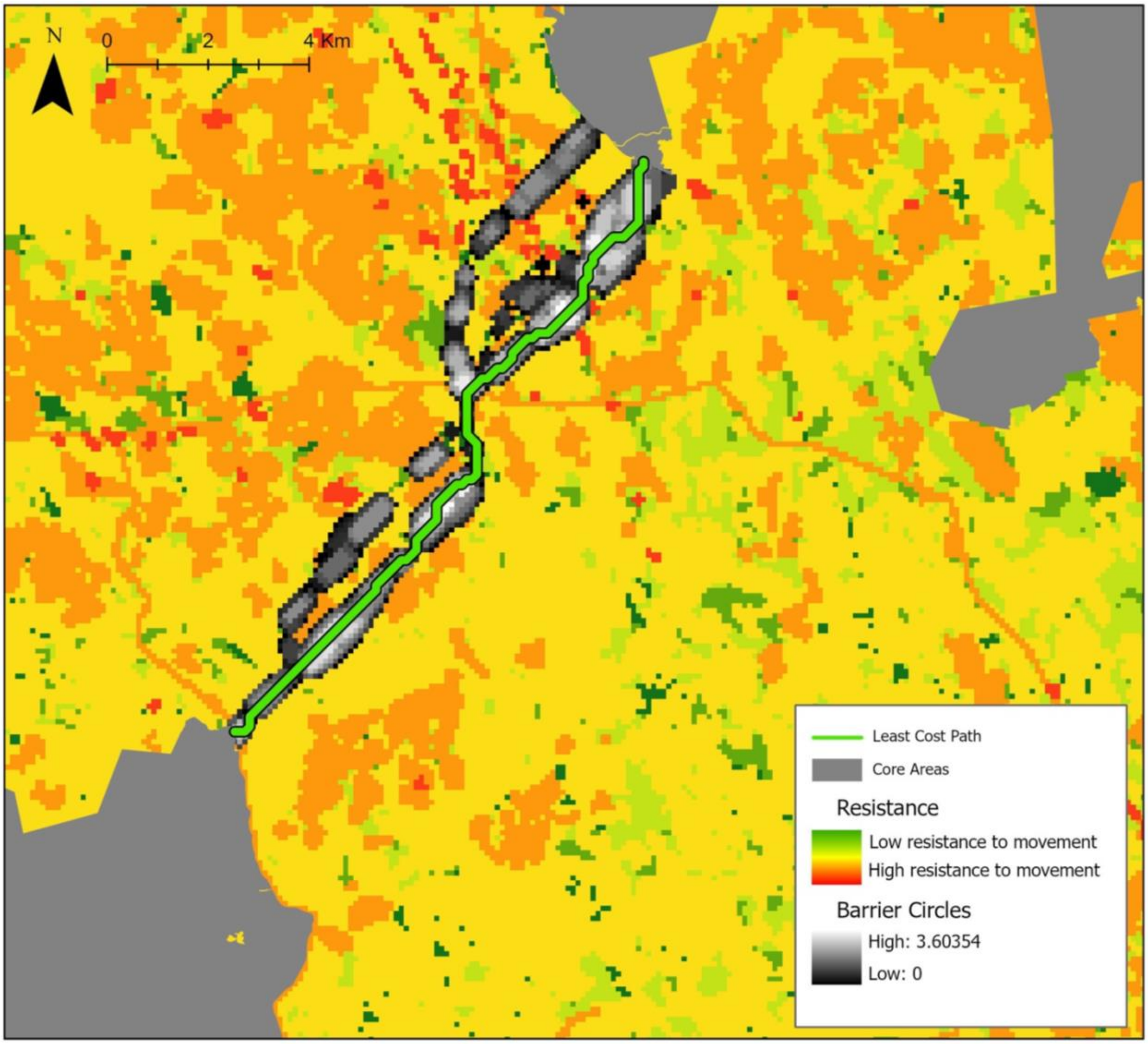

Figure 4.18: Least Cost Paths and Barriers to movement between selected core areas for Wood Turtle between Medway Lakes and Cloud Lakes Wilderness Area

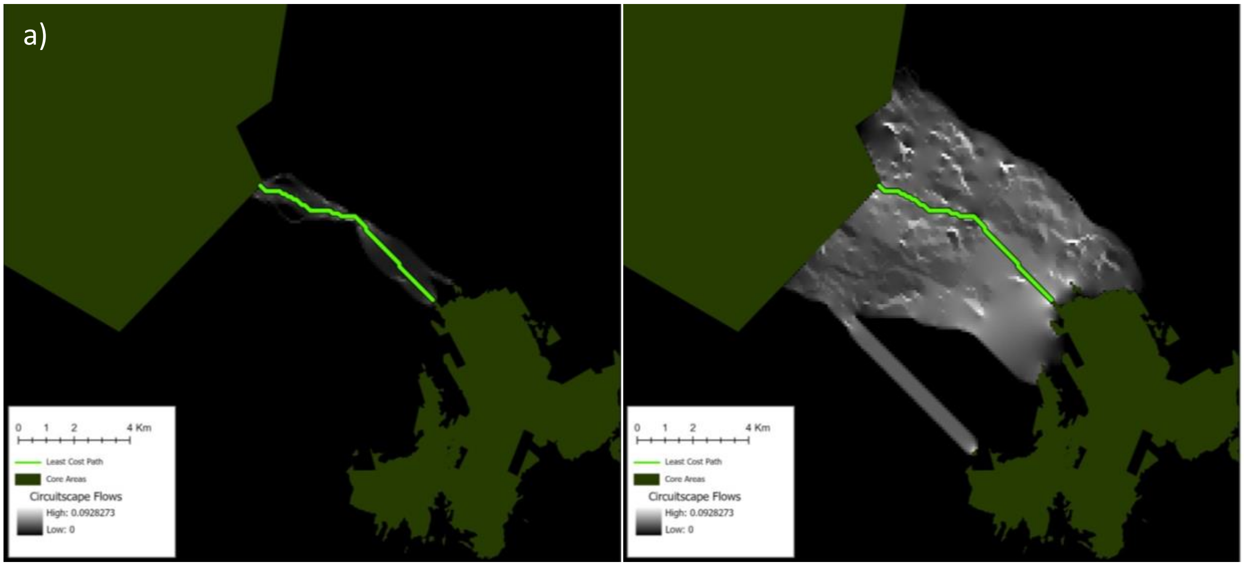

Figure 4.19: Pinchpoints between Kejimkujik National Park and Lake Rossignol Wilderness Area for Wood Turtle at a) 1000m buffer and b) 10,000m buffer

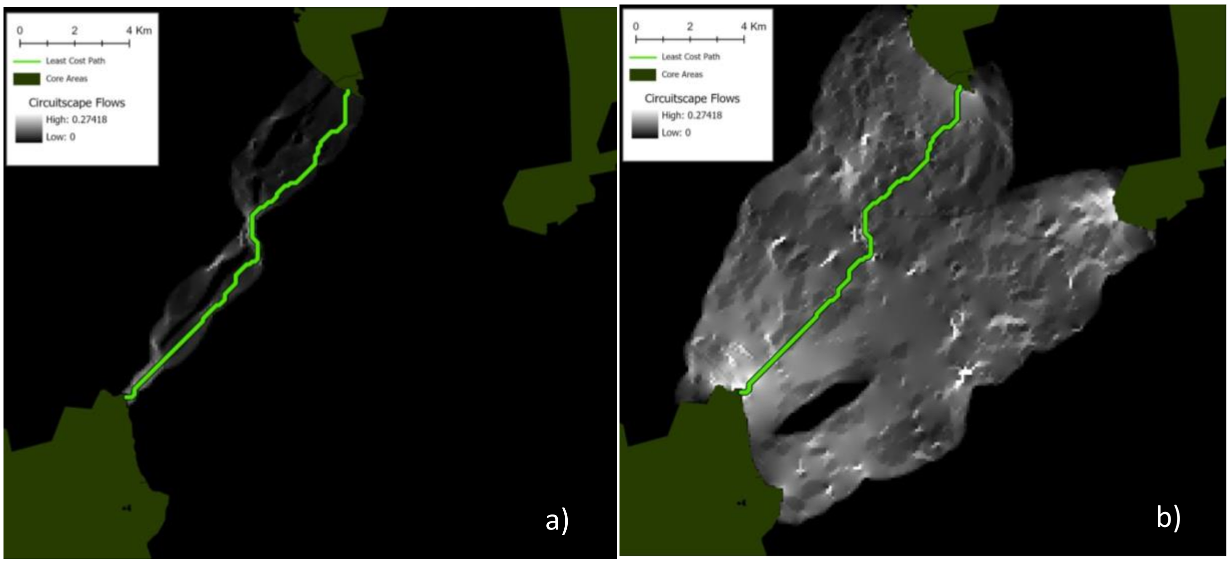

Figure 4.20: Pinchpoints between Medway Lakes and Cloud Lakes Wilderness Area for Wood Turtle at a) 1000m buffer and b) 10,000m buffer

Table 4.5: Linkage Mapper and Pinchpoint Mapper resistance data for Wood turtle.

	CWD	**CWD/Path length Ratio**	**$\hat{R}^2$ (1K)**	**$\hat{R}^2$ (10K)**	**CWD/ $\hat{R}$ (1K)**	**CWD/ $\hat{R}$ (10K)**
Study Region A	26009.0	3.3	5037.1	769.7	5.2	33.8
Study Region B	49950.3	3.2	7623.7	1043.3	6.6	47.9

4.6 Eastern Wood Pewee

With associations with mature to old growth deciduous and deciduous dominant mixed forest types, resistance rasters across the landscape between core areas area overlaid by barriers along least cost paths for the Eastern Wood Pewee is shown in figures 4.21 and 4.22. There is a large barrier to movement south of Cloud Lakes Wilderness area impeding movement. Least cost corridors are mapped using linkage pathways (Table 4.6). Study region B has a higher CWD and CWD/ path length ratio indicating a higher cost to movement between core areas. Study region B had a higher $\hat{R}$ value indicating a higher resistance. However, region B also had a higher CWD/$\hat{R}$ ratio for both 1000m and 10,000m buffer showing that despite having a higher resistance it also has more quality alternative pathways between core areas (Figure 4.24).

