Landscape Connectivity in Prince Edward Island (Updated for 2025)

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Key Takeaways

- An updated **Road Effect Zone (REZ)** was calculated using 2024 road data, which indicated that a higher proportion of the land area on Prince Edward Island is within a shorter distance to the road compared to 2019.
- The **Protected Network (ProNet)** and **Protected Connected (ProtConn)** metrics were calculated provincially and regionally for Prince Edward Island to compare the effectiveness of the metrics for assessing landscape connectivity.
    - Landscape connectivity in the **western region** of the province is lower than in the eastern region.
    - **Highways** bisect the province into regions which may limit provincial connectivity. Connectivity of regions divided by highways was compared using both metrics. The Summerside-Borden Carlton and Kensington-Morell regions consistently demonstrated low connectivity.
    - **ProtConn is recommended** for assessing landscape connectivity due to its larger suite of indicators and more realistic approach.
- An updated **Circuitscape current map** was generated using Corporate Land Use Inventory data from 2020; resulting maps indicate that the **decrease in natural and forested land** from 2010 to 2020 has increased the intensity of several pinch points, while sometimes reducing the pressure in other areas.

Introduction

In 2016, **Resolution 40-3,** Resolution on Ecological Connectivity, Adaptation to Climate Change, and Biodiversity Conservation, was passed at the 40th Conference of New England Governors and Eastern Canadian Premiers. This resolution was signed by Wade MacLauchlan, Premier of Prince Edward Island and conference Co-Chair, and recognizes the significance of the region's forests and the imperative to protect their connectivity and biodiversity. Its passing established a commitment to invest in collaborative conservation efforts, and contributes to *Pathway To Canada Target 1*, a nationwide ecological connectivity strategy (CICS, 2016).

The Northern Appalachian-Acadian Forest, which encompasses the forested land on Prince Edward Island, was recognized as a globally significant region representing the most intact, contiguous temperate broadleaf forest in the world (CICS, 2016). The forests are essential to the region's economy, culture, and identity, both for Indigenous and non-Indigenous communities (CICS, 2016). In addition to recognizing their significance to communities across the region, Resolution 40-3 affirmed the need to maintain ecological connectivity, noting that the connectivity in both aquatic and terrestrial environments plays a key role in the region's native ecosystems and biodiversity (CICS, 2016).

The work presented in this document builds on previous efforts to understand and quantify ecological connectivity in Prince Edward Island (Fulton & Bush, 2020). It also assesses two potential metrics that can be useful for decision makers in their efforts to improve connectivity between protected areas. These metrics utilize updated land use and road data from 2020, allowing for an examination of changes in ecological connectivity in the past decade.

Ecological connectivity is broadly defined as the degree to which the landscape facilitates or impedes movement between blocks of suitable habitat (Laliberté & St. Laurent, 2020; Taylor et al., 1993). It is generally categorized into two components: structural and functional connectivity. Structural connectivity refers to the relationship between landscape elements, while functional connectivity describes the movement of species within the structure of the landscape (Brooks, 2003). The work presented here focuses primarily on the landscape's structural connectivity, examining the physical components of the landscape and their relationship to one another. Specifically, this work uses Circuitscape analysis to understand the structural connectivity between different categories of land use in Prince Edward Island.

Connectivity between suitable habitat in Prince Edward Island has notably declined since the 19th century (Silva et al., 2005). While the island was once heavily dominated by the Acadian Forest region, agricultural activity, timber harvesting, and road infrastructure have led to the loss of 70% of forested area over the last three centuries (Government of Prince Edward Island, 2013; Silva et al., 2005). Forest fragmentation has resulted in significant habitat loss, leading to reduced gene flow throughout the landscape (Silva et al., 2005). The increased development of larger roads has compounding impacts on nearby species, such as noise, visual disturbances from vehicles (headlights), reduced habitat quality (pollution, removal of vegetation), or changes in temperature and moisture caused by the road surface (Forman & Alexander, 1998; Paterson et al., 2019). Some species are more susceptible to these impacts than others, with the effects from the road extending up to a kilometre into the surrounding area for some animals (Benítez-López et al., 2020). This report will re-examine the road effect zone (REZ) concept discussed by Fulton & Bush (2020), updating figures on the impact of roads in Prince Edward Island for 2025.

One piece of the broader strategy for ecological conservation in Prince Edward Island has been the development of protected areas. Approximately 4.9% of provincial land is protected from development, and only 0.3% is formally protected on private land. The province has committed to protecting 7% of the total land base, contributing to broader national goals which seek to conserve 30% of Canada's land and water by 2030 (Government of Prince Edward Island, 2023; Environment Canada, 2024). Protected areas integrate with ecological connectivity by providing (relatively) undisturbed patches of land that animals can use to move throughout the landscape (Saura et al., 2017). However, the mere existence of protected land does not guarantee effective movement for species – protected areas must be well-maintained and well-connected to support ecological connectivity priorities (Saura et al., 2017).

This report introduces and compares two measures of connectivity between protected areas – ProNet and ProtConn – that can be used to assess the functional connectivity of protected area networks (Saura et al., 2017; Theobald et al., 2022).

