A Wildlife Connectivity Analysis for the Chignecto Isthmus

Patrick Nussey

Josh Noseworthy

2018

Acknowledgements

The Nature Conservancy of Canada would like to thank the New Brunswick Wildlife Trust Fund and the Nova Scotia Habitat Conservation Fund for financially supporting the original Chignecto connectivity studies conducted in 2014 and 2016, respectively. Their support has enabled NCC to advance our work and provide an opportunity to generate additional support for conservation on the Isthmus. In no particular order, we would like to thank the Nova Scotia Department of Natural Resources Wildlife Division in Kentville for their feedback and input throughout the development of this project. We would also like to thank Dan Majka, co-creator of the Corridor Designer Toolbox, for his assistance in trouble-shooting some software issues. We would also like to thank Dan Beaudette and the Habitat Section team from the New Brunswick Department of Energy and Resource Development for reviewing the initial species lists and ranking the habitat requirements of each species. Finally, thanks to JD Irving, ltd. for providing in-kind support to this project by allowing NCC to use their forest inventory data on freehold land. This allowed us to form a complete picture of structural connectivity across the Isthmus.

Introduction

The Nature Conservancy of Canada (NCC) is a national charity dedicated to the preservation of biological diversity through land protection and stewardship. NCC aims to conserve Canada's natural heritage by securing ecologically significant land through purchase, donation, conservation agreements or other mechanisms, and by implementing management on those lands for the long-term stewardship of biodiversity. NCC practices sound science to implement effective conservation, which ensures that limited resources are invested wisely and with maximum conservation impact.

In this regard, the Chignecto Isthmus has been recognized regionally, nationally and internationally as a critical wildlife corridor. It provides the only terrestrial connection between Nova Scotia and the rest of North America. Passage of terrestrial animals and plants along this critical migration corridor has already been significantly altered by anthropogenic impacts from highways, urban development, agriculture and forestry (Mazerolle et al., 2016). By facilitating gene-flow between New Brunswick and Nova Scotia, the Chignecto Isthmus plays an important role in maintaining healthy wildlife populations over the long-term. For this reason, NCC undertook two analyses to model wildlife connectivity across the isthmus. The first, in 2014 (see Noseworthy, 2014), focused only on the New Brunswick side of the isthmus using a suite of species developed in partnership with the NB Dept. of Natural Resources (now the NB Dept. of Energy and Resource Development). A second analysis was conducted in 2016 (see Nussey, 2016) to extend the study across the Nova Scotia portion of the isthmus using a suite of species developed in partnership with the NS Dept. of Natural Resources. Although the majority of species included in the 2014 and 2016 studies were the same, there were several differences that made the results incompatible. To remedy this, the following report describes the methods and results of a combined approach that includes all species identified in both the 2014 and 2016 studies. The results of this analysis will help to identify structural connectivity corridors for wildlife movement throughout the Isthmus region, assist in the identifying priority private lands for securement, support the development of communication materials related to Isthmus connectivity, and provide decision-support for landowners, natural resource developers, and government land managers.

The process of modelling connectivity within the Chignecto Isthmus region involved the following steps, which will be discussed in further detail throughout the remainder of this report:

1) Merging the 2014 and 2016 lists of terrestrial wildlife species and their respective habitat requirements.

2) Creating habitat suitability models for each of the species identified through literature review and expert opinion.

3) Model habitat suitability across the study area for each species to determine potential patches of suitable habitat.

4) Use cost-distance mapping to optimize the least-cost paths within the Chignecto Region for each species.

5) Optimize a connectivity corridor(s) using the combined least-cost paths.

6) Identify connectivity "pinch-points" for more detailed study and action planning.

Study Area

The boundary of the analysis was confined to the Chignecto Isthmus region of New Brunswick and Nova Scotia using level 2 watersheds that incorporate the major linkage features identified in Figure 1. The five major linkage features represent the largest legislatively protected areas within the Chignecto region. The Canaan Bog Protected Natural Area in NB, the Cape Chignecto Provincial Park, Kelley River Wilderness Area, Economy River Wilderness Area, and Portapique Wilderness Area in NS, were selected as core linkage areas due to their large size and the legal protection assigned to them.

Methods

Species Selection

One of the fundamental principles of wildlife connectivity is to use an inclusive species-strategy in as much as is operationally feasible. Since the habitat requirements of every species of wildlife cannot be assessed, the alternative is to develop a suite of species that will act as a surrogate for a broader range of biodiversity (Beier & Loe, 1992). The initial list of species from the 2014 analysis was adapted from a report by MacDonald & Clowater (2005) and modified to capture a broader range of terrestrial habitat requirements (forest community and wetland type; age-class) and life-history strategies (territory size; ecological guild). Consideration was also given to those species that have well-documented habitat requirements, which provide greater confidence in the resulting habitat models. The final species included in this analysis are listed in Table 1.

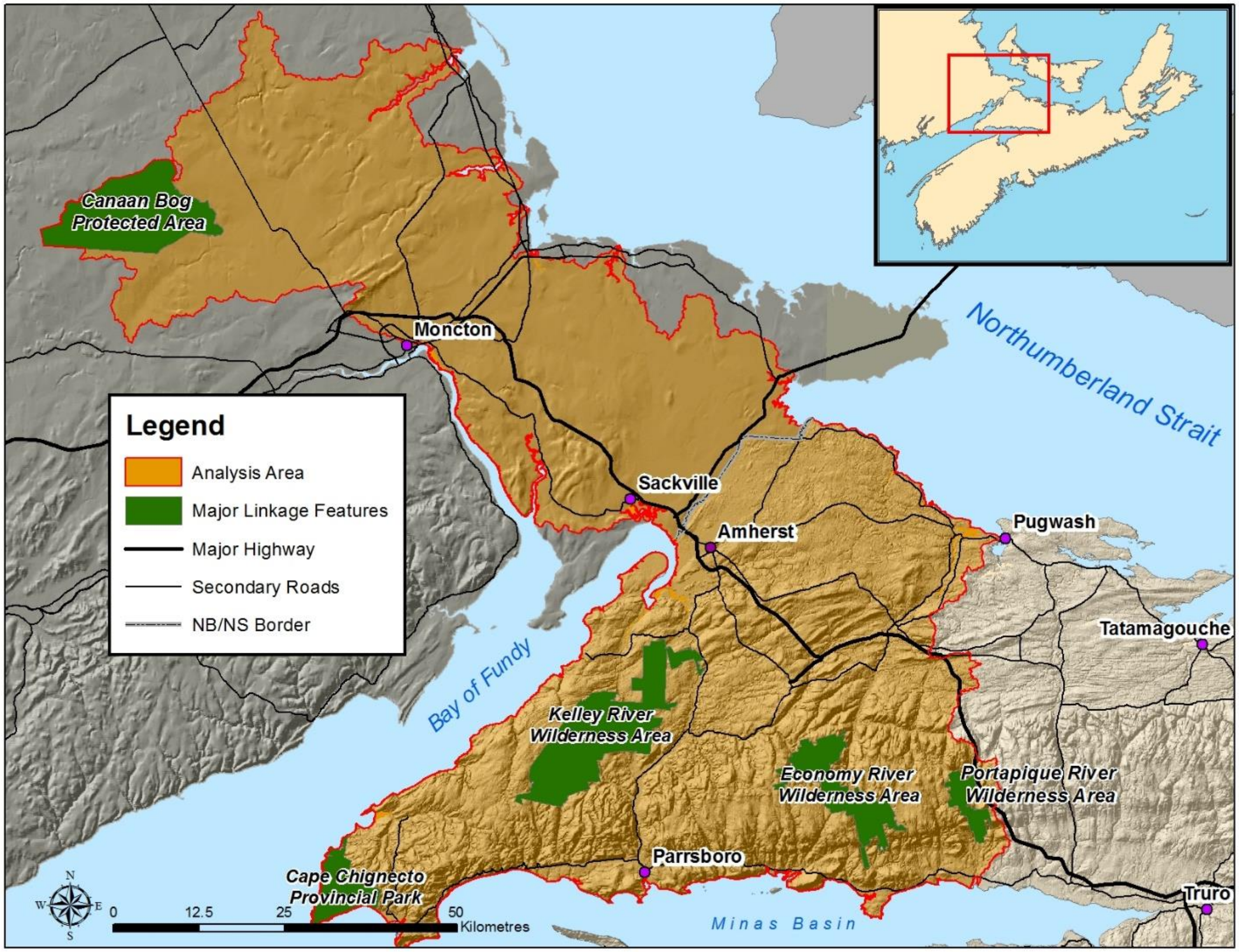


Figure 1: Geographic scope of the Chignecto Isthmus connectivity study, with major linkage features and transportation corridors, 2018.

Table 1. Common name, scientific name and justification for inclusion of the 15 species used to model connectivity across the Chignecto Isthmus, 2018.

Common Name	Scientific Name	Justification for Inclusion
Moose	*Alces alces*	Habitat generalist; large territory size; wide ranging
Black Bear	*Ursus americanus*	Habitat generalist; large territory size; wide ranging
Red Fox	*Vulpes vulpes*	Habitat generalist; medium ranging
Bobcat	*Lynx rufus*	Habitat specialist; wide ranging; large territory size
Snowshoe hare	*Lepus americanus*	Habitat generalist; important prey species
Fisher	*Martes pennanti*	Habitat specialist; large territory size; fragmentation sensitive
Northern Flying Squirrel	*Glaucomys sabrinus*	Habitat specialist; umbrella species; fragmentation sensitive
Barred Owl	*Strix varia*	Habitat specialist; umbrella species; large home range
Northern Goshawk	*Accipiter gentilis*	Habitat specialist; umbrella species; large home range
Pileated Woodpecker	*Dryocopus pileatus*	Habitat specialist; umbrella species; keystone species
Yellow Warbler	*Dendroica petechia*	Habitat specialist; umbrella species
Brown Creeper	*Certhia americana*	Habitat specialist; fragmentation sensitive
Ruffed Grouse	*Bonasa umbellus*	Habitat generalist; important prey species
Boreal Chickadee	*Poecile hudsonicus*	Habitat specialist; fragmentation sensitive
Blackburnian Warbler	*Setophaga fusca*	Habitat specialist; fragmentation sensitive

Habitat Suitability Modelling

Modelling habitat suitability across the Isthmus for each of the 15 species required the development of a standardized land cover grid within a GIS framework. Following the methods as described within the CorridorDesign approach (Majka et al., 2007), a land cover class system was developed for the Chignecto Isthmus based on the 35 distinct classes identified in the 2014 study. The land cover classes were originally selected in NB using the New Brunswick Resource Inventory Database (NBDNR, 2008), which included forest, wetlands and anthropogenic features. The forest inventory was grouped into seven habitat types based on the NBDNR habitat definitions (NBDNR, 2013), each of which was further separated into 3 age class categories (young, mid-aged, old). Wetland features were grouped into cover types based on vegetation (non-vegetated, emergent, shrub, forested) and anthropogenic features were grouped by land use (agriculture, human settlement, forest plantation, etc.). Once the finalized list of land cover types was completed and reviewed (see Appendix A), numerical identifiers were assigned to each class and spatially projected across the study area. To adapt the analysis for the NS side of the Isthmus, the same 35 habitat classes were used. However, the Nova Scotia provincial forest resource and wetland inventories had to be re-classified to best mimic the habitat class qualifiers identified for NB. Five thematic GIS layers were used to accomplish this. The NS provincial forest resource inventory (NSDNR, 2014) was used to delineate anthropogenic landcover types including roads, human settlement, agriculture, soil/gravel extraction sites, and plantations, as well as natural features such as shrublands and some non-vegetated wetlands. The recently developed Forest Ecosystem Classification (FEC) layer obtained from NSDNR Wildlife section (NSDNR, 2015a) is a species based re-classification of the original provincial forest inventory, and was used to classify the various forest habitat types.

The Development Class layer obtained from NS DNR Forestry (NSDNR, 2015b) was used to assign an age class to the forest types classified using the FEC layer. The Wet Areas Mapping / Depth to Water layer (Arp, 2009) was used to delineate wet and poorly drained stands of Black Spruce forest. Finally the provincial wetlands inventory vegetation layer (NSDNR, 2011) was used to classify wetland types to best mimic their classification in the 2014 study. The combination of these layers resulted in the creation of a seamless habitat layer for the study area. Appendix A compares the NB and NS classifications as well as the inventory qualifiers for each class.

Once the re-classification of the NS land cover layer was completed, the NB and NS layers were combined. Additional editing was necessary along the border where provincial datasets did not align. Habitat polygons along the border were manually merged based on habitat classes to eliminate gaps and overlaps between provincial layers. Habitat suitability scores were then assigned to each land cover class for each species based on a scoring system between 0 and 100 (100 = best available habitat or highest survival and reproductive success; 0 = absolute non-habitat). The method of assigning these habitat parameters involved a literature review and expert opinion survey. The literature review was conducted using a variety of sources, but relied heavily on U.S. Fish and Wildlife Habitat Suitability Index reports whenever possible (Appendix B1). Expert opinion was given by the NBDNR Habitat Section. Once completed, the values from both the review and survey were compared to assess the level of agreement between the predicted values. Generally, values were found to be in close agreement for all species. In the few cases where a discrepancy was found, the issues were resolved through discussion and further review of the literature. The final species/land cover matrix can be viewed in Appendix C.

The final step in the habitat assessment was to establish patch sizes for each species (Appendix B2), following the CorridorDesign approach (Majka et al., 2007), which suggests that patch sizes for each species be determined based on the following definitions:

(1) <u>Breeding patch</u>: the smallest area of suitable habitat to support 1 breeding pair for 1 breeding season, and

(2) <u>Population patch</u>: the smallest area of suitable habitat to sustain an isolated breeding population for 5-10 years.

These values were derived from a literature review on territory size of each species. Generally, breeding patch size metrics were easily obtained, as territory sizes are well known for many species of wildlife. However, population patch size metrics were often not available within the literature. To account for this, breeding patch sizes were multiplied by 5, as suggested by Majka et al. (2007). Additionally, a habitat quality threshold value of 75% was assigned for all species. This value was used across all NBDNR Habitat Definitions (NBDNR, 2013), and was therefore deemed suitable to apply within this analysis.