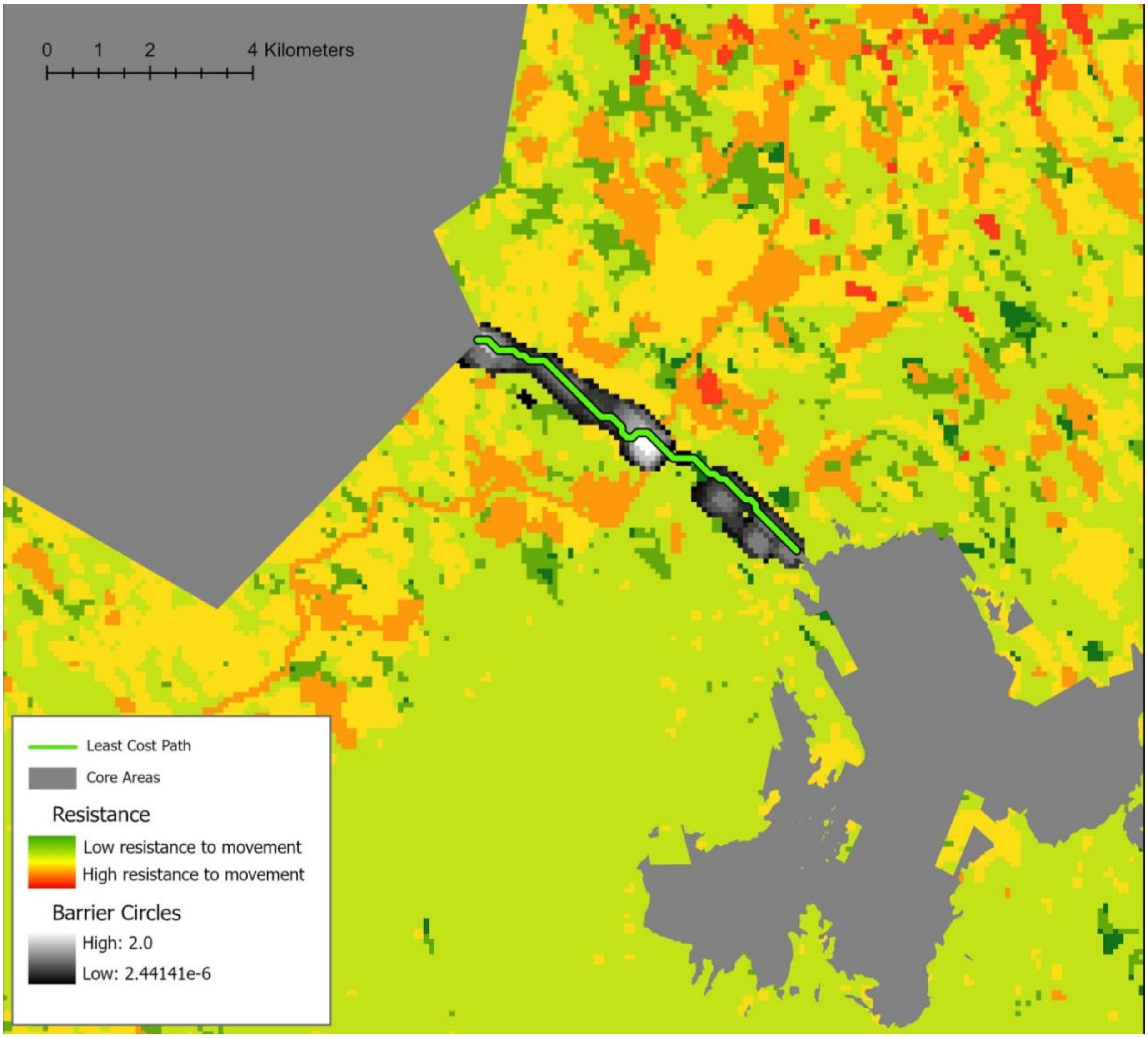

Figure 4.21: Least Cost Paths and Barriers to movement between selected core areas for Eastern Wood Pewee between Kejimkujik National Park and Lake Rossignol Wilderness Area

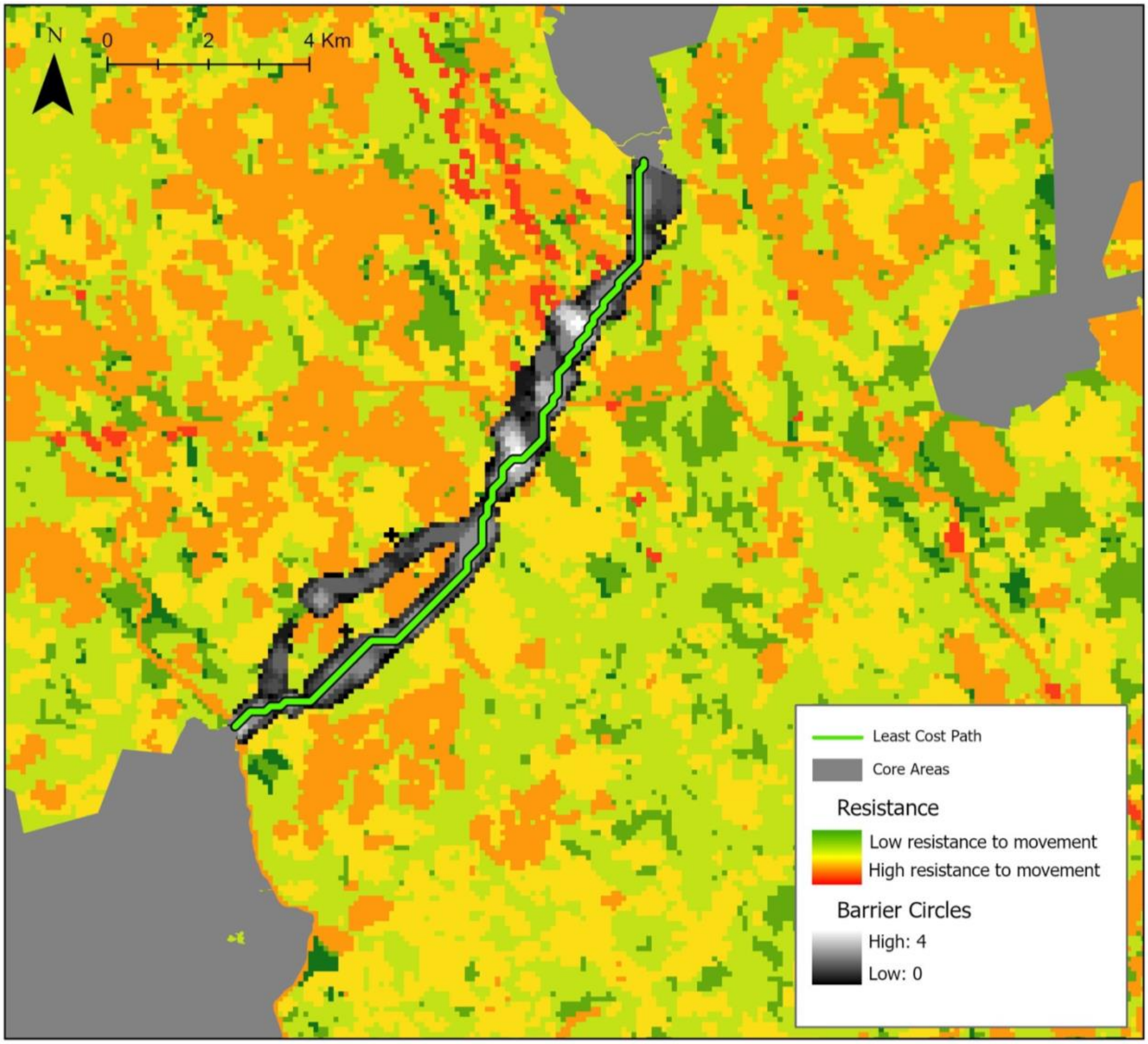

Figure 4.22: Least Cost Paths and Barriers to movement between selected core areas for Eastern Wood Pewee between Medway Lakes and Cloud Lakes Wilderness Area

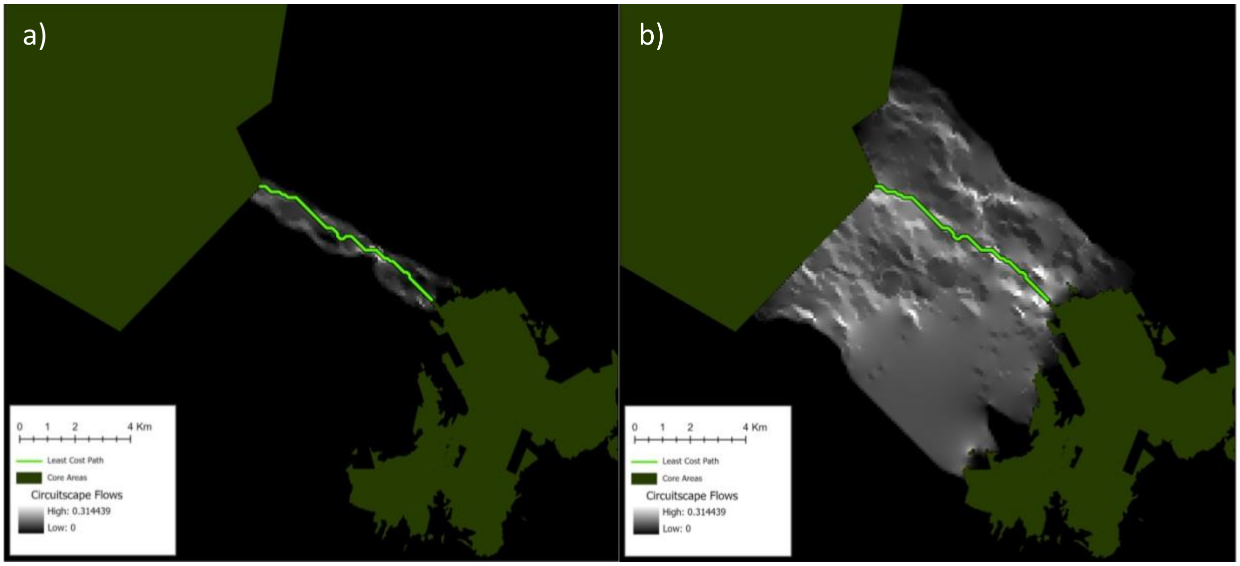

Figure 4.23: Pinchpoints between Kejimkujik National Park and Lake Rossignol Wilderness Area for Eastern Wood Pewee at a) 1000m buffer and b) 10,000m buffer

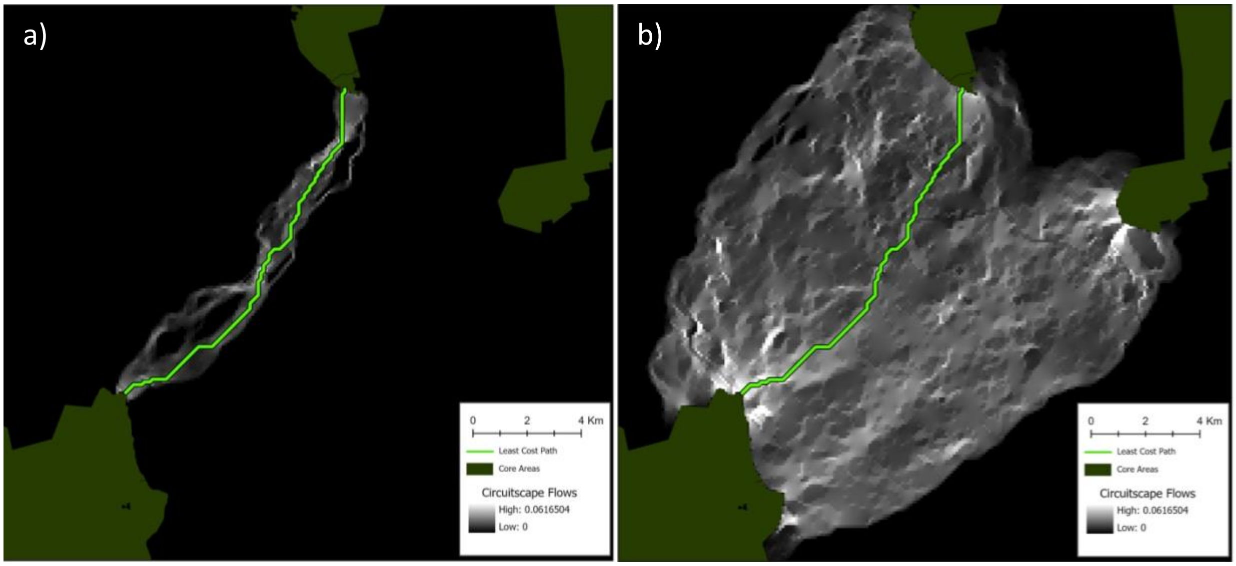

Figure 4.24: Pinchpoints between Medway Lakes and Cloud Lakes Wilderness Area for Eastern Wood Pewee at a) 1000m buffer and b) 10,000m buffer

Table 4.6: Linkage Mapper and Pinchpoint Mapper resistance data for Eastern Wood Pewee.

	CWD	**CWD/Path length Ratio**	**$\hat{R}^2$ (1K)**	**$\hat{R}^2$ (10K)**	**CWD/ $\hat{R}$ (1K)**	**CWD/ $\hat{R}$ (10K)**
Study Region A	20020.0	2.5	2780.1	435.7	7.2	45.9
Study Region B	43749.3	2.8	6341.6	656.3	6.9	66.7

4.7 Black Ash

As a habitat specialist found in swamps and flood prone sites Black Ash was found to a have a high cost to movement across the landscape. Linkage pathways was used to provide the least cost path between core areas for each study region. Study region A was found to have a slightly CWD and CWD/ path length ratio (Table 4.7). Barrier mapper was used to identify areas in need of restoration and that are inhibiting the quality of the corridors. Both areas were found to have larger barriers that are in need of mitigation efforts (Figures 4.25, 4.26). Study area B was found to have both a higher $\hat{R}$ and a higher CWD/$\hat{R}$ ratio, indicating that despite having a higher resistance, area B also has more high-quality alternative pathways (Figure 4.28).

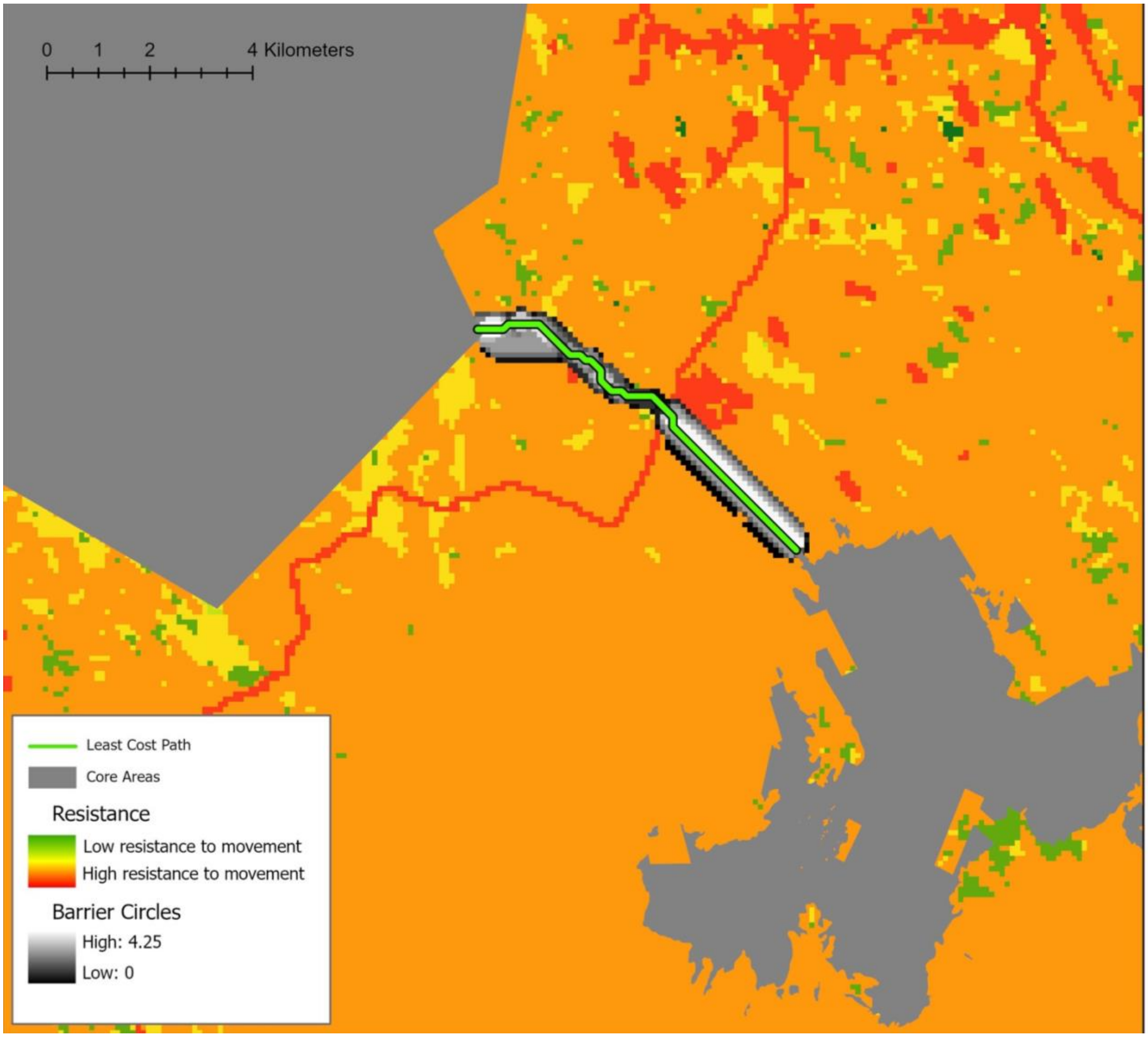

Figure 4.25: Least Cost Paths and Barriers to movement between selected core areas for Black Ash between Kejimkujik National Park and Lake Rossignol Wilderness Area

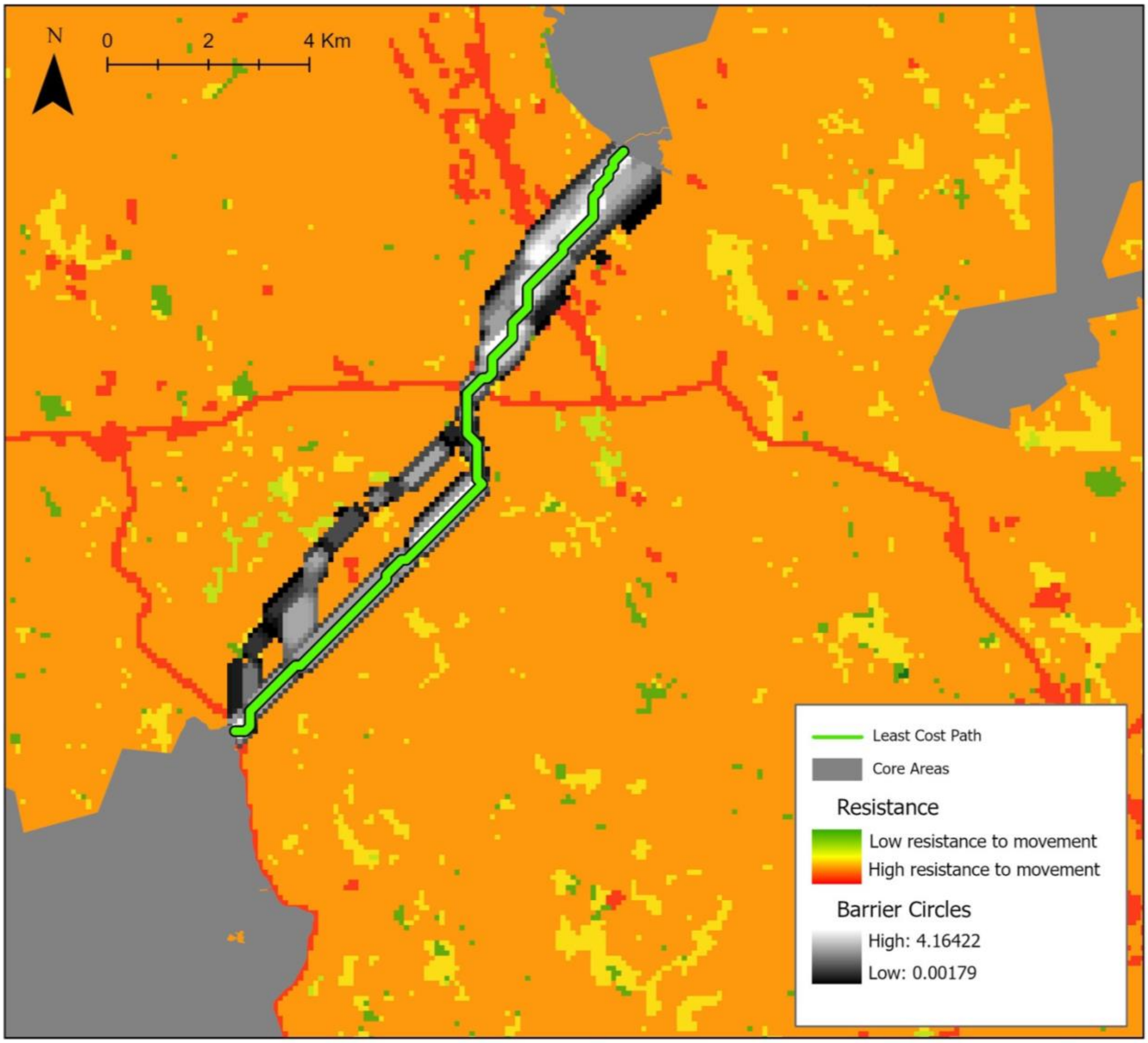

Figure 4.26: Least Cost Paths and Barriers to movement between selected core areas for Black Ash between Medway Lakes and Cloud Lakes Wilderness Area