Connectivity Modelling

Connectivity throughout the analysis area was modeled for each species using the Linkage Mapper software (McRae & Kavanagh, 2014) for ArcGIS 10. The tool relies on least-cost algorithms to identify a route between the linkage features that would minimize the resistance of movement (energetic cost, difficulty or mortality risk) for each species based on their habitat suitability as described above. The final output for each species is a linear pathway for each respective species. Wildlife corridors can then be spatially assigned where multiple species share common pathways across the landscape.

Identifying Pinch Points

In addition to identifying wildlife corridors, the combined species least-cost paths can also be used to identify connectivity "pinch points" across the landscape. Pinch points are habitat bottlenecks, where multiple species paths tend to congregate due to a lack of suitable habitat in the surrounding matrix (e.g. a forest fragment within an agricultural landscape). Identifying pinch points can assist conservation initiatives by, (1) informing prioritization of lands for protection to facilitate long-term structural connectivity, (2) identifying potential areas of elevated wildlife crossings where further on-the-ground research could be focused, and (3) assisting transportation agencies in identifying areas where wildlife overpasses or other wildlife collision mitigation strategies can be implemented.

Results

As is seen in Figure 2, habitat based movement pathways for most species are restricted to within a 5 – 10 km corridor in New Brunswick, while paths begin to diverge and become less concentrated on the NS side of the Isthmus. All species paths are seen to converge at the NS/NB border within a narrow 5 km stretch. For individual maps depicting each species' least-cost path with modelled habitat patches, see Appendix D.

To model potential wildlife corridors across the Isthmus, the 15 species' least-cost paths were combined using a Kernel Density model. The Kernel Density model estimates the probability of corridors across the landscape based on the density of least-cost paths per unit area ($10m^2$) within a 1.5 km search radius. The result of the Kernel Density analysis (Figure 3) does not portray a corridor with discrete boundaries, but instead reflects a high-low probability scale of corridor occurrence across the landscape.

To create a discrete corridor, the Kernel Density model was reclassified using a Jenks natural breaks optimization, which aims to minimize the variance within each class (n=2) while maximising the variance between classes. This results in the best possible arrangement of density values into 2 classes (high density and low density). The resulting high density class was extracted as the optimal corridor across the study area, and is 81,531 ha in size: 42,608 Ha in NB, and 38,923 Ha in NS (Figure 4).

Pinch points were manually selected by reviewing the least-cost paths in relation to anthropogenic features (roads, agricultural land, urban and rural settlement, etc.), as well as by reviewing the kernel density model extracted from the high-density class corridor (Figure 5). Since the kernel density tool highlights the areas of greatest density within the restricted boundary of the corridor, the areas of high probability may potentially signify connectivity pinch points. A number of connectivity pinch points are clearly visible from the results, the most obvious being the convergence of all species at the New Brunswick - Nova Scotia border.

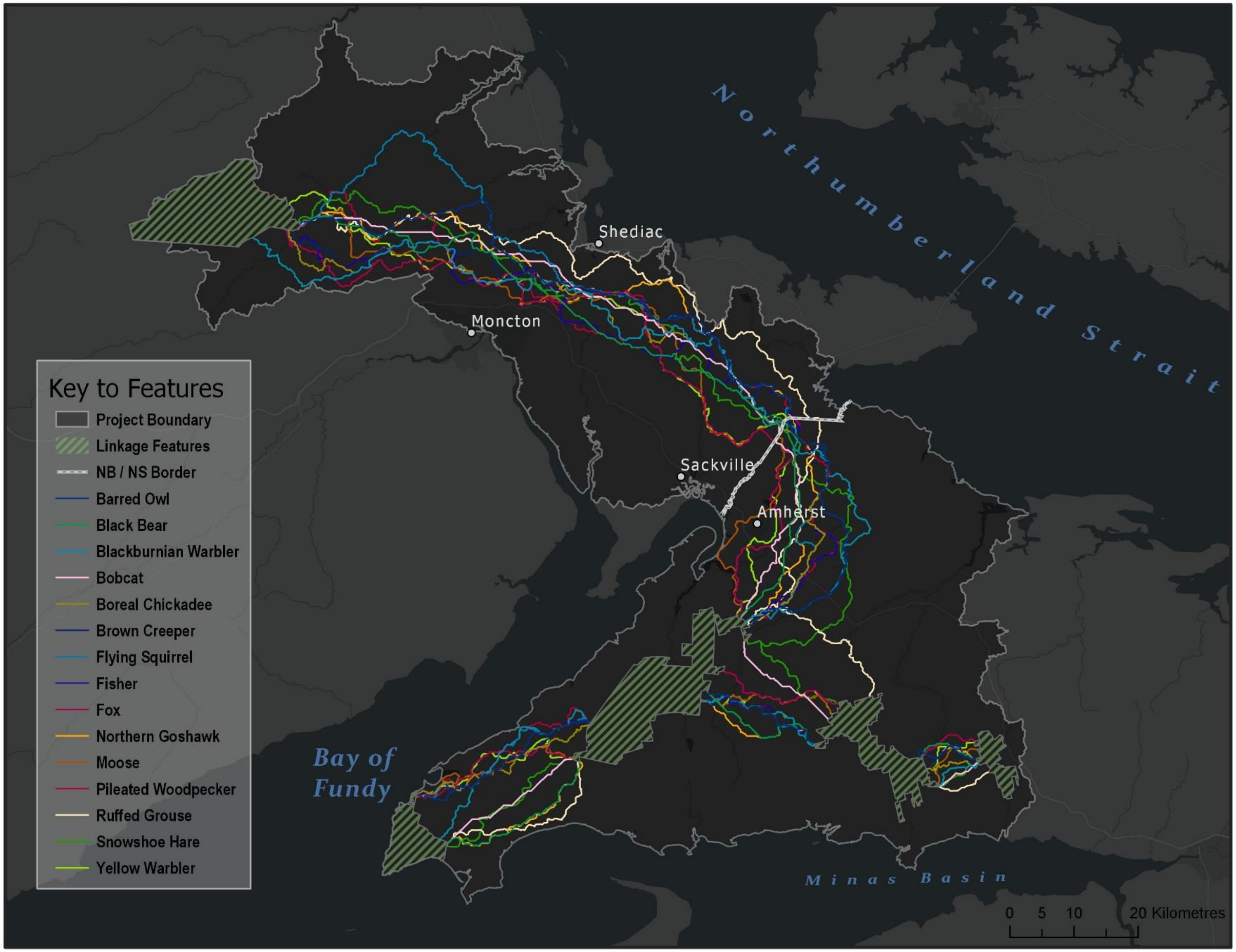


Figure 2: Least-cost paths of the 15 species used to model connectivity across the Chignecto Isthmus, 2018.

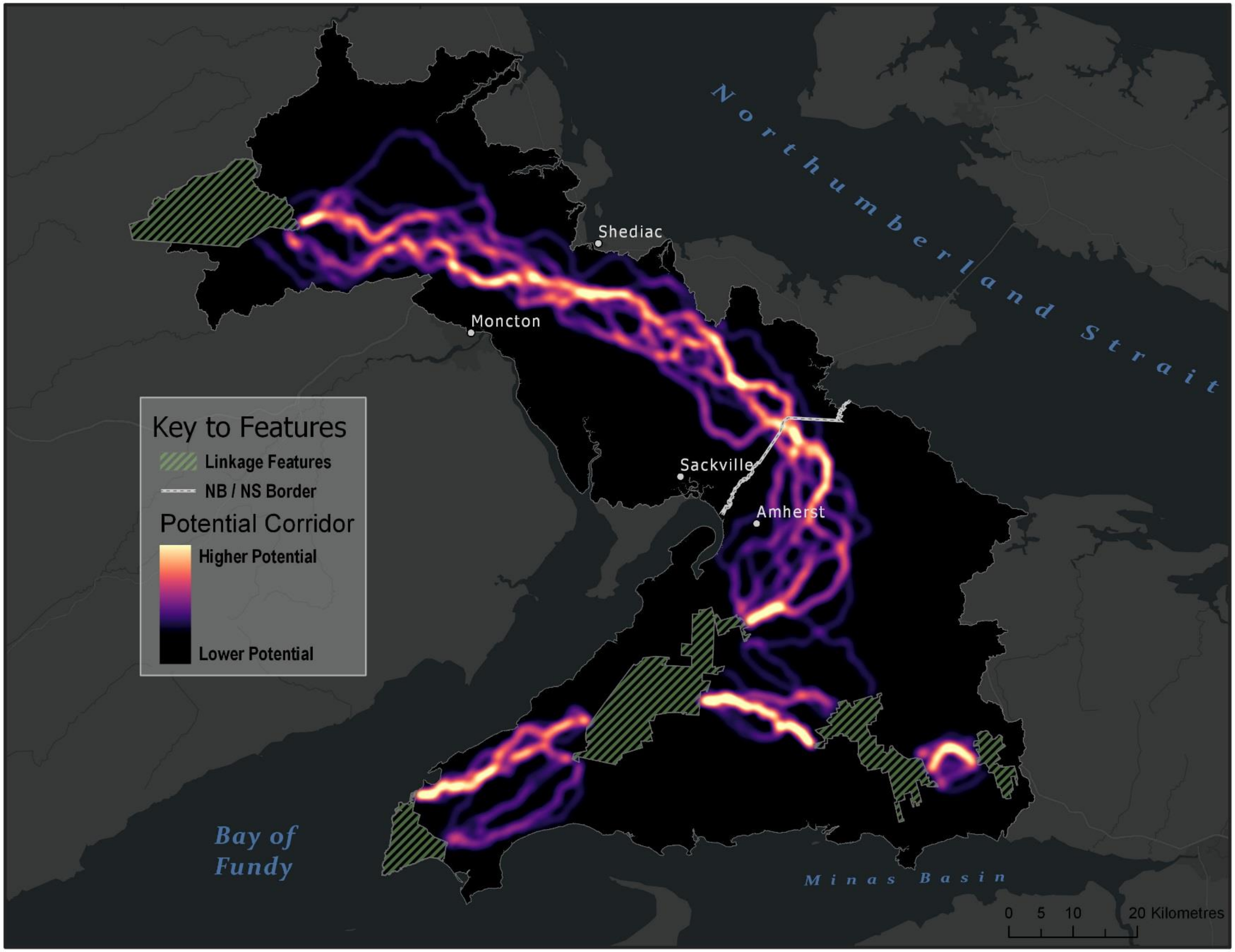


Figure 3: Kernel Density model of corridor probability across the Chignecto Isthmus, 2018.

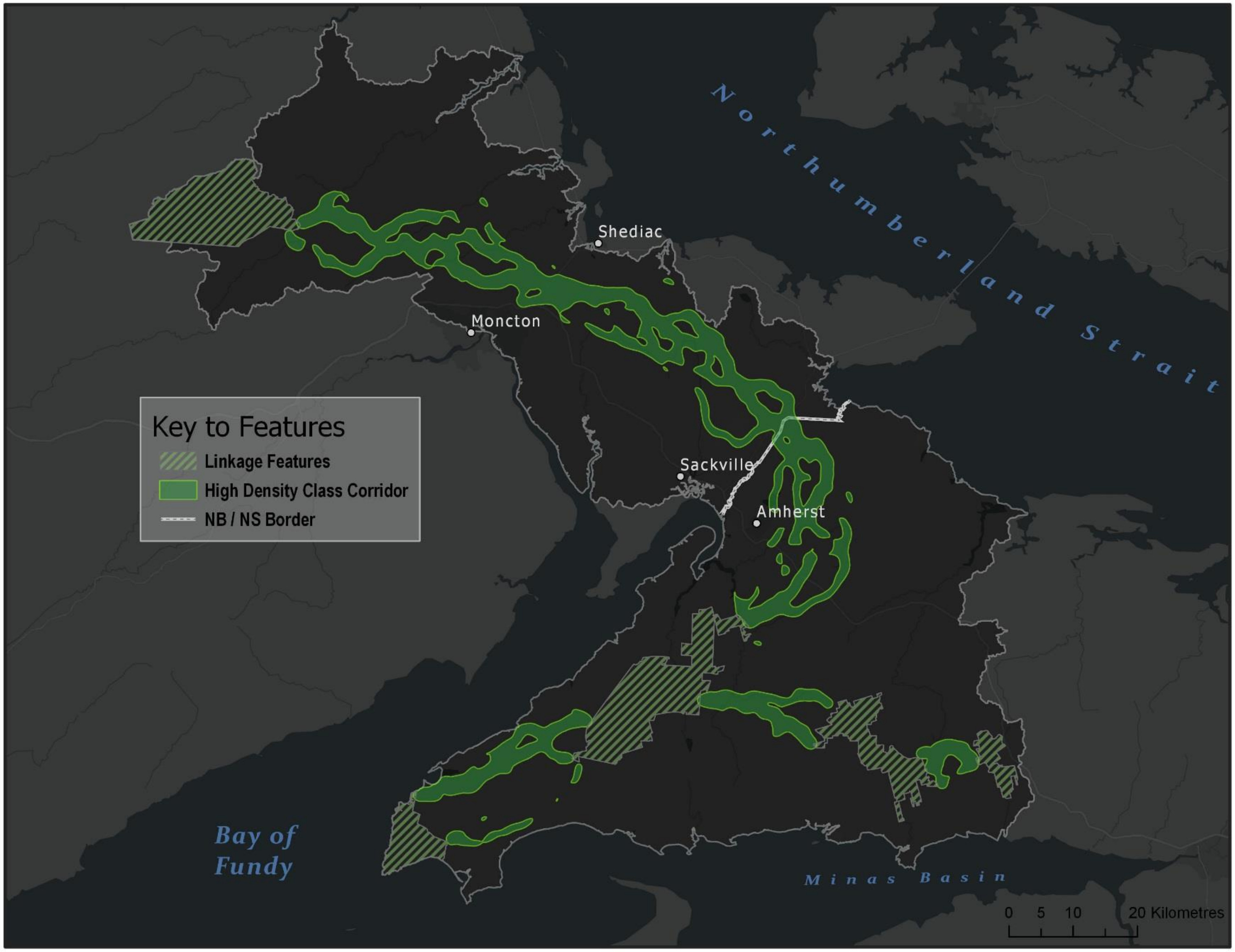


Figure 4: The predicted high-density class corridor across the Chignecto Isthmus, 2018.

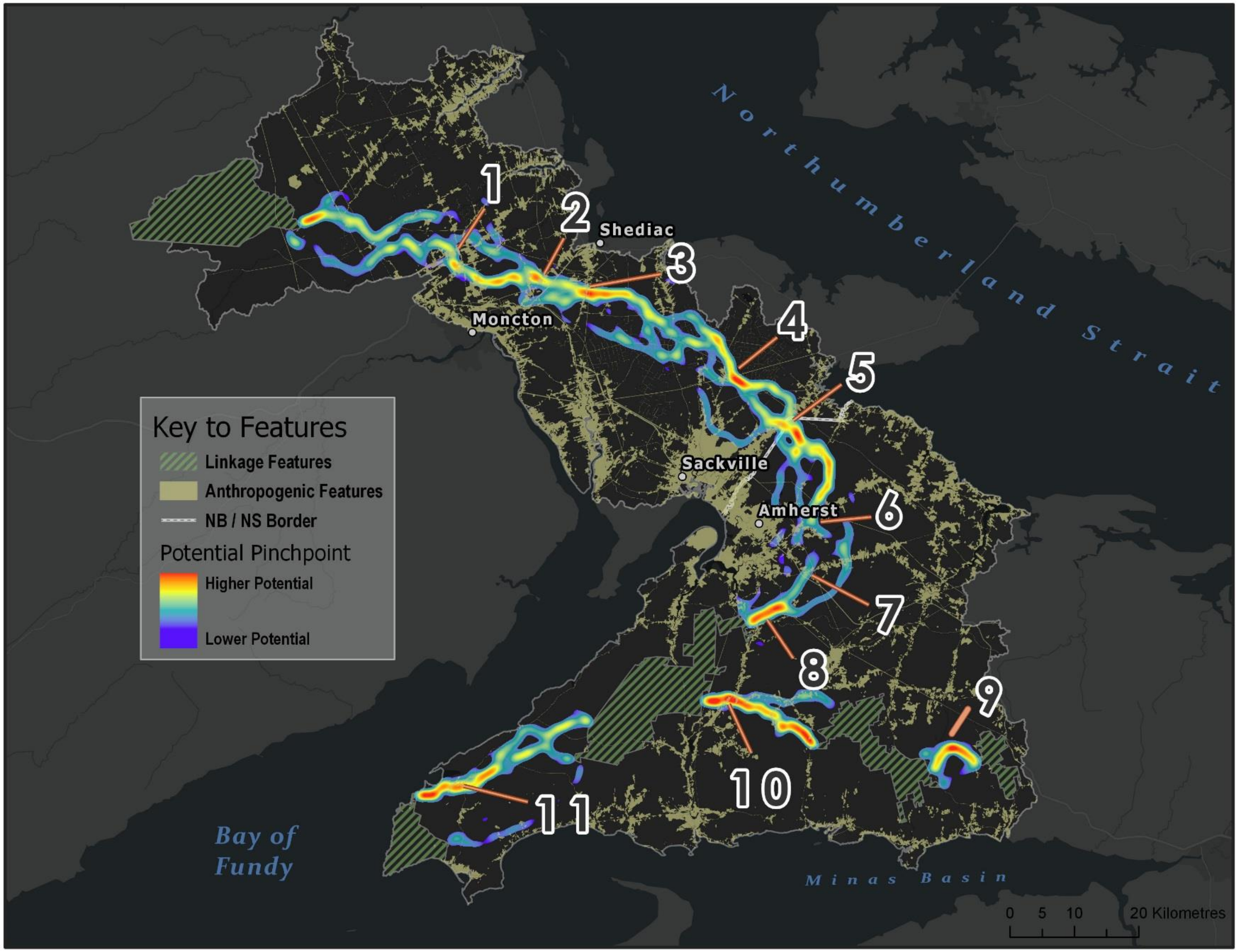


Figure 5: Pinch points identified using the high-density class corridor across the Chignecto Isthmus, 2018.

Discussion

In addition to the 2014 and 2016 analyses that this report is based on, a number of past analyses have been conducted within the Chignecto Isthmus to assess wildlife connectivity at the landscape scale as well (see MacDonald & Clowater 2005; Nussey 2010; de Graaf 2011). However, the attempt to capture structural connectivity based on the specific habitat requirements of focal species for the entire cross border Chignecto region is the first of its kind. The results are based on the best available data to reflect the reality of landscape conditions on the ground. However, Type I and II errors should be expected in the initial interpretation and creation of the forest inventories used to create the landcover layer. Other errors in landcover data could be attributed to landscape disturbances occurring after the most recent inventory updates were made. This analysis is meant as an early step in the identification of *potential corridors* in the Isthmus region and should not be used as a stand-alone product when directing resources into conserving or enhancing connectivity. The results are ultimately meant to direct further study within the identified corridor area, and more specifically within the identified pinch points (Figure 5).

Possible next steps could include landcover verification and modelling within the high density corridor (Figure 4) using up-to-date satellite and aerial imagery; wildlife camera placement within pinch points that cross transportation corridors; discussions with land and woodlot owners in the region to visually communicate the importance of connectivity in the region; and testing the validity of identified habitat patches and movement pathways with species observation data.

As previously mentioned, this analysis is limited to an investigation and analysis of structural connectivity within the Chignecto region. The second aspect is functional connectivity, which is the response of individual organisms to modelled habitat structure, both of which are required to ensure long-term viability of wildlife populations. Beier & Loe (1992) suggest five criteria that can be used to evaluate corridor functional connectivity:

1. Wide-ranging animals can travel, migrate and breed;

2. Plants can propagate;

3. Genetic interchange can occur;

4. Populations can move in response to environmental change;

5. Individuals can recolonize habitat from which populations have been locally displaced.

Whether the corridor(s) identified within this analysis meet these criteria is yet to be determined, and considerable time / financial resources will be needed to address these questions. However, given the fragmented landscape and ongoing land development and resource extraction occurring throughout the Chignecto region, this analysis should be used to inform and assist in taking a precautionary approach to resource extraction and development throughout the Chignecto region.

Literature Cited

Allen, A.W. (1986). Habitat suitability index models: Fisher. U.S. Dept. Int., Fish Wildl. Serv. FWS/OBS-82/10.45. 19 pp.

Allen, A.W., P.A. Jordan, and J.W. Terrell. (1987). Habitat suitability index models: moose, Lake Superior region. U.S. Fish Wildl. Servo Bio1.Rep. 82(10.155). 47 pp.

Arp, P. (2009). High-resolution flow-channel and wet-areas maps: a tool for better forest operations planning. *SFM Research Note Series*. pp 1-6.

Beier, P. & Loe, S. (1992). In My Experience: A Checklist for Evaluating Impacts to Wildlife Movement Corridors. *Wildlife Society Bulletin*. 20(4). pp. 434-440

Boyle, K.A., and T.T. Fendley. (1987). Habitat suitability index models: bobcat. U.S. Fish Wildl. Serv. Biol. Rep. 82(10.147). 16 pp.

Cade, B.S. and Sousa, P.J., 1985. Habitat suitability index models: ruffed grouse (No. 82/10.86). US Fish and Wildlife Service.

Catlin, D., M. Koenen and D.W. Mehlman. 1999. Species Management Abstract: Blackburnian Warbler (*Dendroica fusca*). The Nature Conservancy, 4245 North Fairfax Drive, Suite 100, Arlington, VA 2220

Carreker, R. G. (1985). Habitat suitability index models: Snowshoe hare. U.S. Fish Wildl. Serv. Biol. Rep. 82(10.101). 21 pp.

Costello, C.N., and Sage, R.W. (1997). Predicting Black bear habitat selection from food abundance under 2 forest management systems. Int. Conf. Bear Res. and Manage. 9(1):375-387.

Davis, C. M. (1978). A nesting study of the brown creeper. *Living Bird* 17:237-63.

de Graaf, M. (2011). Strategic Conservation Planning for the Chignecto Bay Natural Area. Final Report. Nature Conservancy of Canada.

DeGraaf, R. M., & Yamasaki, M. (2001). New England Wildlife: Habitat. Natural History, and Distribution. University Press of New England, Hanover, NH, 3755.

Dussault, C., Ouellet, J-P., Laurian, C., Courtois, R., Poulin, M., and Breton, L. (2007). Moose Movement Rates Along Highways and Crossing Probability Models. *The Journal of Wildlife Management*; 71(7), pages 2338–2345.

Erskine, H. J. (1977). Birds in Boreal Canada. Canadian Wildlife Service Report Series 41.

Graves, R.A., and Wang, D. (2012). Wildlife Habitat Linkages in the Eastern Adirondacks: Applying Functional Connectivity Modeling to Conservation Planning for Three Focal Species. Adirondack Journal of Environmental Studies. Vol(18).

Hadley, A. (2006). Winter habitat use by Boreal Chickadee flocks within a managed forest landscape. Laval University. Accessed on March 22, 2016 from: http://theses.ulaval.ca/archimede/fichiers/23847/23847.html

Hamer, T. E., Forsman, E. D., & Glenn, E. M. (2007). Home range attributes and habitat selection of barred owls and spotted owls in an area of sympatry. *Condor*, 750-768.

Lemaitre, J., and Villard, M. (200)5. Foraging patterns of pileated woodpeckers in a managed Acadian forest: a resource selection function. *Can. J. For. Res*. 35: 2387–2393

Litvaitis, J.A., Sherburne, J.A., and Bissonette, J.A. (1986). Bobcat habitat use and home range size in relation to prey density. *The Journal of Wildlife Management*. Vol. 50, No. 1 (Jan., 1986), pp. 110-117

MacDonald, A. & Clowater, R. (2005). Natural Ecosystem Connectivity across the Chignecto Isthmus – Opportunities and Challenges. Canadian Parks and Wilderness Areas.

Majka, D., J. Jenness, & P. Beier. (2007). CorridorDesigner: ArcGIS tools for designing and evaluating corridors. Available at http://corridordesign.org.

Mazerolle, D., A. Belliveau, S. Robinson, S. Blaney. (2016). Ecological Significance of Twenty Priority Sites in the Chignecto Isthmus. A report to the ECHO Foundation. Sackville, NB.

McRae, B.H. & D.M. Kavanagh. (2011). Linkage Mapper Connectivity Analysis Software. The Nature Conservancy, Seattle WA. Available at: http://www.circuitscape.org/linkagemapper.

Morse, D.H. (1994). Blackburnian warbler, Dendroica castanea. In A. Poole and F. Gill, (eds.) The Birds of North America, No. 102. The Academy of Natural Sciences, Philadelphia, and The American Ornithologists' Union, Washington, D.C.

NatureServe. (2014). NatureServe Explorer: An online encyclopedia of life [web application]. Version 7.1. NatureServe, Arlington, Virginia. Available http://explorer.natureserve.org. (Accessed: November 20, 2014).

NBDNR (New Brunswick Department of Natural Resources). (2008). New Brunswick Natural Resources Data Dictionary. Documentation of ArcSDE geodatabase (SDE Data Feature): New Brunswick Forest Inventory Database. Fredericton, New Brunswick.

NBDNR (New Brunswick Department of Natural Resources). (2013). Old Forest Community and Old-Forest Wildlife Habitat Definitions for New Brunswick 2012. Fredericton, New Brunswick.

Nicholls, T. H., & Warner, D. W. (1972). Barred Owl habitat use as determined by radiotelemetry. *The Journal of Wildlife Management*, 213-224.

Noseworthy, J. (2014). Prioritizing Private Land for Wildlife Connectivity across the Chignecto Isthmus, New Brunswick. Nature Conservancy of Canada – Atlantic Region. Fredericton, New Brunswick. 24pp.

NSDNR (Nova Scotia Department of Natural Resources). (2015). Provincial Wetlands Inventory Vegetation Layer. Kentville, Nova Scotia.

NSDNR (Nova Scotia Department of Natural Resources). (2014). Provincial Forest Resource Inventory. Truro, Nova Scotia.

NSDNR (Nova Scotia Department of Natural Resources). (2015a). Forest Ecosystem Classification (FEC) layer. Kentville, Nova Scotia.

NSDNR (Nova Scotia Department of Natural Resources). (2015b). Development Class layer. Truro, Nova Scotia.

Nussey, P. (2010). Potential for the Conservation of an Ecological Corridor across the Chignecto Isthmus: A science-based approach for landscape level conservation. University of New Brunswick Master of Environmental Management. Final Report. Fredericton, New Brunswick.

Nussey, P. (2016). A Wildlife Connectivity Analysis for the Chignecto Isthmus Region. Nature Conservancy of Canada – Atlantic Region. Halifax, Nova Scotia. 30pp.

O'Connell, A.F., Servello, F.A., Higgins, J, and Halteman, W. (2001). Status and habitat of northern flying squirrels on Mount Desert Island, Maine. *Northeastern Naturalist*: Vol. 8, Issue 2, pg(s) 127-136

Poulin J-F, Villard M-A, Edman M, Goulet PJ, and Eriksson A-M. (2008). Thresholds in nesting habitat requirements of an old forest specialist, the Brown Creeper (*Certhia americana*), as conservation targets. *Biol Conserv* 141: 1129–1137.

Ritchie, L.E., Betts, M.G., Forbes, G., and Vernes, K. (2009). Effects of landscape composition and configuration on northern flying squirrels in a forest mosaic. *Forest Ecology and Management*; 257 (2009) 1920–1929.

Rogers, L.L., and A.W. Allen. (1987). Habitat suitability index models: black bear, Upper Great Lakes Region. U.S. Fish Wildl. Serv. Biol. Rep. 82(10.144). 54 pp.

Savignac, C., Desrochers, A., and Huot, J. (2001). Habitat use by Pileated Woodpeckers at two spatial scales in eastern Canada. *Can. J. Zool*. 78: 219–225.

Schroeder, R. L. (1982a). Habitat suitability index models: Pileated Woodpecker. U.S. Dept. Int., Fish Wildl. Serv. PWS/OBS-82/10.39. 15 pp.