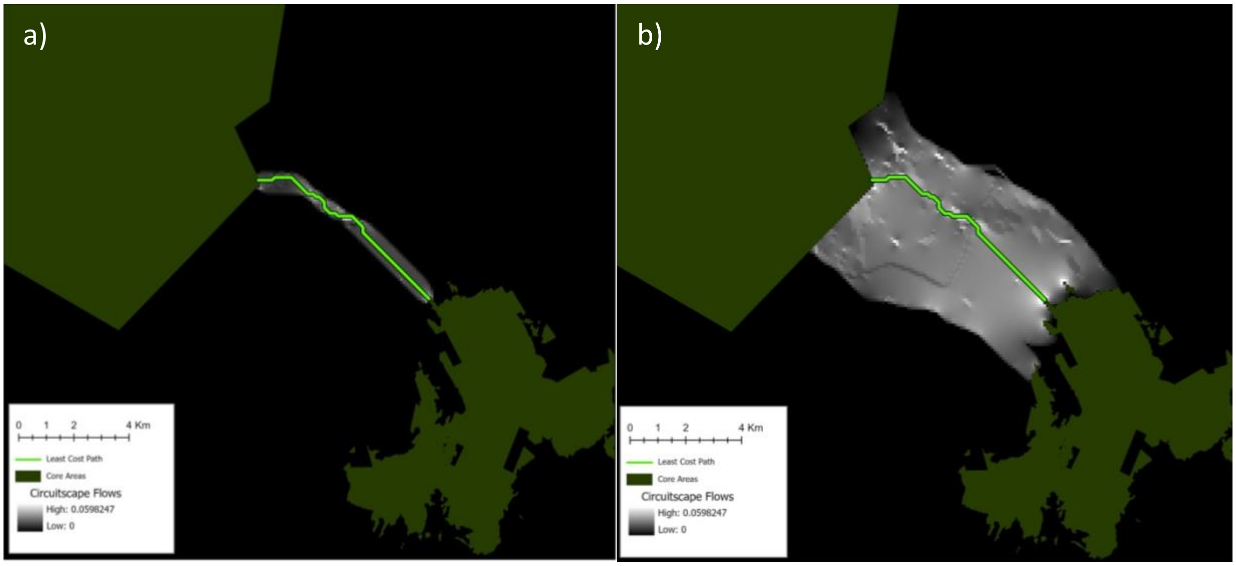

Figure 4.27: Pinchpoints between Kejimkujik National Park and Lake Rossignol Wilderness Area for Black Ash at a) 1000m buffer and b) 10,000m buffer

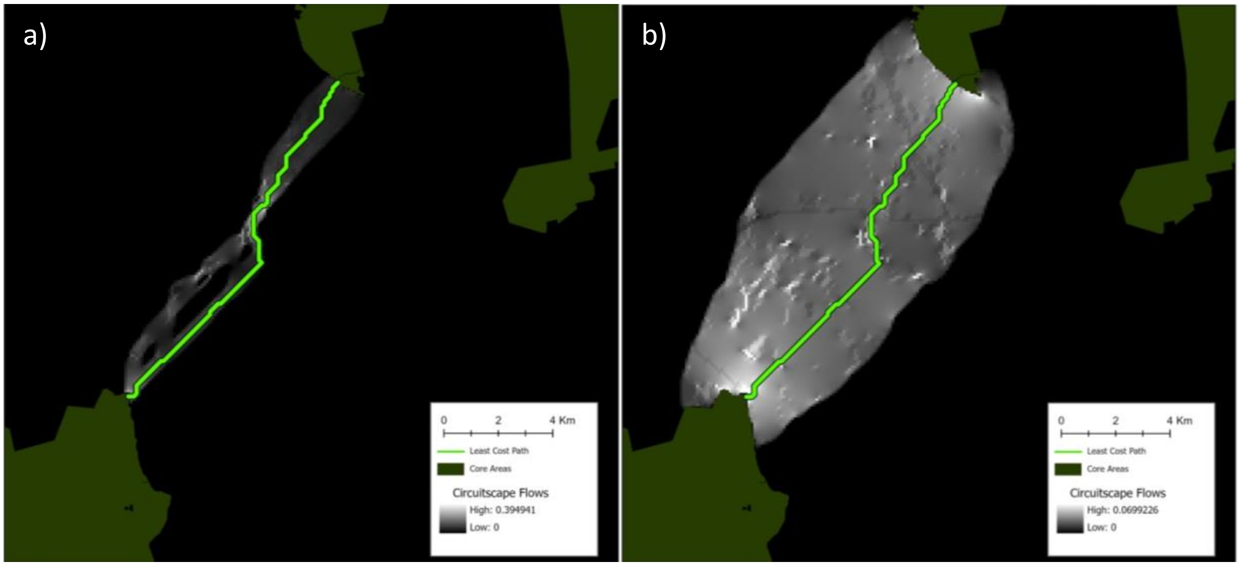

Figure 4.28: Pinchpoints between Medway Lakes and Cloud Lakes Wilderness Area for Black Ash at a) 1000m buffer and b) 10,000m buffer

Table 4.7: Linkage Mapper and Pinchpoint Mapper resistance data for Black Ash.

	CWD	**CWD/Path length Ratio**	**$\hat{R}^2$ (1K)**	**$\hat{R}^2$ (10K)**	**CWD/ $\hat{R}$ (1K)**	**CWD/ $\hat{R}$ (10K)**
Study Region A	34007.3	4.1	10817.9	1563.2	3.1	21.8
Study Region B	64306.1	4.2	12868.0	2480.4	5.0	25.9

4.8 Comparisons

Comparing the distribution of least cost paths for all species through the landscape found that study region A had more areas in common with overlap between corridors than study region B (Figure 4.29). Figure 4.31 shows a bar chart comparing the CWD/ $\hat{R}$ ratio for both buffer zones of 1000m and 10,000m for both study regions across all species. Apart from moose, 6 of the 7 species analyzed had a higher CWD/ $\hat{R}$ ratio in study region B. This indicates that area B has higher quality pathways, and the flow is less constrained in a larger area. Furthermore, across all 7 species the CWD/ $\hat{R}$ ratio is higher when evaluated with a buffer zone of 10,000m rather than at 1000m (Figure 4.33). Figure 4.31 shows the CWD/ path length ratio for both study regions across all species. Mainland moose, northern flying squirrels and wood turtles had a higher CWD/ path length ratio in region A while marten, black bear, eastern wood pewees, and black Ash all had a higher ratio in region B. The $\hat{R}^2$ is graphed to show which study regions have a higher resistance to movement across the landscape when evaluated using circuit theory (Figure 4.32). Across all seven species analysed study region A had a lower $\hat{R}^2$ for both 1000m and 10,000m buffers, indicating a lower resistance. However, as region A also had the higher CWD/$\hat{R}$ ratio showing that despite having a lower resistance area A also has lower quality corridors and flow is more constricted in this region.

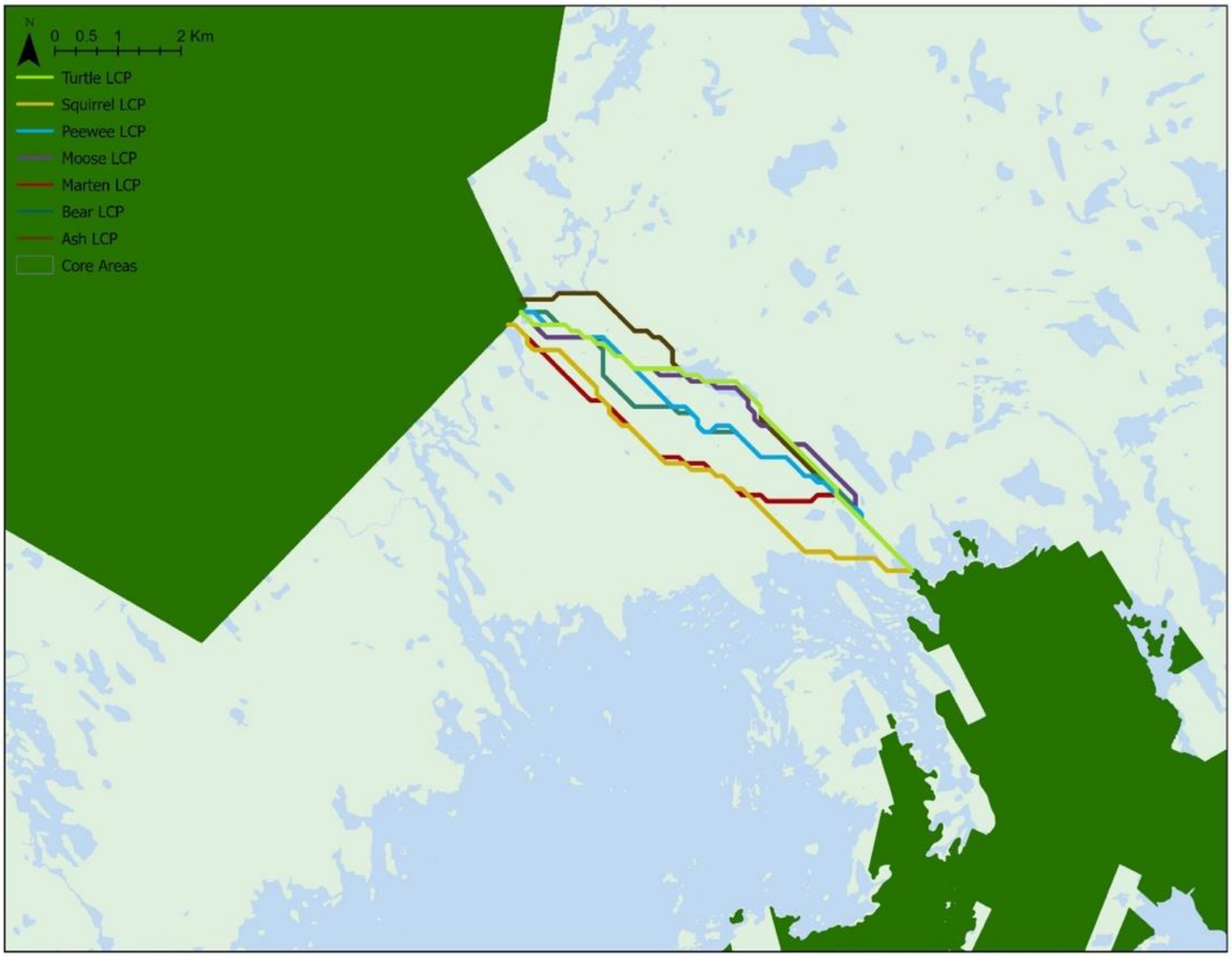

Figure 4.29: Map of species' least-cost paths for Study Region A connecting Kejimkujik National Park to Lake Rossignol Wilderness Area.