Schroeder, R. L. (1982b). Habitat suitability index models: Yellow Warbler. US Fish and Wildlife Service. (No. 82/10.27)

Smith, W.P. (2007). Ecology of *Glaucomys sabrinus*: Habitat, Demography, and Community Relations. *Journal of Mammalogy*. Vol. 88, No. 4, pp. 862-881.

Spieser, R., and Bosakowski, T. (1987). Nest Site Selection by Northern Goshawks in Northern New Jersey and Southeastern New York. *The Condor*; Vol. 89, No. 2, pp. 387-394.

Squires, J.R., and Kennedy, P.L. (2006). Northern Goshawk ecology: An assessment of current knowledge and information needs for conservation and management. *Studies in Avian Biology* No. 31:8–62.

Thompson, I. D., Davidson, I. J., O'donnell, S., & Brazeau, F. (1989). Use of track transects to measure the relative occurrence of some boreal mammals in uncut forest and regeneration stands. *Canadian journal of zoology*, 67(7), 1816-1823.

Appendix A – Land Cover Classes

Vegetation class	NB Inventory Qualifiers	NS Inventory Qualifiers
Evergreen Forest		
Young Black Spruce Forest	Forest Community = BS (wet and poorly drained)	FEC = SP?, SP5, SP6, SP7, SP8 (< 1m DTW)
Mid Black Spruce Forest		
Old Black Spruce Forest		
Young Jack Pine Forest	Forest Community = JP	FEC = SP1
Mid Jack Pine Forest		
Old Jack Pine Forest		
Young Pine Forest	Forest Community = WP, RP	FEC = SP2, SP3, SP4
Mid Pine Forest		
Old Pine Forest		
Young Spruce - Fir Forest	Forest Community = HE, CE, RS, WS, SWTH, BF, TOSW, SWMX, BS (moderately drained)	FEC = SH?, SH1, SH2, CE2, SH3, SH4, SH5, SH6, SH7, SH10, SH8, SH9, MW1, MW?, MW2, MW3, MW4, OF1; FEC = SP?, SP5, SP6, SP7, SP8 (>1m DTW)
Mid Spruce - Fir Forest		
Old Spruce - Fir Forest		
Young Larch Forest	Forest Community = TL	FEC = SP10
Mid Larch Forest		
Old Larch Forest		
Deciduous Forest		
Young Intolerant Hardwood Forest	Forest Community = IH	FEC = All IH Types, MW5, MW6, SP9
Mid Intolerant Hardwood Forest		
Old Intolerant Hardwood Forest		
Young Tolerant Hardwood Forest	Forest Community = THP, THSW, THIH	FEC = All TH types
Mid Tolerant Hardwood Forest		
Old Tolerant Hardwood Forest		
Shrubland		
Shrubland	(Forest Inventory) L1S1 = AL	FORNON = 33, 38, 39, 83, 88, 89, 84, 85
Wetland		
Emergent Wetland	Wetland VT = EV, FV, OV	Wet Veg = Gramanoid, Aquatic, Sphagnum, Salt Marsh
Forested Wetland	Wetland VT = FF, FH, FS	Wet Veg = Treed
Non-vegetated Wetlands	Wetland VT = FU	FORNON 76, 94; Wet Veg = Exposed
Shrub Wetland	Wetland VT = AW, SV	Wet Veg = Tall Shrub, Low Shrub, Lichen
Open Water		
River or Stream	Wetland VT = OW; Water_Code = PN, LK	NS Openwater - Double-line Rivers
Lake or Pond	Water_Code = RV	NS Openwater - Lakes
Developed and Agriculture		
Agriculture	NONFOREST PLU = AGR	FORNON = 86
Soil / Gravel Extraction	NONFOREST PLU = IND	FORNON = 95
Transportation	NONFOREST PLU = INF	FORNON = 96, 97, 98, 99
Human Settlement	NONFOREST PLU = SET, REC	FORNON = 87, 92, 93
Young Softwood Plantation	L1TRT = PL (Overrides the forest community classifiers)	FORNON = 20
Mid Softwood Plantation		
Old Softwood Plantation		

Forest Age Class Categories		
	New Brunswick (L1DS)	**Nova Scotia (Development Class)**
Young	Regenerating (R) and Sapling (S)	Establishment
Mid-aged	Young (Y) and Immature (I)	Young / Mature 1
Old	Mature (M) and Overmature (O)	Mature 2 / Multi Aged

Appendix B – Habitat Suitability Data Sources

B1 – Habitat requirement data sources by species

Species	Source
Moose	Allen et al., 1987; Dussault et al., 2006
Black Bear	Rogers & Allen, 1987; Graves and Wang, 2012; Costello and Sage, 1997
Red Fox	DeGraaf & Yamasaki, 2001; Thompson et al., 1989; Natureserve
Bobcat	Litvaitis et al., 1986; Graves and Wang, 2012
Snowshoe hare	Carreker, 1985; Natureserve
Fisher	Allen, 1986; Graves and Wang, 2012
Northern Flying Squirrel	Smith, 2007; Ritchie et al., 2009; O'Connell et al., 2001
Barred Owl	Hamer et al., 2007; Nicholls and Warner, 1972
Northern Goshawk	Squires & Kennedy, 2006; Speiser and Bosakowski, 1987; Natureserve
Pileated Woodpecker	Schroeder, 1982a; Lemaître & Villard, 2005; Savignac et al., 2001
Yellow Warbler	Schroeder, 1982b; Natureserve
Brown Creeper	Davis, 1978; Poulin et al., 2008; Natureserve
Ruffed Grouse	Cade & Sousa, 1985; Natureserve
Boreal Chickadee	Hadley, 2006; Erskine, 1977
Blackburnian Warbler	Catlin et al., 1999; Morse, 1994

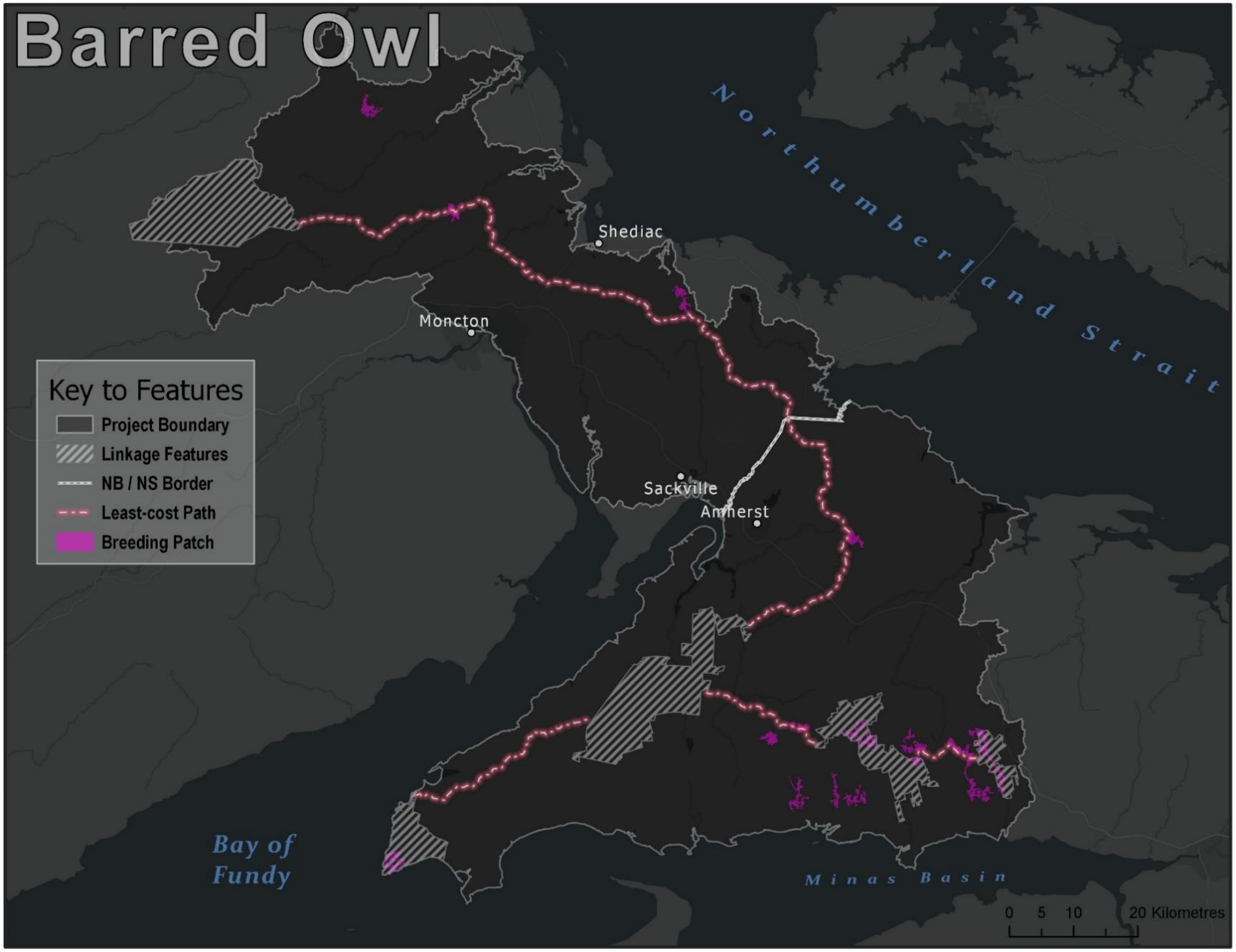
B2 - Habitat patch size requirements by species

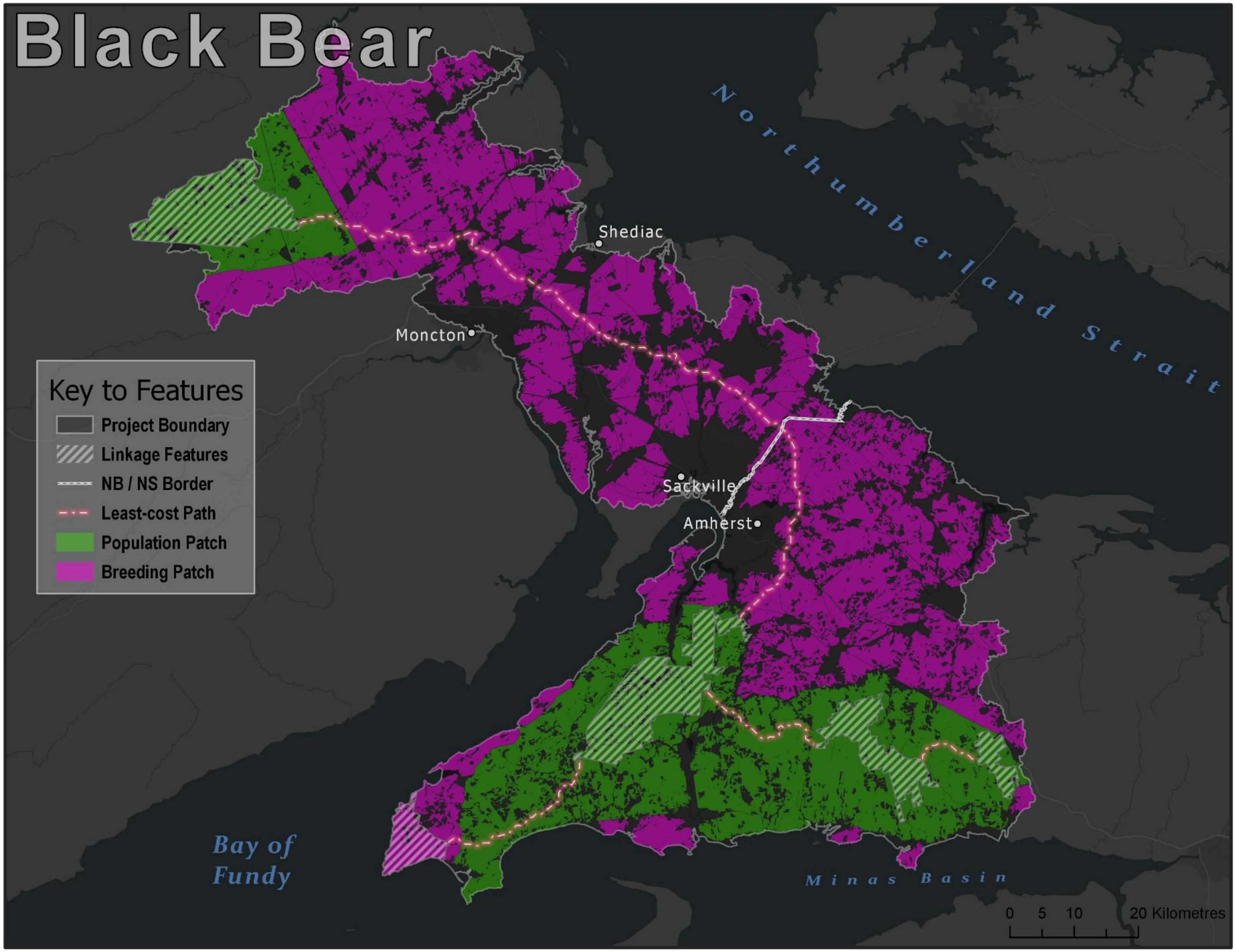
Species	Patch Size (ha)		Source
	Breeding	Population	
Moose	40	243	Allen et al., 1987
Black Bear	388	11655	Rogers et al., 1987
Red Fox	900	4500*	DeGraaf & Yamasaki, 2001
Bobcat	3120	15600	Litvaitis et al., 1986
Snowshoe hare	3	160	Carreker, 1985
Fisher	1920	9600*	Allen, 1986
Northern Flying Squirrel	10	50*	Smith, 2007
Barred Owl	205	1025*	Hamer et al., 2007
Northern Goshawk	12	60*	Squires & Kennedy, 2006
Pileated Woodpecker	129	645*	Schroeder, 1982a
Yellow Warbler	1	5*	Schroeder, 1982b
Brown Creeper	2	10*	Davis, 1978
Ruffed Grouse	2	20	Cade & Sourse, 1985
Boreal Chickadee	2	10*	Erskine, 1977
Blackburnian Warbler	1	5*	Morse, 1994
* Values obtained by multiplying breeding patch size by 5			