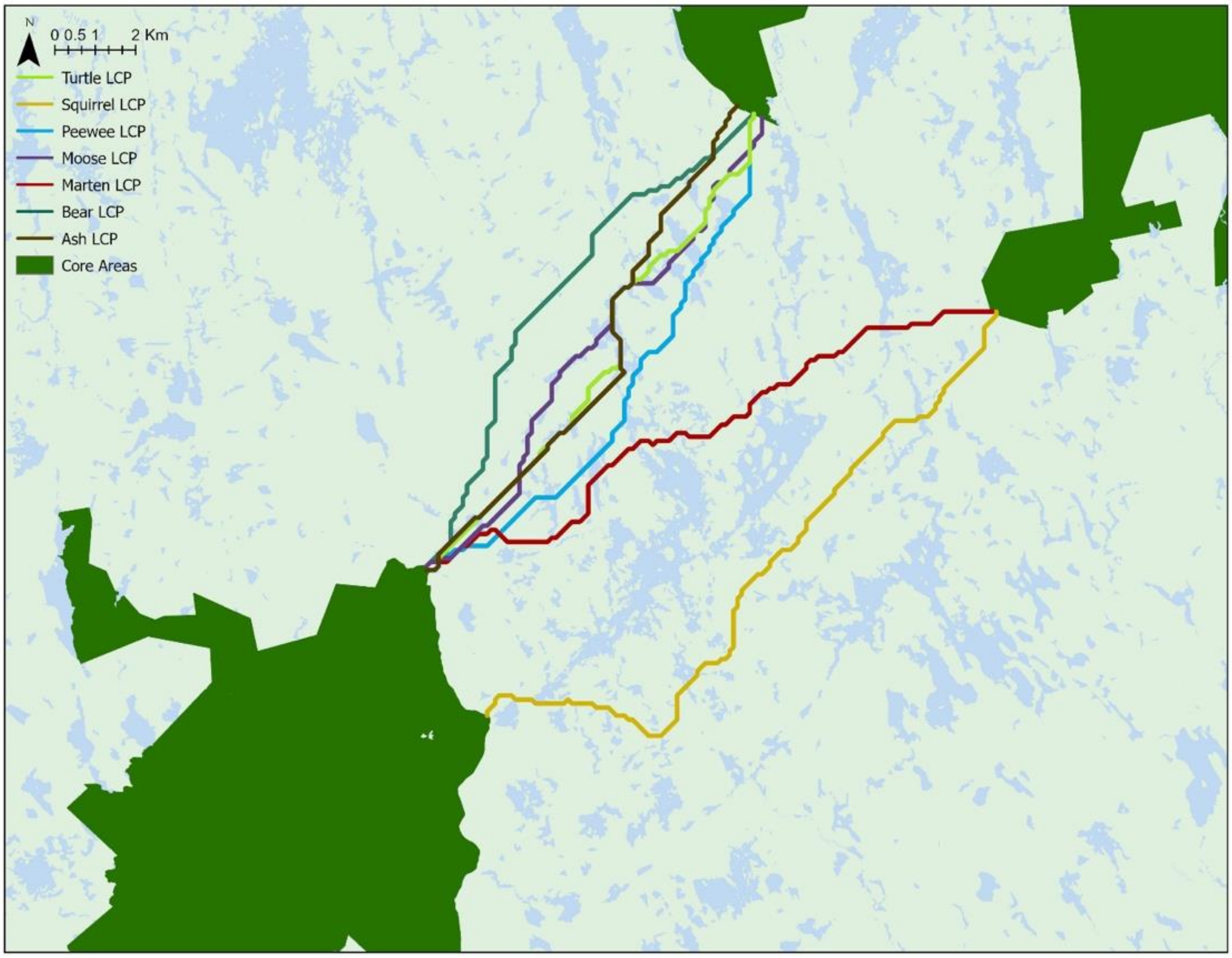

Figure 4.30: Map of species' least-cost paths for Study Region B connecting Medway Lakes and Cloud Lakes Wilderness Area.

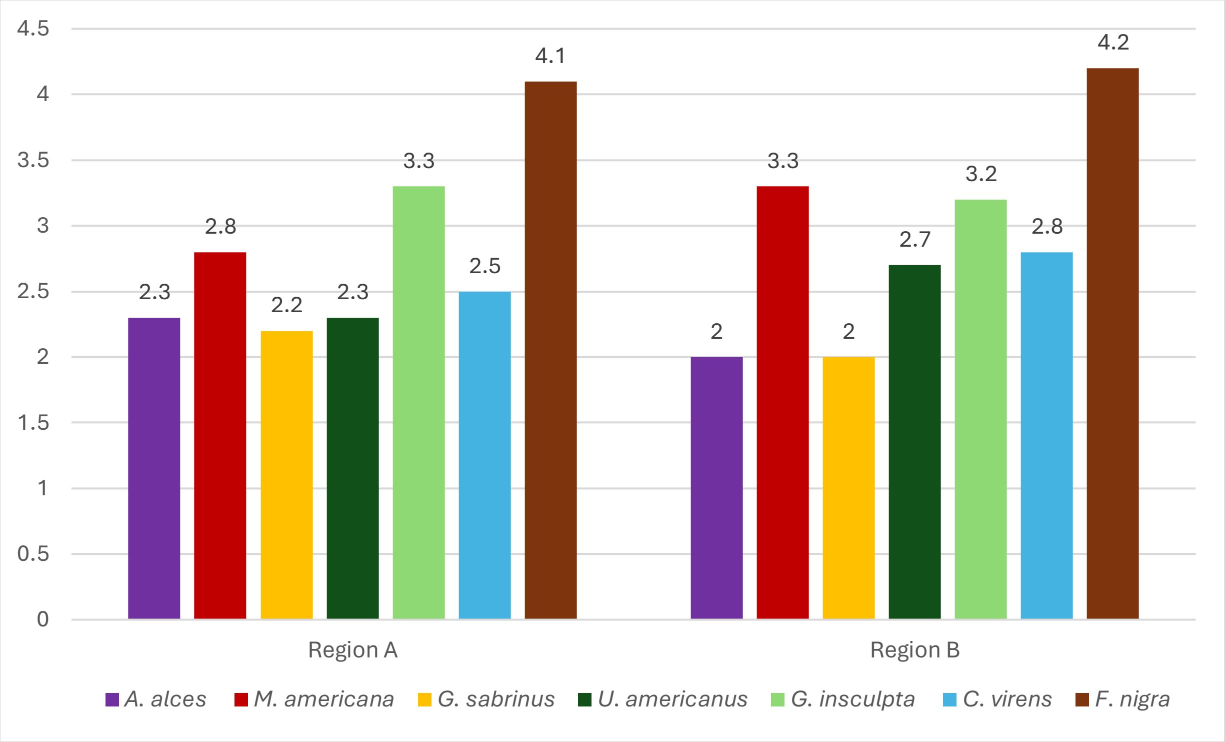

Figure 4.31: Bar chart comparing CWD/Path Length Ratios for seven species across study regions A and B.

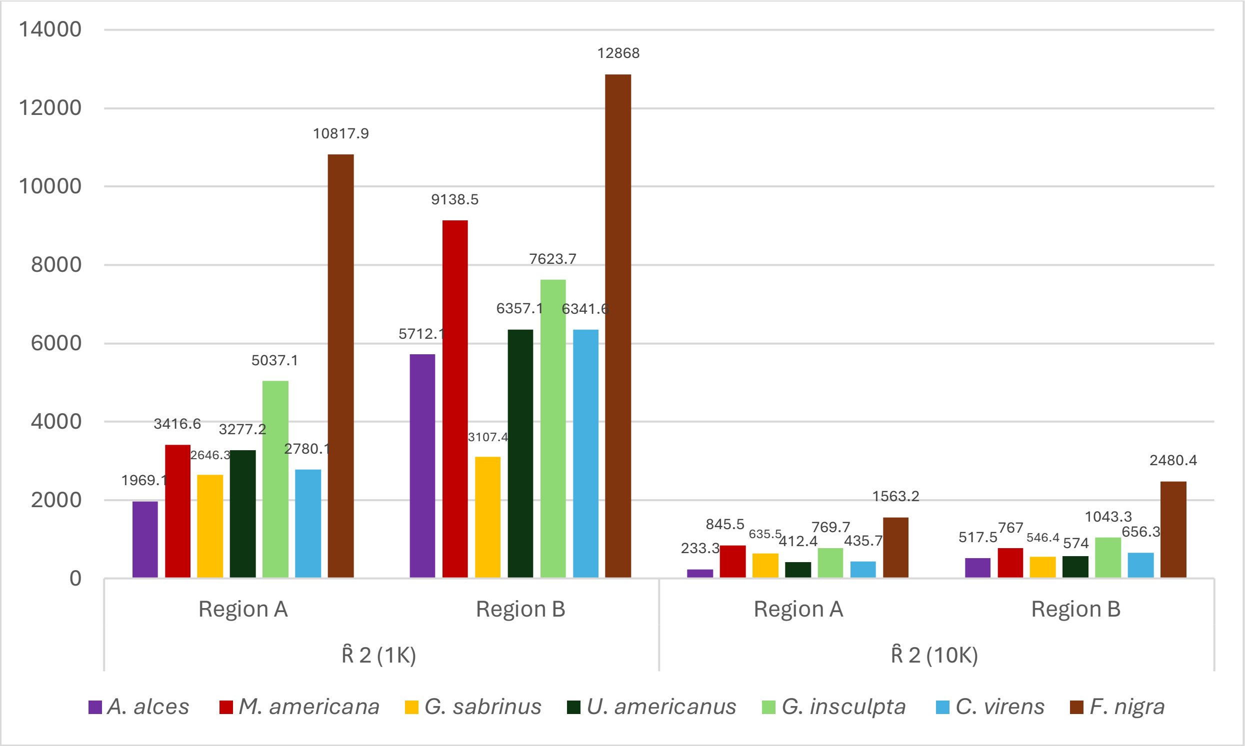

Figure 4.32: Bar chart comparing $\hat{R}^2$ for seven species across study regions A and B with buffer zones from the least cost pathways of 1000m and 10,000m.

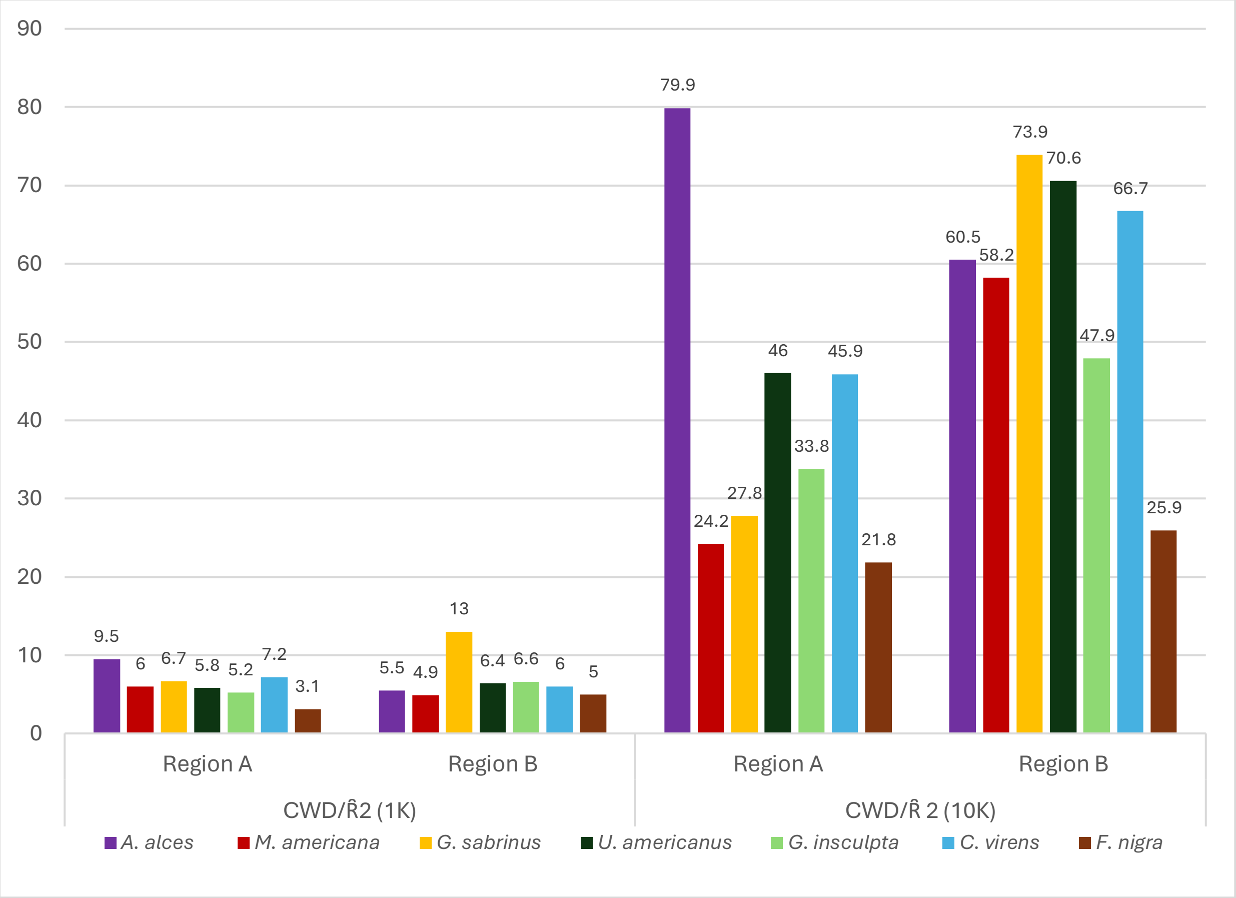

Figure 4.33: Bar chart comparing CWD/R̂ for seven species across study regions A and B with buffer zones from the least cost pathways of 1000m and 10,000m.

3.9 Areas of Significance

Figures 4.34 and 4.36 provide a closer look at where least cost paths and Circuitscape flows overlap. The highlighted areas in red are where conservation is most important as the multiple species travel through these areas in the least cost path and Circuitscape had a high flow through the area. Region A had two areas where conservation and restoration initiatives may be imperative (Figure 4.34). The first area is central to the region with pathways with the Eastern Wood Pewee and Black Bears overlapping the area with the highest flow across the entire study area. Additionally, the second area for conservation in region A is located near Lake Rossignol and is mainly comprised of wetlands and wet forest with six of the seven species studied traveling through this area. Region B connecting Medway Lakes to Cloud Lakes Wilderness area had one key area of overlap between least cost pathways of Ash, Moose and Wood turtles in an area with high Circuitscape flow indicating it is an important area in maintaining the flow of species across the landscape between the two core protected areas. (Figure 4.36).

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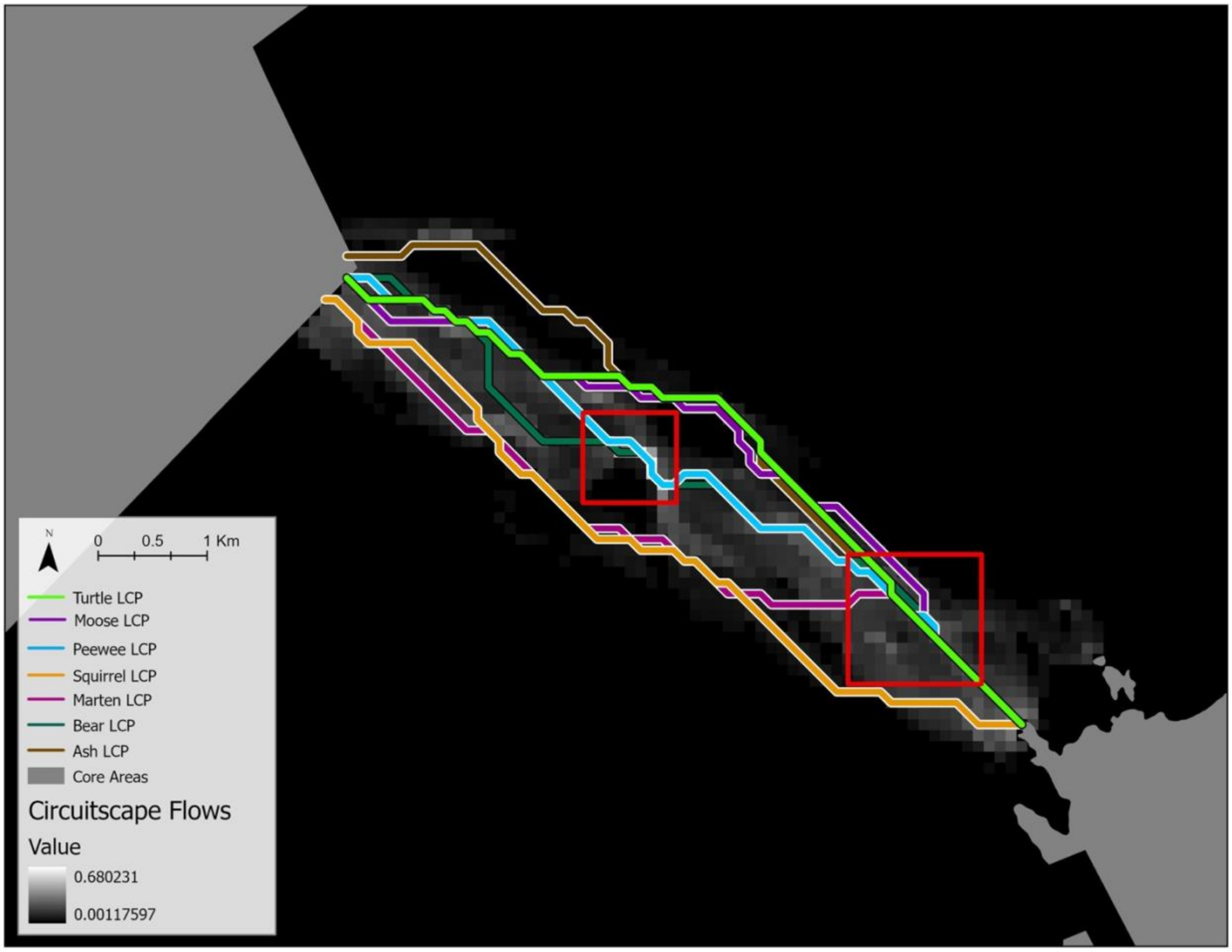

Figure 4.34: Map of species' least cost paths between Kejimkujik National Park and Lake Rossignol Wilderness Area over Circuitscape Flows analysis with areas of overlap indicated by red squares.

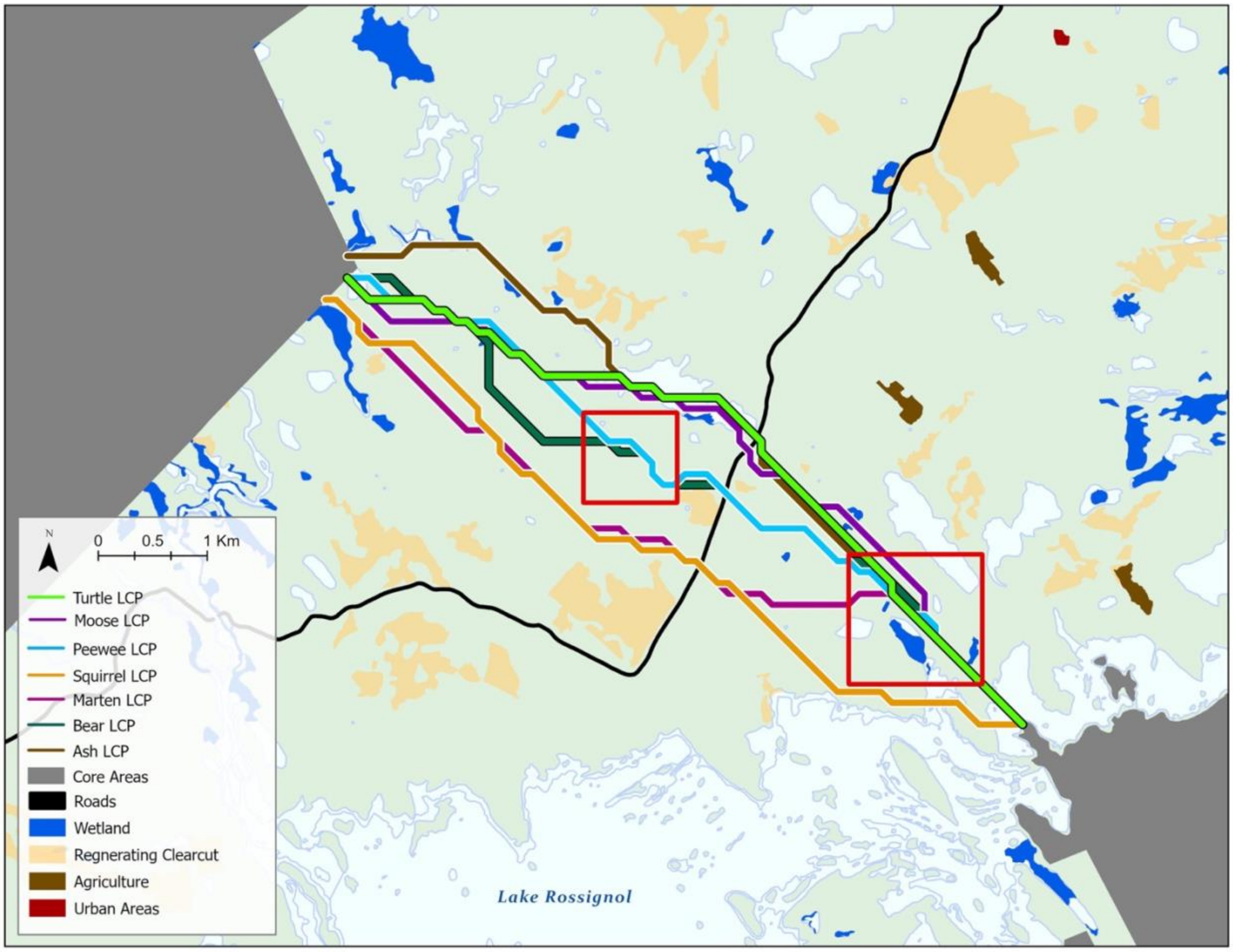

Figure 4.35: Map of species' least cost paths between Kejimkujik National Park and Lake Rossignol Wilderness Area over landscape class types