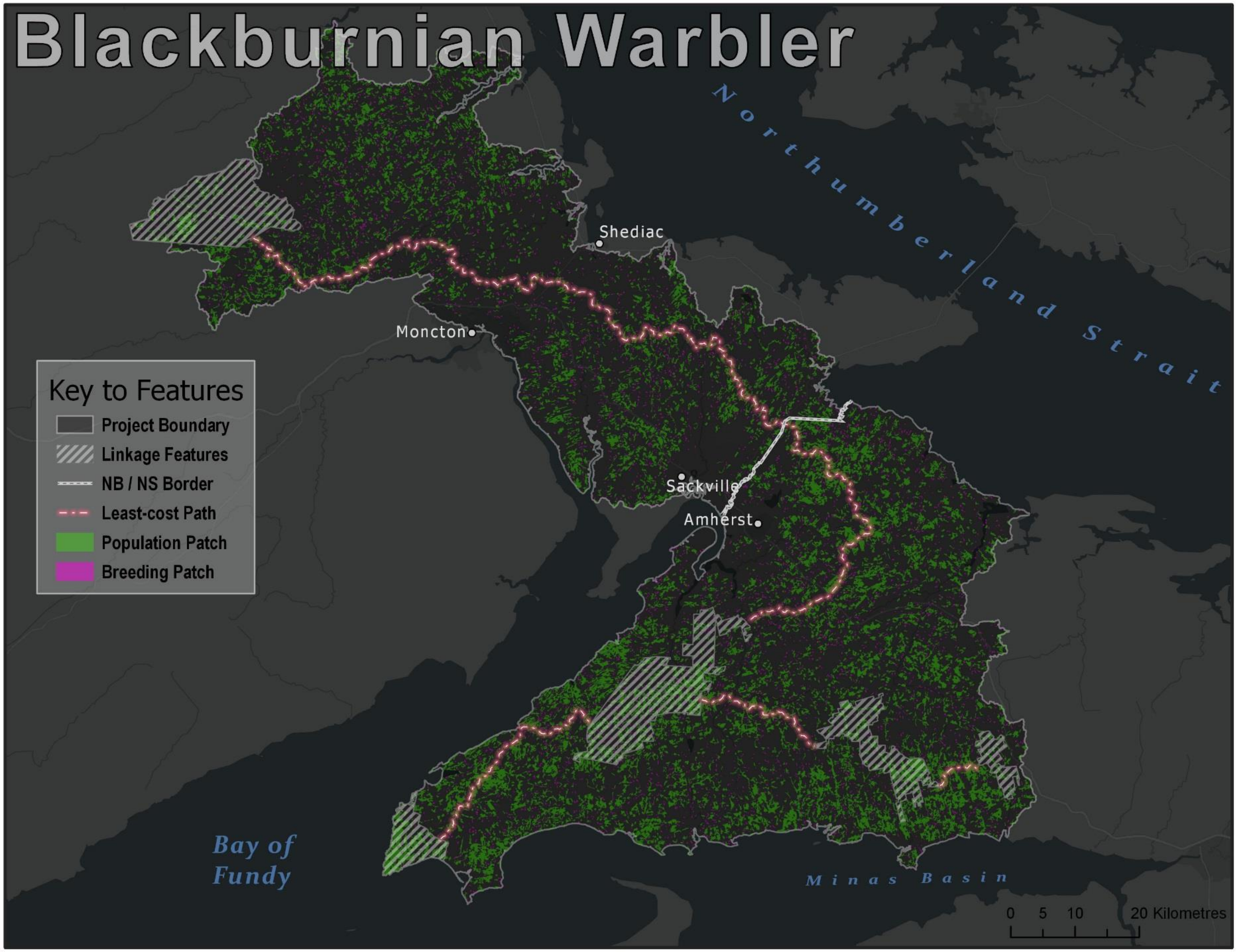
Appendix C – Habitat Suitability Matrix (100 is most Suitable Habitat)

	Moose	Bear	Fox	Bobcat	Hare	Fisher	Squirrel	Owl	Goshawk	Wood_P	Creeper	Y_Warb	Grouse	Chick	B_Warb
Agriculture	20	30	70	40	30	0	0	20	20	10	0	0	0	10	10
Non-vegetated Wetlands	100	45	90	20	30	30	20	45	45	30	10	30	30	10	10
Mid Black Spruce Forest	40	90	65	90	65	90	45	65	45	65	65	50	65	80	60
Old Black Spruce Forest	60	90	65	70	80	100	65	65	65	90	90	50	65	100	100
Young Black Spruce Forest	40	90	90	90	100	80	30	45	45	45	45	50	45	50	10
Emergent Wetland	100	45	90	50	30	30	20	45	45	30	30	45	30	10	10
Forested Wetland	100	90	70	80	40	50	50	65	65	45	90	90	65	80	20
Mid Intolerant Hardwood Forest	30	90	65	90	80	90	65	65	65	65	65	30	100	10	10
Old Intolerant Hardwood Forest	30	90	65	90	65	100	90	65	90	100	30	30	90	30	60
Young Intolerant Hardwood Forest	90	90	30	90	90	80	45	45	45	45	45	30	45	10	10
Soil / Gravel Extraction	0	20	40	10	10	20	0	0	20	0	0	0	0	0	0
Transportation	20	0	30	10	0	0	0	20	20	0	0	0	0	10	10
Mid Jack Pine Forest	30	90	65	90	80	90	45	65	45	65	65	30	65	10	10
Old Jack Pine Forest	30	90	65	70	90	100	60	65	65	70	90	30	45	10	10
Young Jack Pine Forest	30	90	90	90	100	80	30	45	45	45	45	30	45	10	10
Lake or Pond	90	20	20	10	20	20	20	20	45	30	30	50	10	30	30
Mid Larch Forest	30	90	65	90	65	90	50	65	45	65	65	30	65	70	10
Old Larch Forest	40	90	65	70	90	100	90	65	90	70	100	30	65	80	20
Young Larch Forest	30	90	90	90	100	80	45	45	45	45	45	30	45	40	20
Mid Pine Forest	30	90	65	90	65	90	50	65	45	65	65	30	65	20	20
Old Pine Forest	30	90	65	70	65	100	90	65	90	70	100	30	45	10	40
Young Pine Forest	30	90	90	90	100	80	45	45	45	45	45	30	45	10	10
Mid Softwood Plantation	20	45	65	65	45	65	45	45	45	45	45	20	45	10	10
Old Softwood Plantation	45	45	65	90	45	65	65	65	65	65	65	20	45	30	70
Young Softwood Plantation	30	40	90	90	90	45	30	45	45	20	45	20	30	30	10
River or Stream	90	45	20	10	20	20	20	30	45	30	30	50	10	30	30
Shrubland	30	90	100	100	90	70	30	30	45	30	30	100	30	10	10
Shrub Wetland	90	90	100	90	90	70	30	30	45	30	30	100	30	10	10
Human Settlement	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10
Mid Spruce - Fir Forest	65	90	65	90	80	90	80	65	70	65	65	30	65	80	80
Old Spruce - Fir Forest	90	90	65	70	90	100	100	100	90	90	100	30	65	100	100
Young Spruce - Fir Forest	65	90	90	90	100	80	45	45	45	45	45	30	45	40	30
Mid Tolerant Hardwood Forest	45	90	65	90	70	90	65	65	80	65	65	30	90	20	40
Old Tolerant Hardwood Forest	90	100	65	90	80	100	90	100	100	100	90	30	90	20	50
Young Tolerant Hardwood Forest	90	80	90	90	90	80	45	45	45	45	45	30	45	10	20

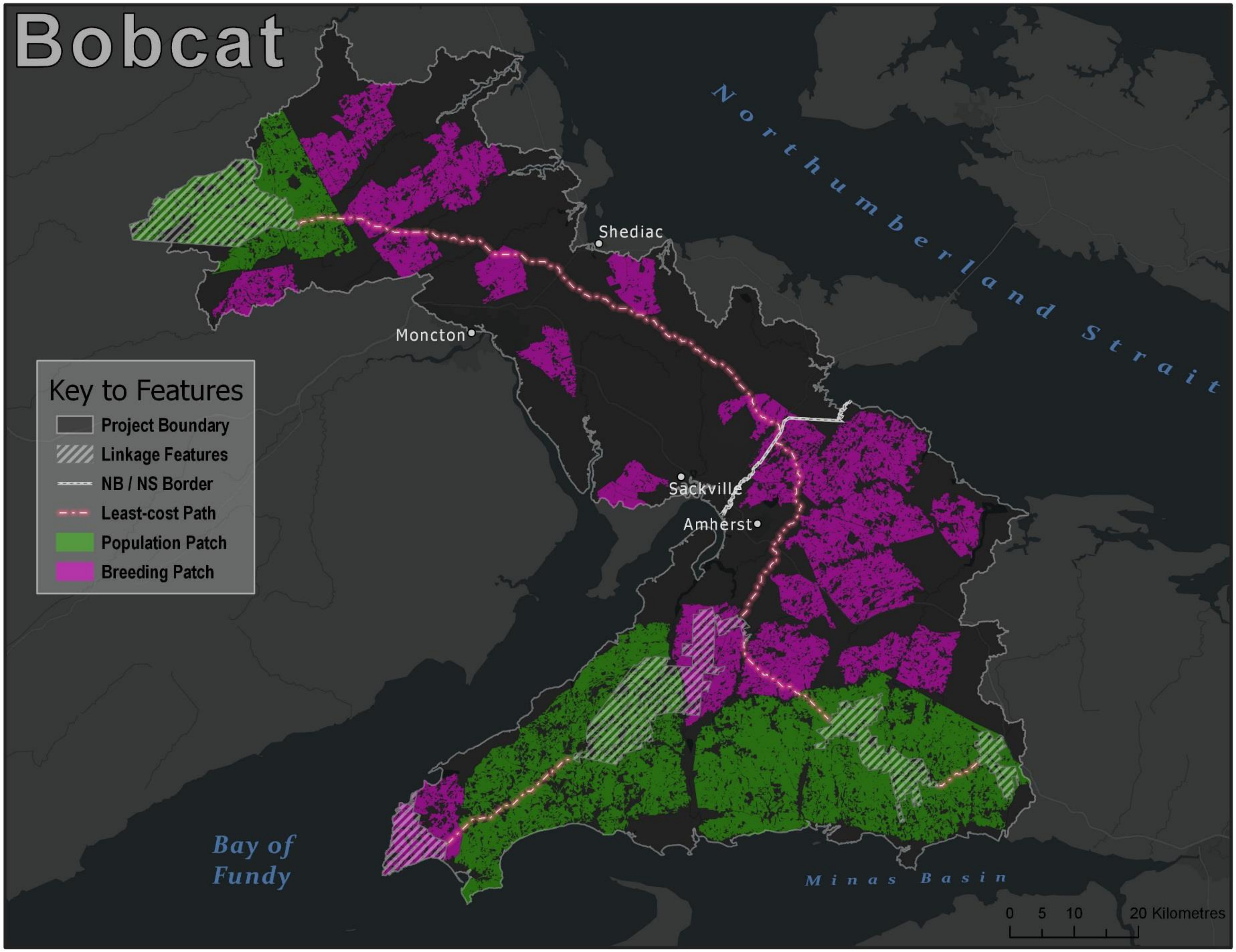
Appendix D – Modelled least-cost paths and habitat patches

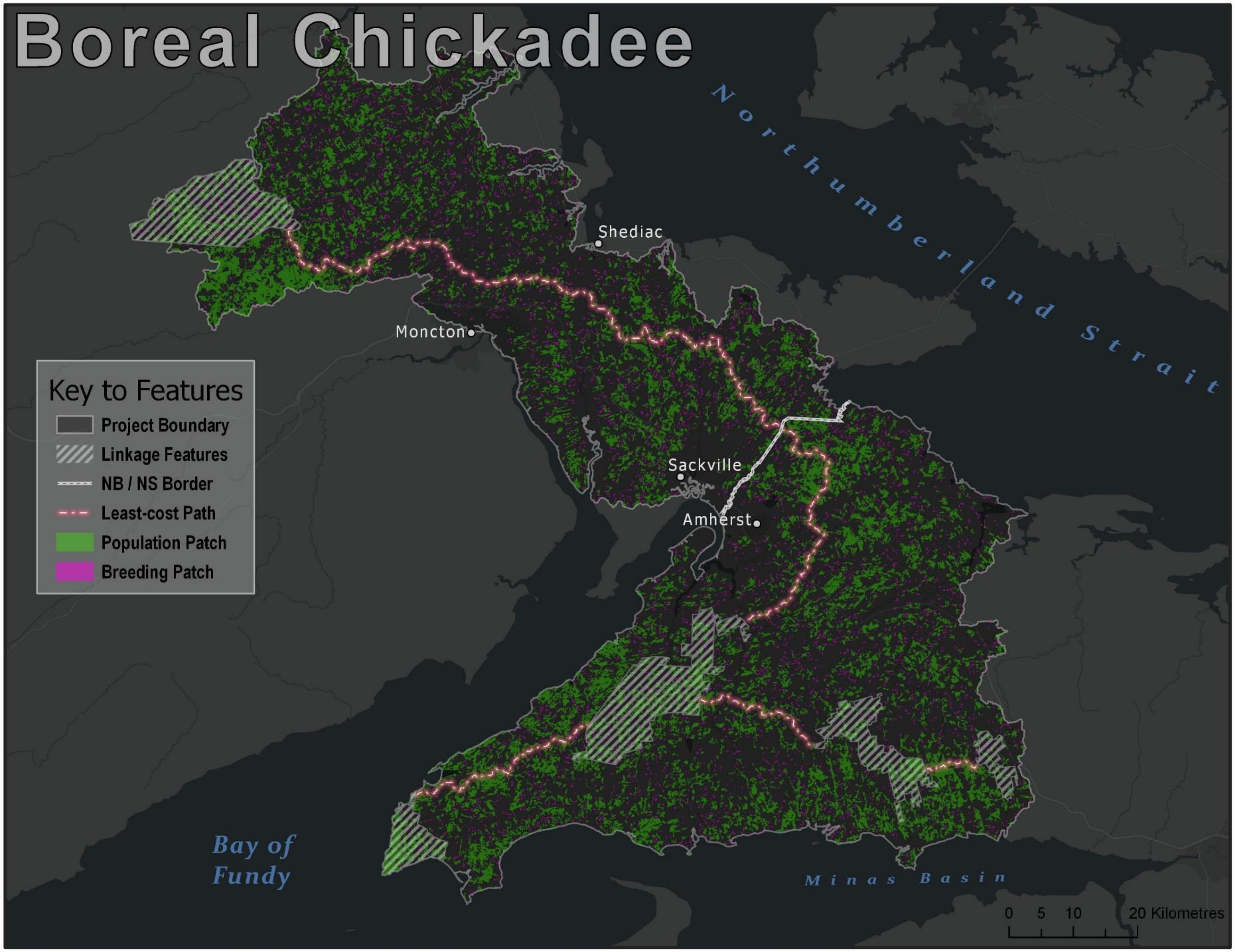


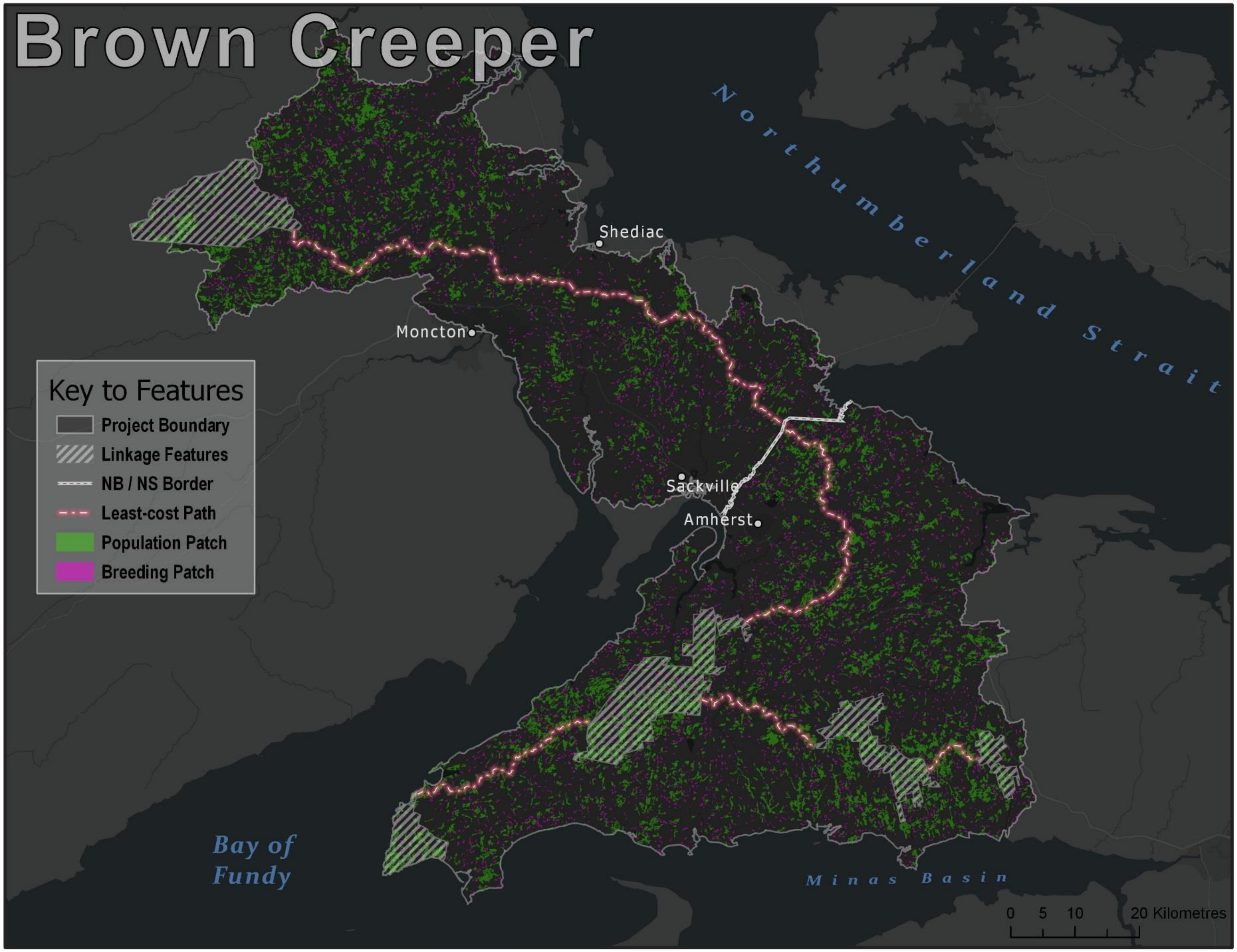

Black Bear
Northumberland Strait
Shediac
Moncton
Sackville
Amherst
Key to Features
Project Boundary
Linkage Features
NB / NS Border
Least-cost Path
Population Patch
Breeding Patch
Bay of Fundy
Minas Basin
0 5 10 20 Kilometres

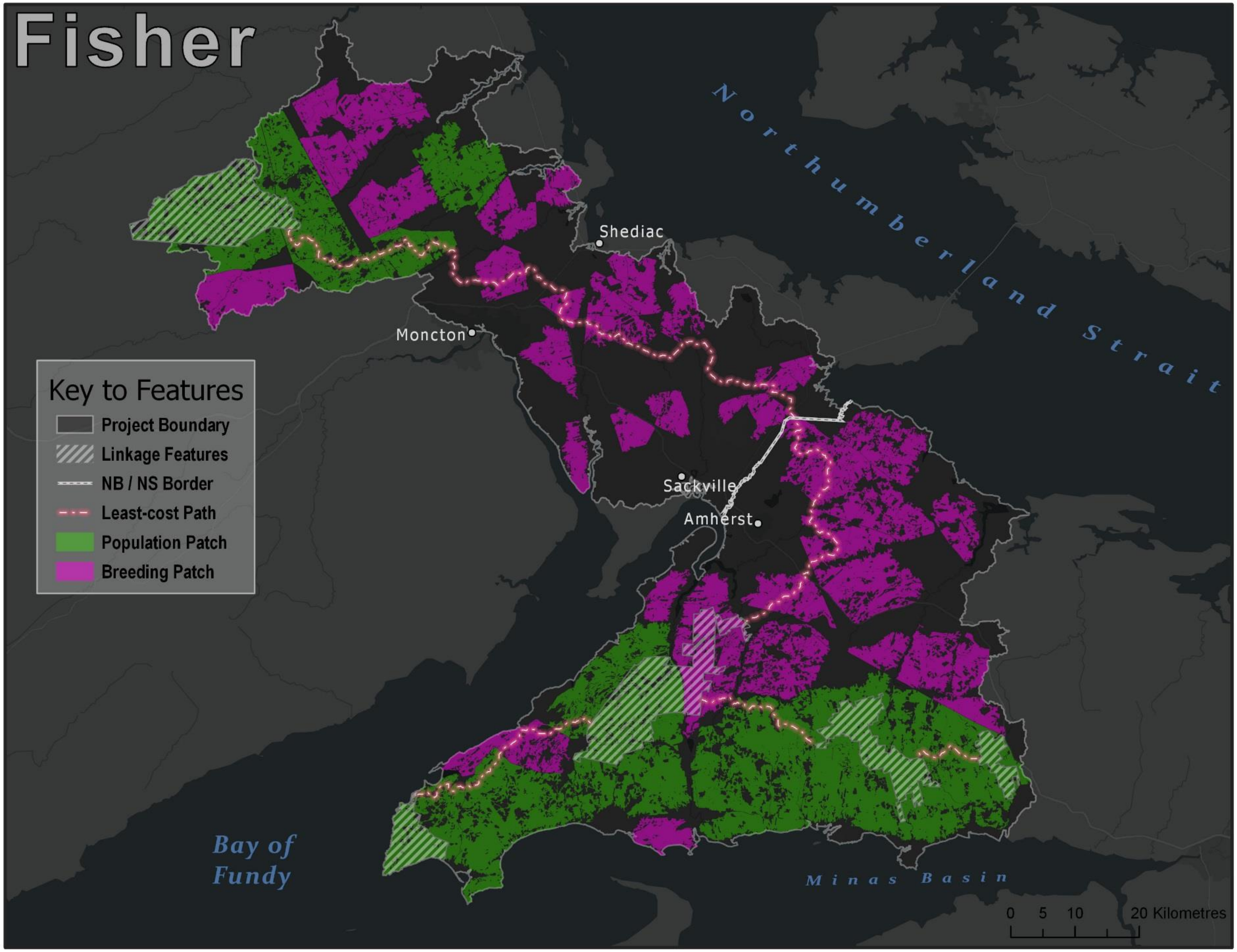


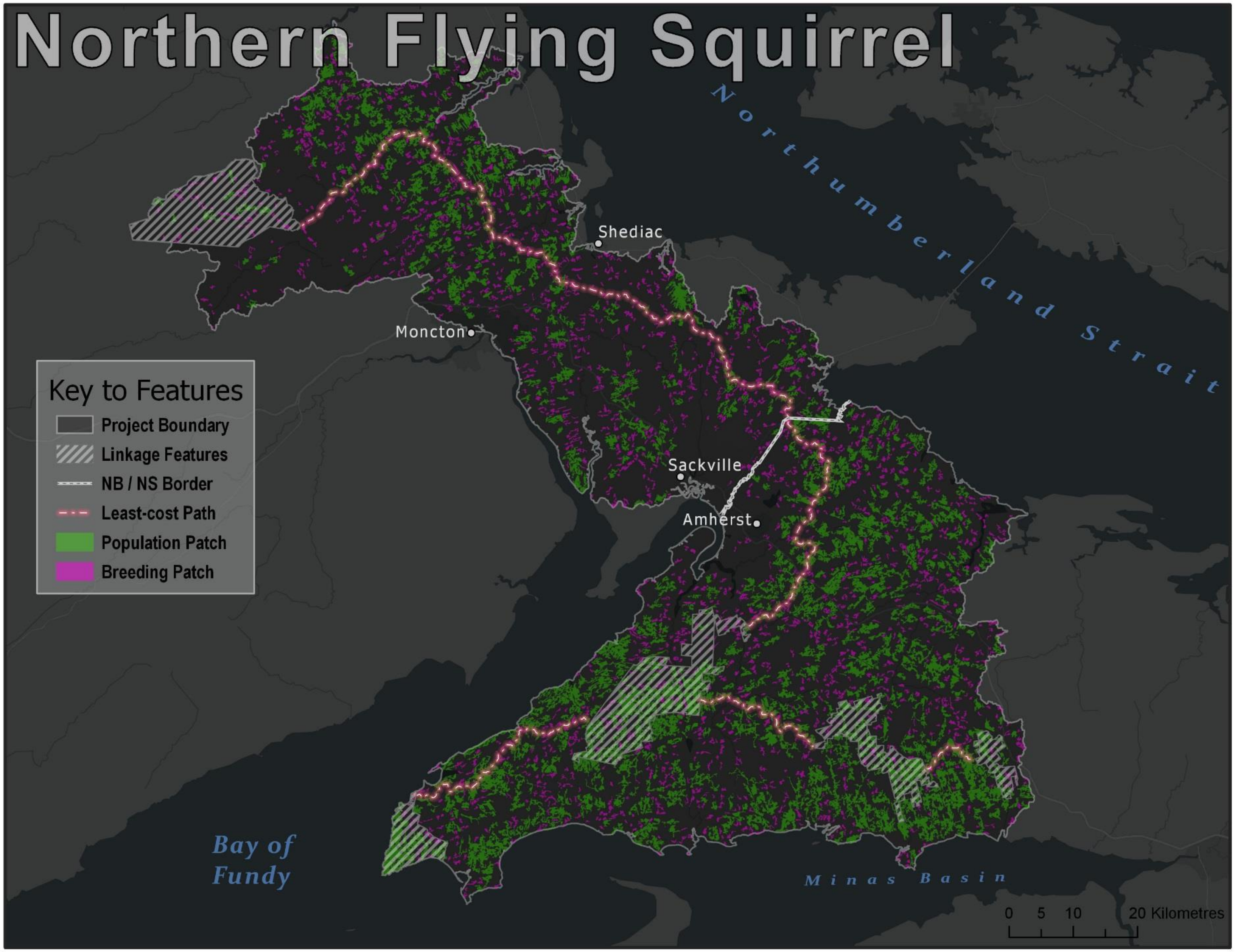
Blackburnian Warbler
Northumberland Strait
Shediac
Moncton
Sackville
Amherst
Bay of Fundy
Minas Basin
Key to Features
Project Boundary
Linkage Features
NB / NS Border
Least-cost Path
Population Patch
Breeding Patch
0 5 10 20 Kilometres