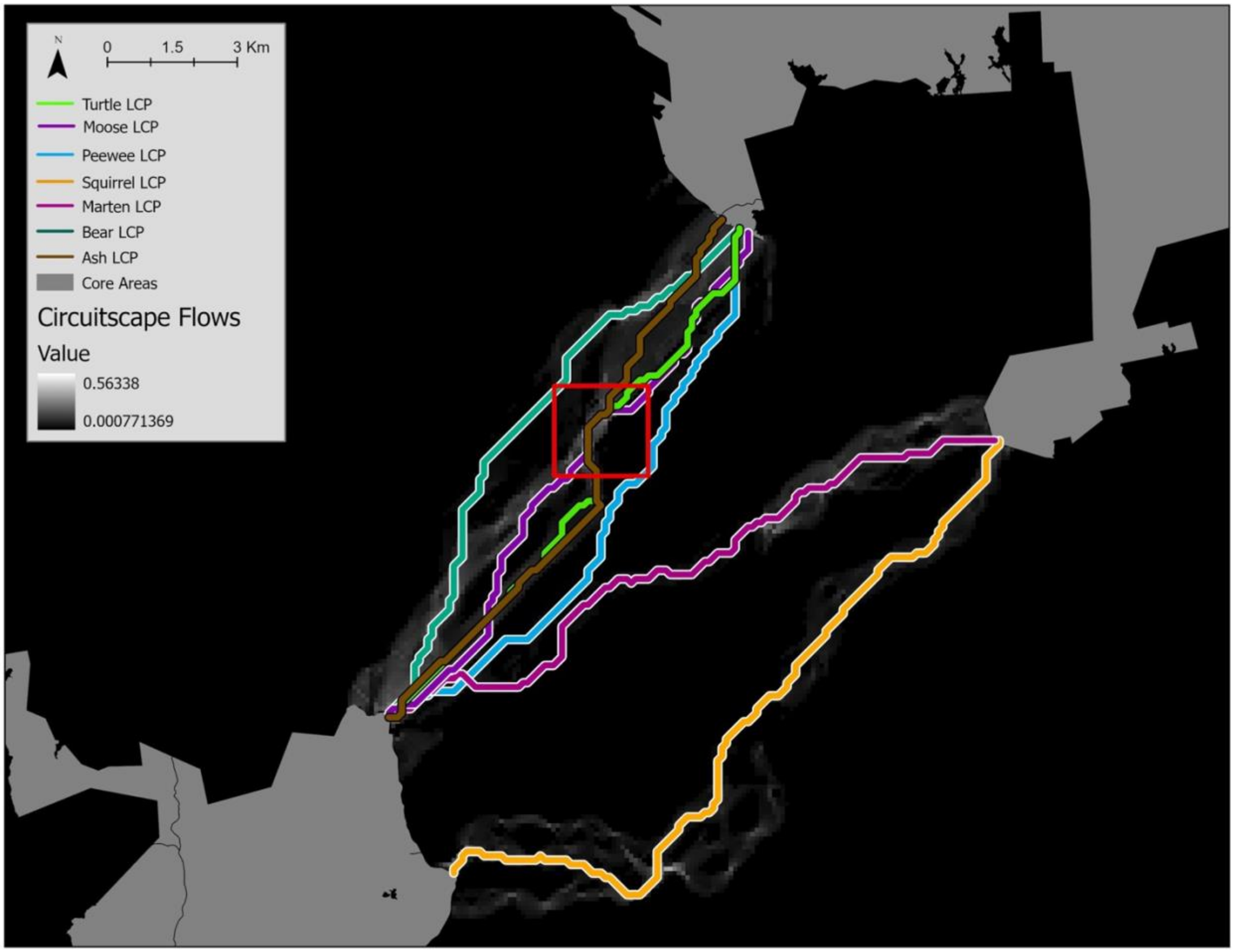

Figure 4.36: Map of species' least cost paths between Medway Lakes and Cloud Lakes Wilderness Area over Circuitscape Flows analysis with areas of overlap indicated by red squares.

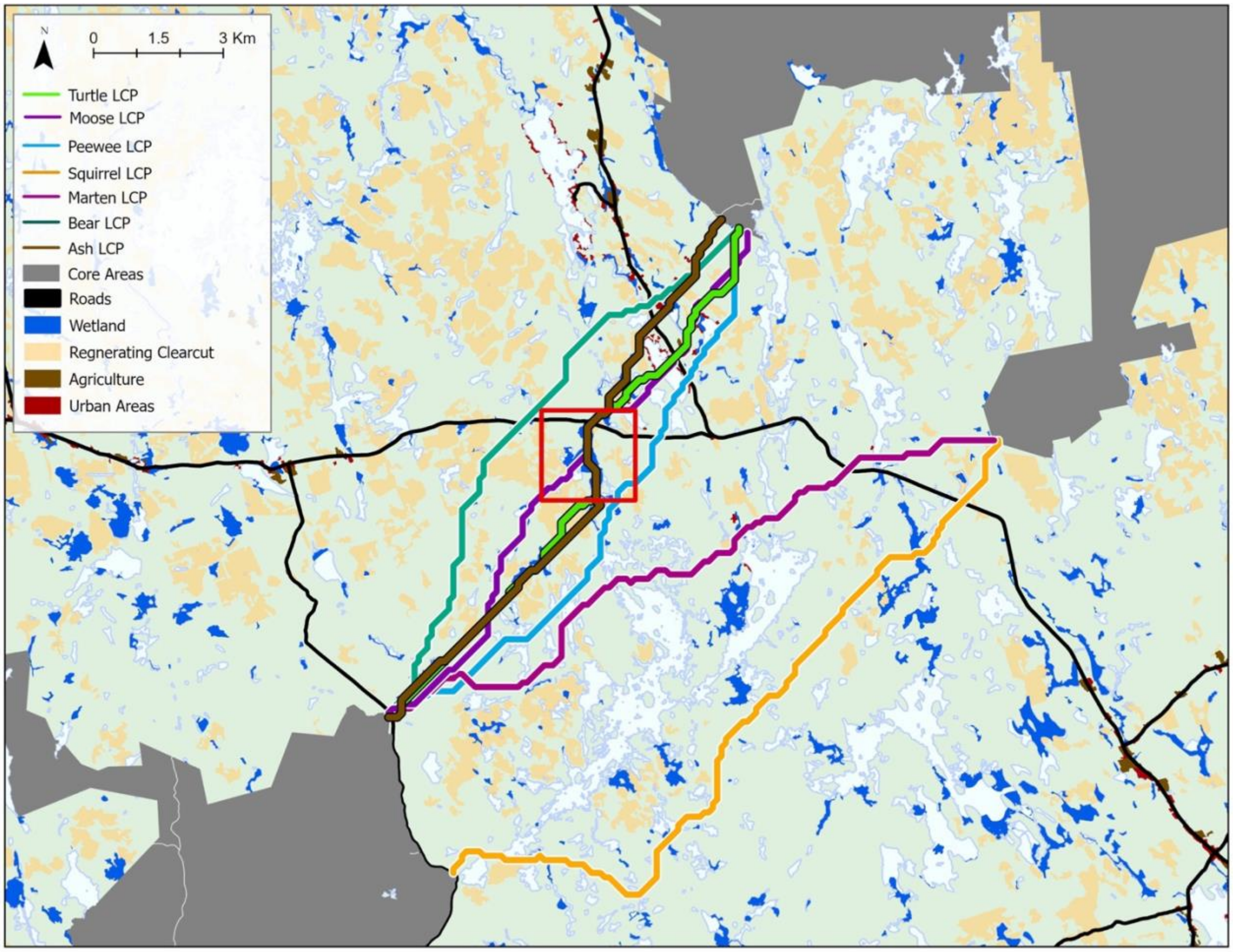

Figure 4.36: Map of species' least cost paths between Medway Lakes and Cloud Lakes Wilderness Area over landscape class types.

CHAPTER 5

Discussion

5.1 Linkage Pathways

The “Build Linkage Pathways” tool in the Linkage Mapper Toolbox uses a resistance raster to calculate the path of least resistance between identified core areas. It gives an output of overall CWD and CWD/path length ratio which is the ratio between the cumulative cost to travel across the landscape and the non-weighted least cost path length. Overall, Black Ash had the highest resistance to movement through the landscape. This is likely due to ash’s nature as a habitat specialist with preference to wetlands, floodplains, and wet forested areas. Ash had a lower CWD in study region A as this region has a higher number of wetlands connecting the core areas. However, this area also has a large number of lakes and ponds in which Black Ash cannot grow and reproduce creating a barrier to movement.

In study region A, Northern flying squirrel had the lowest CWD and CWD/path length ratio indicating that area A had a good amount of mature coniferous to mixed coniferous forest allowing for movement of species between core areas. However, region A shows fragmented wetlands and wet forests inhibiting the flow of species such as black ash and wood turtle. In study region B, apart from Ash the American marten had the next highest CWD and CWD/ path length ratio. This indicates fragmentation of mature and old growth forest inhibiting species flow.

5.2 Pinchpoint Mapper

Pinchpoint mapper utilizes Circuitscape and electrical circuit theory analysis to consider alternate dispersal pathways across the landscape apart from the least cost path. Circuitscape measures the flow through pathways and highlights pinchpoints, or areas where flow is highest, and movement may be restricted if the land-use changes occur and areas with high flow are important to preserve. The pinchpoint mapper analysis give the resistance (R̂), or the opposition to current flow between two core areas (McRae et al., 2012). R̂ is squared for this research to accentuate differences in resistance values between species. It also complements the least cost paths by providing the CWD/ R̂ ratio which is the redundancy between pathways outlining the amount of suitable alternative pathways between cores.