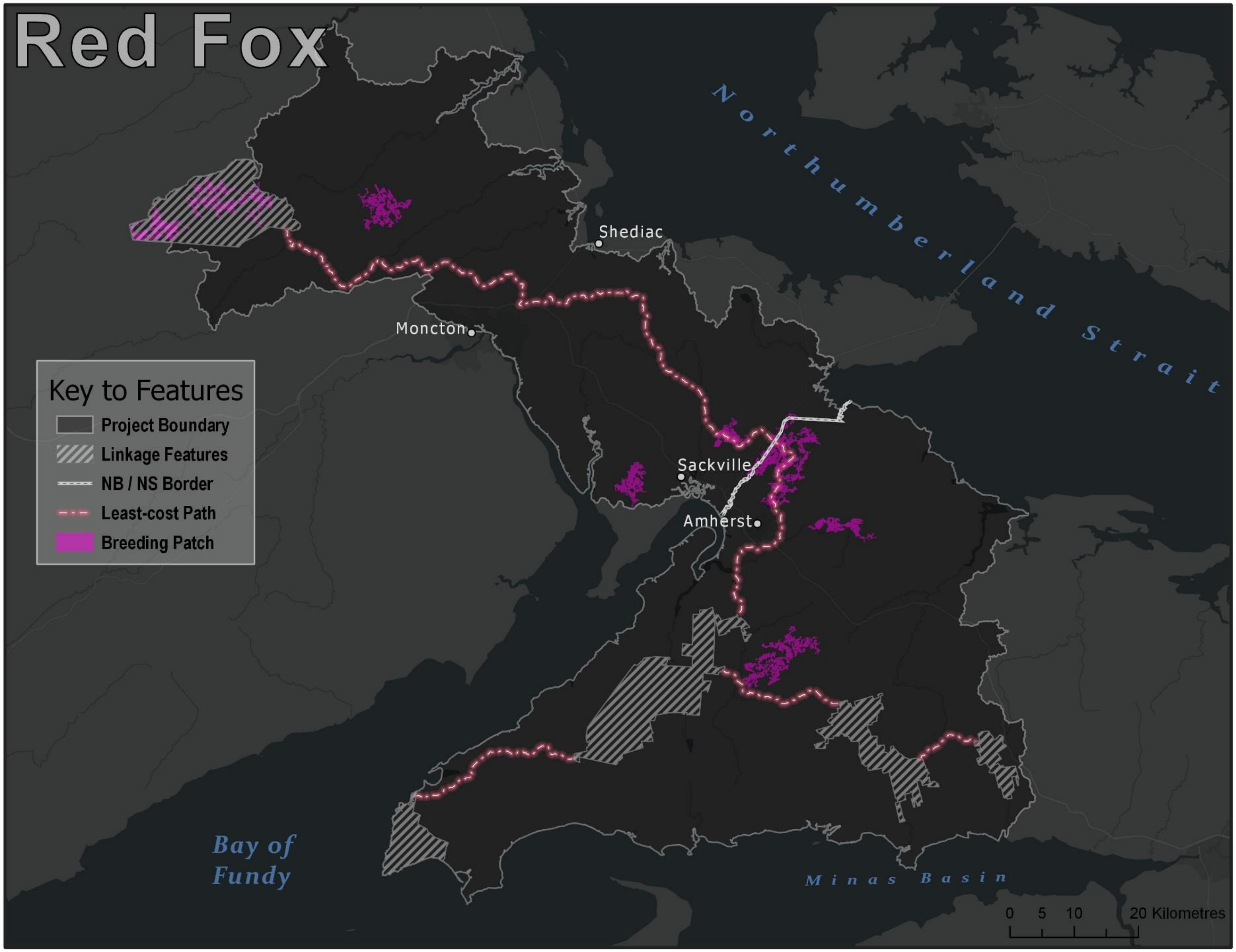

Bobcat
Northumberland Strait
Shediac
Moncton
Sackville
Amherst
Bay of Fundy
Minas Basin
Key to Features
Project Boundary
Linkage Features
NB / NS Border
Least-cost Path
Population Patch
Breeding Patch
0 5 10 20 Kilometres


Boreal Chickadee
Northumberland Strait
Shediac
Moncton
Sackville
Amherst
Key to Features
Project Boundary
Linkage Features
NB / NS Border
Least-cost Path
Population Patch
Breeding Patch
Bay of Fundy
Minas Basin
0 5 10 20 Kilometres

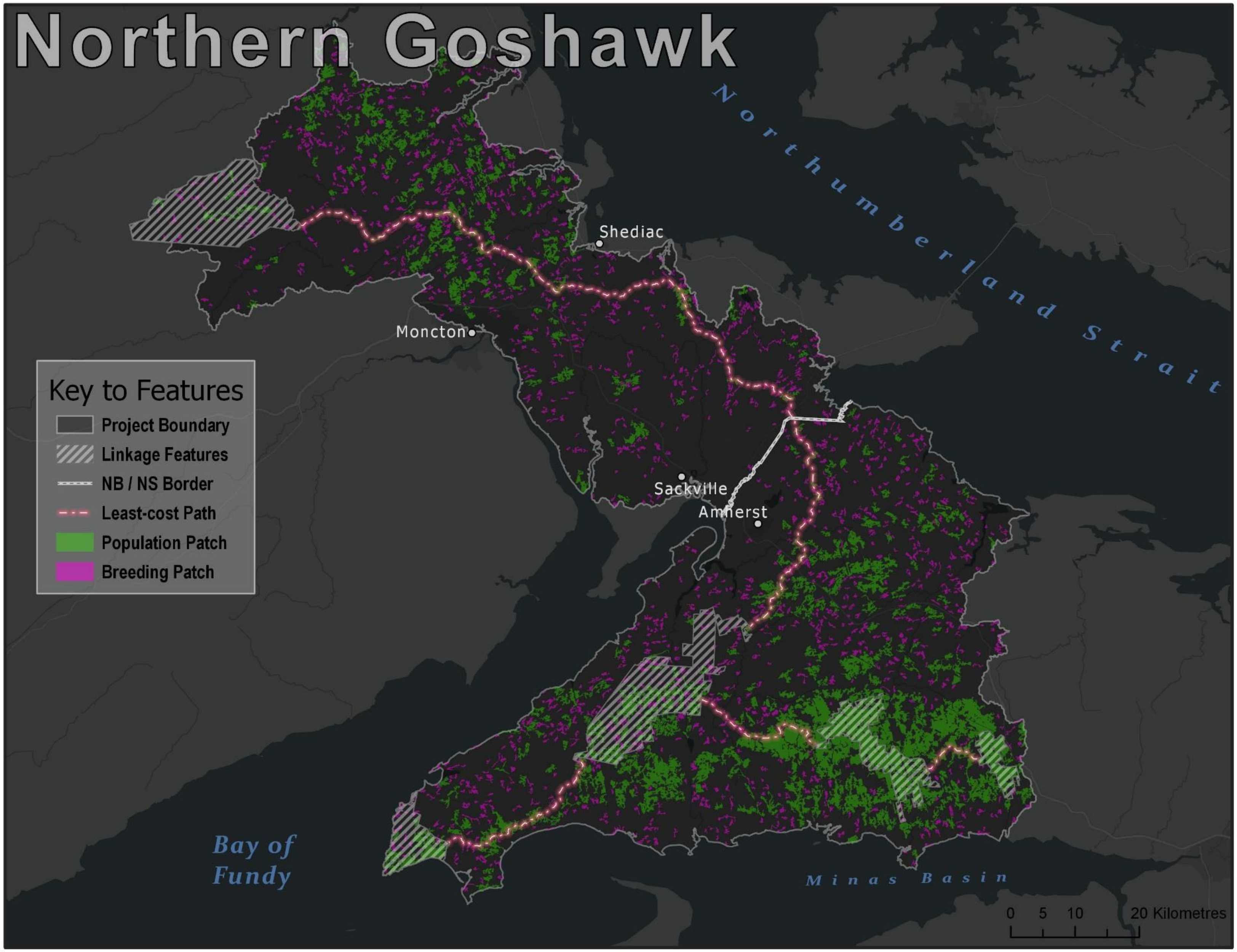

Brown Creeper
Northumberland Strait
Shediac
Moncton
Sackville
Amherst
Key to Features
Project Boundary
Linkage Features
NB / NS Border
Least-cost Path
Population Patch
Breeding Patch
Bay of Fundy
Minas Basin
0 5 10 20 Kilometres

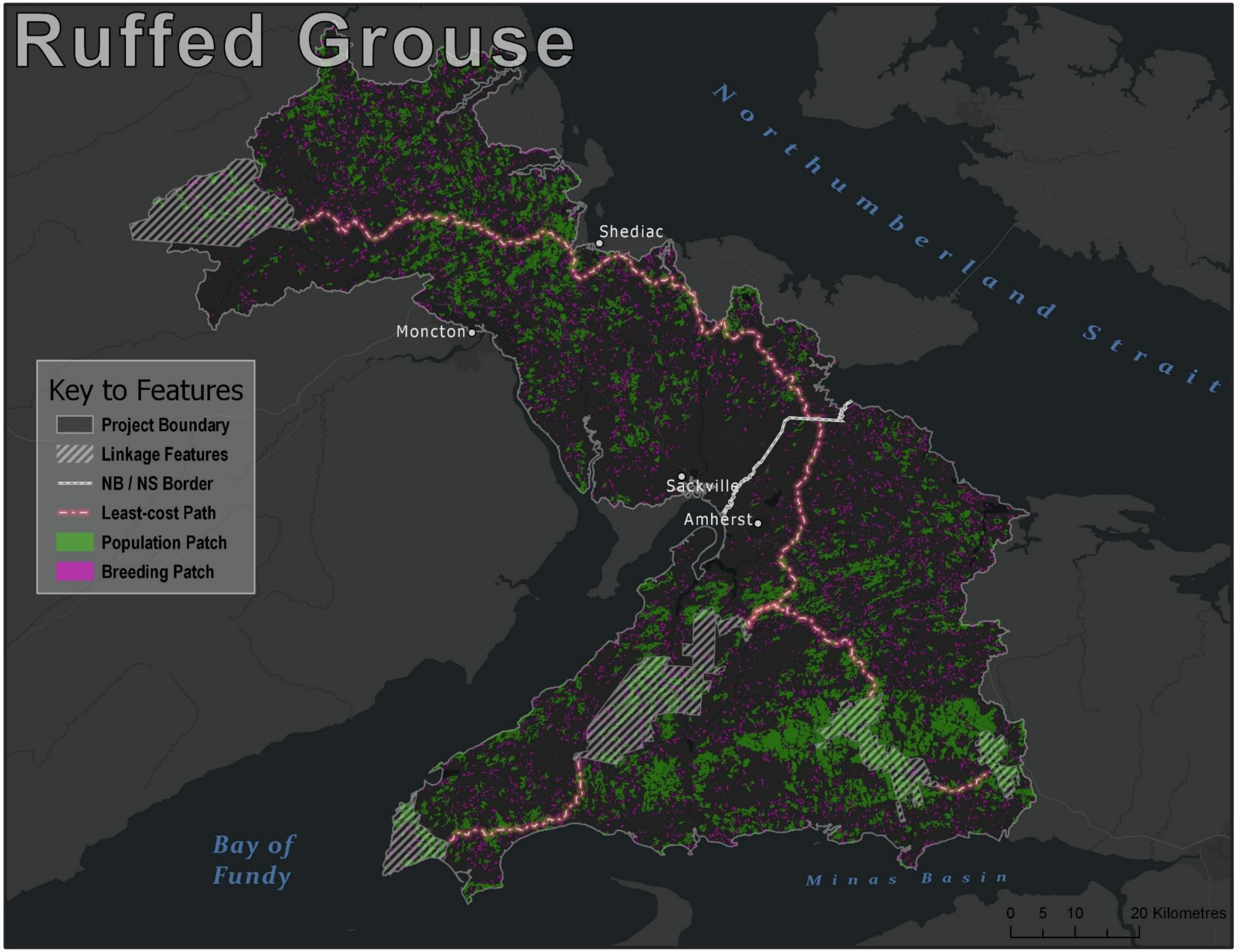

Fisher
Northumberland Strait
Shediac
Moncton
Sackville
Amherst
Bay of Fundy
Minas Basin
Key to Features
Project Boundary
Linkage Features
NB / NS Border
Least-cost Path
Population Patch
Breeding Patch
0 5 10 20 Kilometres

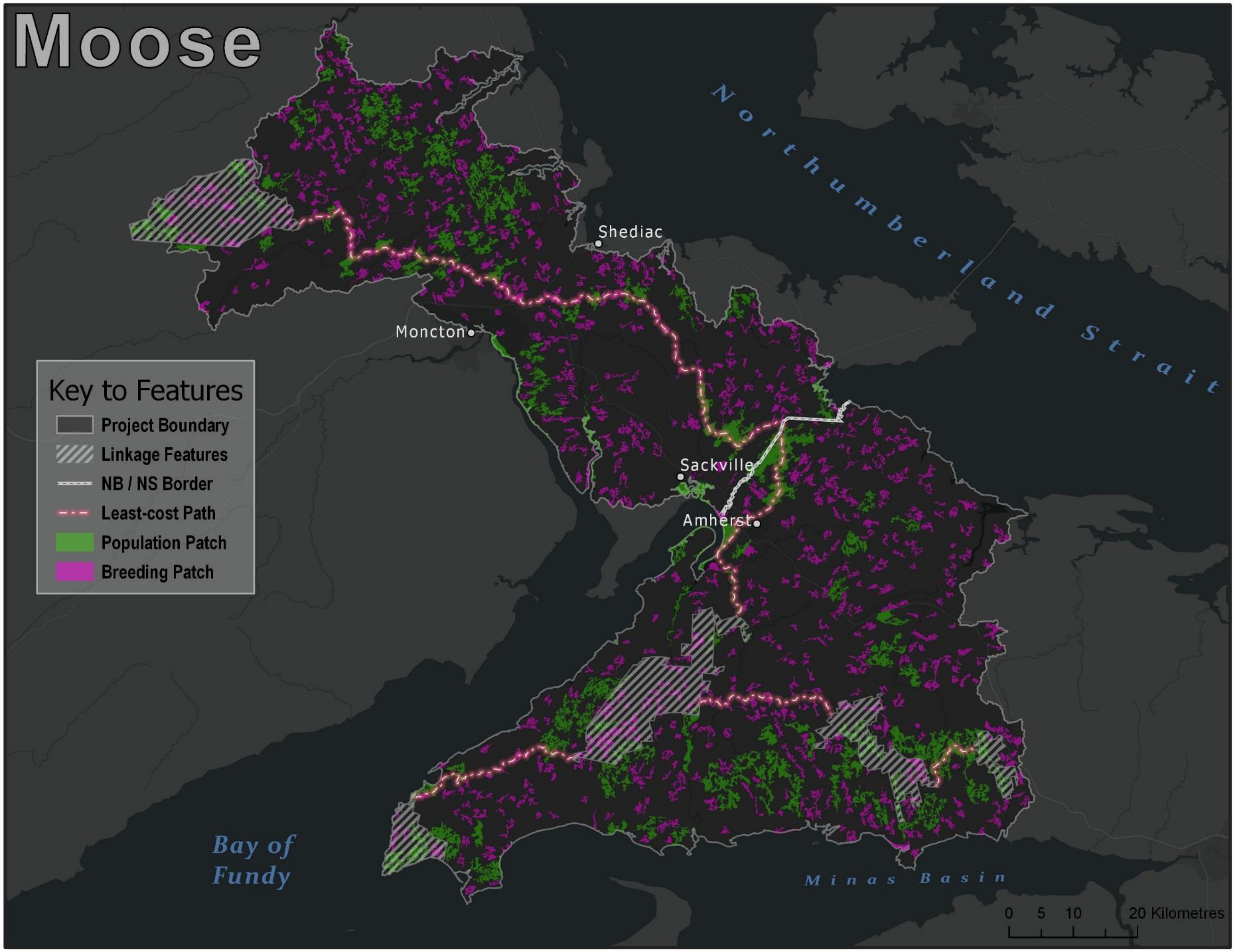

Northern Flying Squirrel
Northumberland Strait
Shediac
Moncton
Sackville
Amherst
Bay of Fundy
Minas Basin
Key to Features
Project Boundary
Linkage Features
NB / NS Border
Least-cost Path
Population Patch
Breeding Patch
0 5 10 20 Kilometres