Pinchpoint mapper was first run with a buffer zone of 1000m and then 10,000m around least cost paths. For study region A, black ash and wood turtles had the highest R̂ value indicating a higher resistance due to the fragmentation of wetland creating barriers to movement. Additionally, the CWD/ R̂ ratio with buffers of 1000m for study region A showed Black Ash and the Wood Turtle as having the most redundancy between pathways and the poorest quality of pathways, indicating that restoration efforts are needed in this area. However, with a buffer area of 10,000m American marten had the second highest R̂ and second lowest CWD/ R̂ ratio indicating that other than the main least cost path the area is lacking dense, old-growth conifer stands. For study region B, Black Ash has the highest R̂ and lowest CWD/ R̂ indicating significant barriers to movement and a high fragmentation of floodplains and wet forest which are critical for the connectivity of Ash.

When comparing the overall R̂ and CWD/ R̂ between both study areas there is a trend emerging in both buffers of 1000m and 10,000m that area A has a lower overall R̂ while area B has the higher CWD/ R̂. This indicates that while Area B may have a higher overall resistance to movement between the core areas the higher CWD/R̂ ratio shows that the pathways available are of a higher quality and less constricted. This could be a result of region B having longer pathways between core areas, contributing to higher overall resistance between core areas. Longer travel distances can increase the cumulative resistance making movement more challenging. Additionally, in region A Lake Rossignol and the surrounding smaller freshwater lakes could be acting as barriers for terrestrial species, creating pinchpoints and constraining flow around these water bodies.

5.3 Barrier Mapper

The Barrier mapper tool uses a moving window analysis of the resistance layer to identify areas of a landscape that are difficult to pass through for wildlife and may be impacting the quality of the corridors and where restoration efforts make help reduce or shorten the least cost paths between core areas (McRae, 2012). In study region A between Kejimkujik and Lake Rossignol, barriers were identified north of Lake Rossignol creating challenges for wildlife movement. This barrier, which is likely a lake forces terrestrial species to detour around it, therefore impacting the quality of the wildlife corridors. Additionally, there is a barrier along the least cost path for the mainland moose, wood turtle, eastern wood pewee and black ash in study region B south of Cloud Lake Wilderness Area (Figure 4.2, 4.18, 4.22, 4.26). These barriers are impacting the quality and functionality of the pathways and restoration efforts should be considered in these areas. Additionally, the restoration of barriers along an already established least cost path could be a more financially efficient then the purchase and conservation of entire least cost paths.

5.4 Conservation Opportunities

Figures 4.34 and 4.36 provide a closer look at where least cost paths and Circuitscape flows overlap with highlighted areas in red were conservation and restoration opportunities are if the utmost importance. Figure 4.34 displays two areas where conservation and restoration initiatives may be important. They first area central to the pathways with the Eastern Wood Pewee and Black Bears least cost path located here. It is identified as the area with highest flow across the entire study area. This area is comprised of mainly mature to old growth mixedwood forest (Figure 4.35) and conservation efforts should be implemented to maintain the health of this region.

Region B connecting Medway lakes to Cloud Lake Wilderness area showed a high fragmentation of wetlands and conservation priority should be given to restoration of wet forest, floodplains, and wetlands for species connectivity though CWD and resistance of wetland dependent species. The highlighted area has overlapping least cost pathways of Ash, Moose and Wood turtles (Figure 4.35), all of which are species preferring wetland features. The area is covered mainly one of the largest connected wetlands in the study region (Figure 4.35) and conservation efforts should be implemented to help facilitate the movement of species.

5.5: Limitations and Future Research

This study does face some notable limitations that are important for future research. To begin, the study does not validate assumptions species requirements used in the suitability rankings. Future studies should examine these assumptions based on local species occurrence data to help ensure that the metrics and suitability scores used to assess connectivity accurately reflect the underlying ecological processes and relationships between selected species and the landscapes. Validating species information is important to ensuring that connectivity metrics accurately reflect underlying ecological processes.

Additionally, while the study examines the cost of movement and land type distribution, a deeper analysis of species distributions on the landscape could provide valuable insights into connectivity dynamics. Acknowledging the presumption that species in the area are attempting to traverse the landscape between core areas, integrating species distribution data could further refine the analysis.

Next steps would also include the differentiation between public and private lands to develop comprehensive conservation strategies that account for differences in land management strategies based on ownership type. Implementing conservation into privately owned land may include incentives for landowners to maintain the health of the ecosystem or purchasing the land and transforming it into protected areas.

CHAPTER 6

Conclusion

This study aimed to assess and compare the functional ecological connectivity and potential corridors for species movement between two study regions, A and B, within Southwest Nova Scotia. Through a comprehensive analysis using spatial tools such as Linkage Mapper, Pinchpoint Mapper, and Barrier Mapper, the study provided valuable insights into the challenges and opportunities for maintaining connectivity in these critical conservation areas.

By accessing seven selected species with varying habitat requirements in two distinct study regions, the study aimed to provide recommendations for conservation and restoration efforts to achieve provincial goals set out in the Nova Scotia Environmental Goals and Climate Change Reduction Act (2021).

The study revealed that while region A exhibited lower overall resistance to movement, it also presented fewer high-quality pathways due to barriers such as lakes and clearcuts. In contrast, region B demonstrated higher resistance but offered more redundant pathways, indicating smoother flow between core areas and better connectivity potential. This means that region A, should prioritize addressing barriers and pinchpoints to improve corridor quality. This could include habitat restoration initiatives aimed at mitigating the impacts of clearcutting and preserving critical corridors around lakes and wetlands. While region B should focus on maintaining connectivity and preserving these redundant pathways. In both regions, Black Ash had the highest cost weighted distance and resistance to movement across the landscape, indicating fragmentation of wetlands and wet forest types. Protected area design should prioritize the conservation and restoration of Black Ash habitats to mitigate fragmentation. This could involve establishing protected areas specifically targeted at conserving Black Ash habitats and implementing landscape-scale restoration efforts to reconnect fragmented landscapes across the province.

Overall, this study provides valuable information for landscape planners, ecologists, and policymakers to aid in decisions for protected area planning to preserve and enhance connectivity in the Southwest Nova Scotia. By identifying key areas for restoration and mitigation, this research contributes to the long-term conservation and sustainable development goals of the region, ensuring the health and resilience of its diverse ecosystems and biodiversity.

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Appendix: Land Cover Classes and Species Suitability Scores

	Moose	Marten	Bear	Squirrel	Turtle	Pewee	B. Ash
Forested							
Coastal Acadian establish	2	1	2	1	2	1	2
Coastal Acadian young	2	2	2	1	2	1	1
Coastal Acadian mature	3	2	3	2	2	2	1
Coastal Acadian multi/old	3	3	3	3	2	2	1
Flood Plain Forest establish	4	2	3	2	5	2	5
Flood Plain Forest young	4	3	3	2	5	3	5
Flood Plain Forest mature	4	4	3	4	5	3	5
Flood Plain Forest multi/old	4	4	3	4	5	3	5
Karst Forest establish	2	2	3	2	2	2	2
Karst Forest young	2	2	3	2	2	2	2
Karst Forest mature	3	4	2	3	2	3	1
Karst Forest multi/old	3	4	2	4	2	3	1
Mixedwood establish	4	2	4	2	3	2	2
Mixedwood young	4	3	4	3	3	3	2
Mixedwood mature	4	4	5	4	4	4	1
Mixedwood multi/old	4	4	5	4	3	4	1
Old Field establish	3	2	4	2	3	3	2
Old Field young	3	3	4	2	3	3	2
Old Field mature	2	3	4	4	3	4	2
Old Field multi/old	2	2	5	3	3	4	2
Open Woodland establish	2	1	4	1	3	2	1
Open Woodland young	2	1	4	1	3	2	1
Open Woodland mature	2	2	5	2	3	3	1
Open Woodland multi/old	2	2	4	2	3	3	1
Spruce Hemlock establish	4	3	2	4	2	2	3
Spruce Hemlock young	4	4	3	4	2	2	2
Spruce Hemlock mature	5	5	3	5	2	3	1
Spruce Hemlock multi/old	5	5	2	5	2	3	1
Spruce Pine establish	2	3	2	3	2	1	2
Spruce Pine young	2	3	3	3	2	2	2
Spruce Pine mature	3	4	3	5	2	3	1
Spruce Pine multi/old	3	5	2	5	2	3	1
Intolerant Hardwood establish	4	2	4	2	2	3	1
Intolerant Hardwood young	4	2	4	3	2	4	1
Intolerant Hardwood mature	3	3	4	4	2	5	1
Intolerant Hardwood multi/old	3	3	4	4	2	5	1

Tolerant Hardwood establish	2	2	3	2	2	2	1
Tolerant Hardwood young	2	2	4	3	2	4	1
Tolerant Hardwood mature	3	3	4	3	2	5	1
Tolerant Hardwood multi/old	3	4	3	3	2	5	1
Wet Coniferous establish	4	1	2	1	5	2	4
Wet Coniferous young	4	1	2	2	5	2	4
Wet Coniferous mature	5	2	2	3	5	3	4
Wet Coniferous multi/old	5	3	2	3	5	3	4
Wet Deciduous establish	4	1	2	1	5	2	4
Wet Deciduous young	4	1	2	2	5	3	4
Wet Deciduous mature	5	2	3	3	5	4	3
Wet Deciduous multi/old	5	3	3	3	5	4	3
Wet Mixedwood establish	4	1	2	2	5	2	5
Wet Mixedwood young	4	1	2	2	5	3	5
Wet Mixedwood mature	5	2	3	3	5	4	5
Wet Mixedwood multi/old	5	3	3	3	5	4	5

	Moose	Marten	Bear	Squirrel	Turtle	Pewee	B. Ash
Non-Forested							
Agriculture	1	0	2	0	3	1	0
Softwood Plantation	2	2	2	2	2	2	1
Water Bodies	4	1	3	1	2	3	1
Gravel pit	0	0	1	0	1	1	0
Transportation	1	0	1	0	1	1	0
Shrubland	2	1	4	1	2	1	0
Landfill	0	0	2	0	1	0	0
Urban	0	0	0	0	0	0	0
Open Wetlands	5	1	3	2	5	3	4
Clearcut	1	0	2	1	1	1	1
Standing Deadwood	2	2	1	1	0	2	1
Christmas Trees	1	1	1	1	1	1	0
Blueberries	2	0	3	1	1	0	0
Burn	2	1	3	1	2	2	2
Windthrow	2	2	2	2	2	2	2
Salt Marsh	1	0	1	0	1	1	1