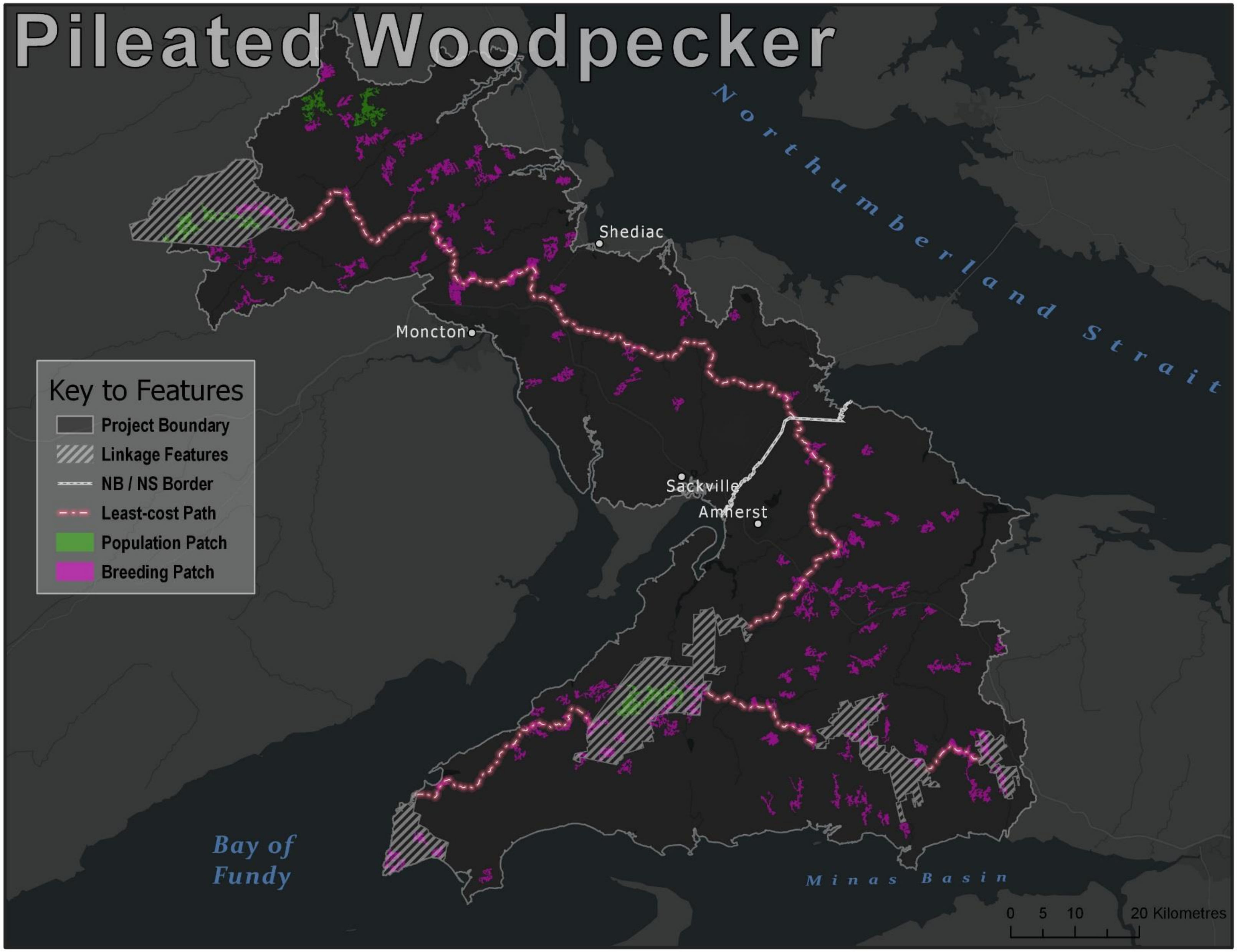


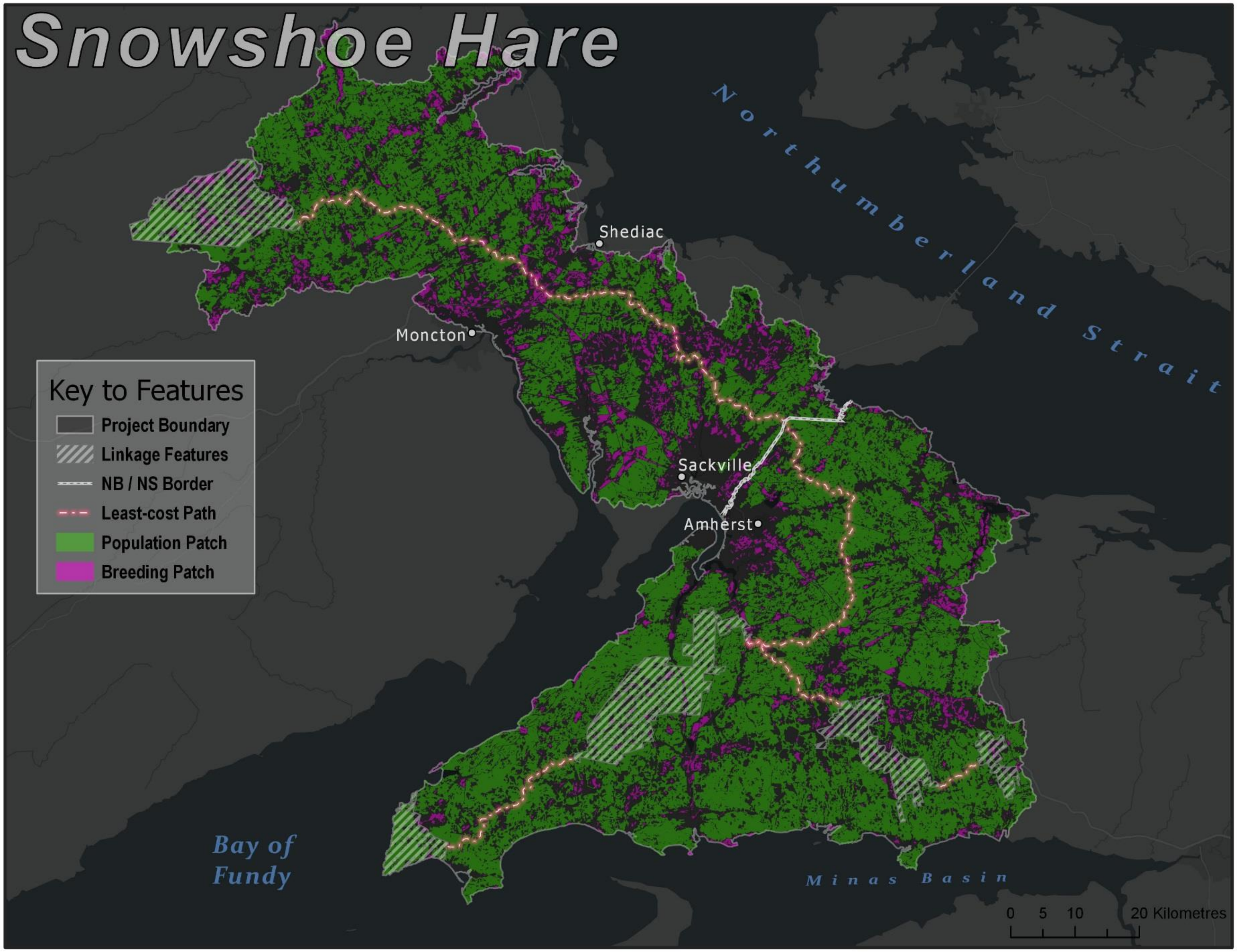
Red Fox
Northumberland Strait
Shediac
Moncton
Sackville
Amherst
Bay of Fundy
Minas Basin
Key to Features
Project Boundary
Linkage Features
NB / NS Border
Least-cost Path
Breeding Patch
0 5 10 20 Kilometres

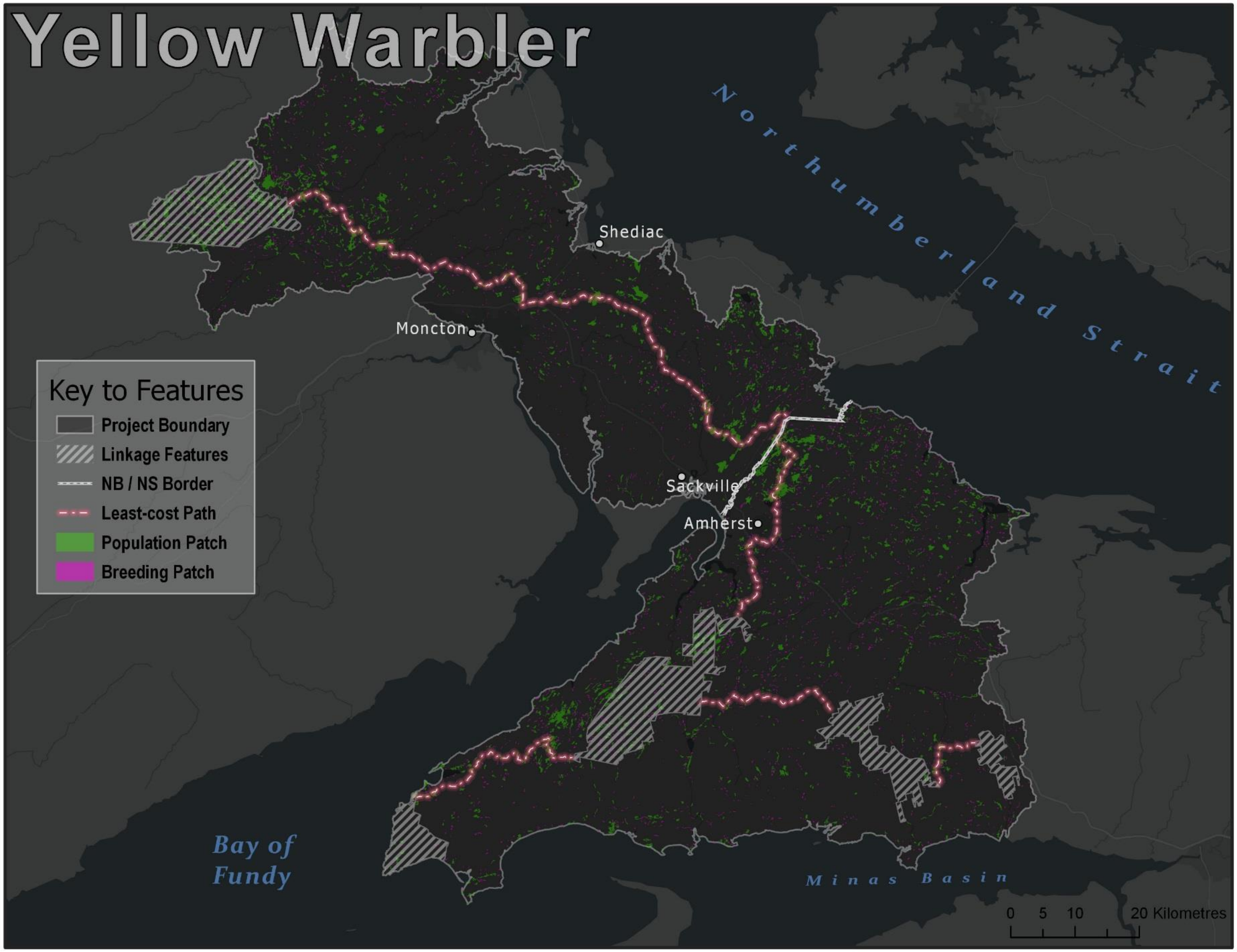

Northern Goshawk
Northumberland Strait
Shediac
Moncton
Sackville
Amherst
Bay of Fundy
Minas Basin
Key to Features
Project Boundary
Linkage Features
NB / NS Border
Least-cost Path
Population Patch
Breeding Patch
0 5 10 20 Kilometres


Ruffed Grouse
Northumberland Strait
Shediac
Moncton
Sackville
Amherst
Bay of Fundy
Minas Basin
Key to Features
Project Boundary
Linkage Features
NB / NS Border
Least-cost Path
Population Patch
Breeding Patch
0 5 10 20 Kilometres


Moose
Northumberland Strait
Shediac
Moncton
Key to Features
Project Boundary
Linkage Features
NB / NS Border
Least-cost Path
Population Patch
Breeding Patch
Sackville
Amherst
Bay of Fundy
Minas Basin
0 5 10 20 Kilometres


Pileated Woodpecker
Northumberland Strait
Shediac
Moncton
Sackville
Amherst
Bay of Fundy
Minas Basin
Key to Features
Project Boundary
Linkage Features
NB / NS Border
Least-cost Path
Population Patch
Breeding Patch
0 5 10 20 Kilometres


Snowshoe Hare
Key to Features
Project Boundary
Linkage Features
NB / NS Border
Least-cost Path
Population Patch
Breeding Patch
Northumberland Strait
Shediac
Moncton
Sackville
Amherst
Bay of Fundy
Minas Basin
0 5 10 20 Kilometres


Yellow Warbler
Northumberland Strait
Shediac
Moncton
Sackville
Amherst
Key to Features
Project Boundary
Linkage Features
NB / NS Border
Least-cost Path
Population Patch
Breeding Patch
Bay of Fundy
Minas Basin
0 5 10 20 Kilometres