Outside of protected areas, animals may also use natural landscapes that are not formally conserved to move from one habitat patch to another. Understanding movement across the whole landscape and understanding where movement may be constricted is helpful in identifying areas where conservation is most necessary. Circuit theory-based tools, like Circuitscape, model the functional connectivity of the landscape (natural, forested, etc.) and can help land managers understand how animals are traversing their environment.

Methods

Study Area

Prince Edward Island covers a land area of approximately 6,000 km^2, and its natural areas are characterized by sand beaches and dunes, coastal estuaries, remnants of Acadian forests, streams, and wetlands (Nature Conservancy of Canada, 2019). Land use is dominated by agriculture and human settlement, representing 36.05% and 6.9% of land use, respectively (Government of Prince Edward Island, 2025; Nature Conservancy of Canada, 2019).

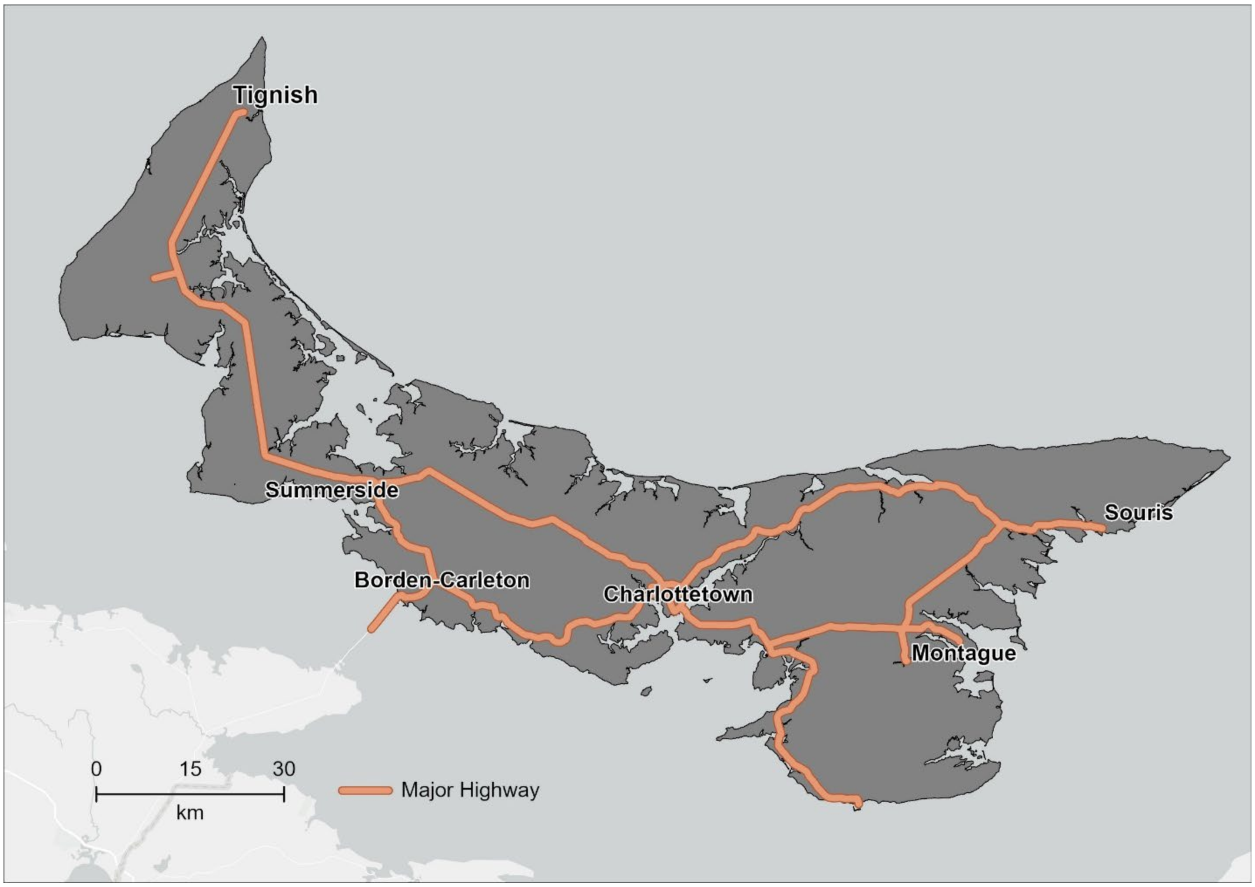


Figure 1. Prince Edward Island (PEI), Canada, with major townships. Provincial boundaries and road data provided by Prince Edward Island. For all maps, datum & projection: D North American 1983, NAD 1982 CSRS Prince Edward Island.

Due to a lack of definition and data regarding ecological land classification in Prince Edward Island, the study area refers to the entirety of the province, where the landscape classifications are divided into natural ecosystems, forests, and mature forests. In this case, mature forests were determined by the height of the forest stand rather than through age-specific characteristics or ecological functions (Fulton & Bush, 2020). Tables 1-3 outline the characteristics of each landscape class (natural ecosystem, forests, mature forests) based on the attributes in the 2020 PEI Corporate Land Use Inventory. Dominant classes, including open water, were excluded from the analysis, as the work focused on the structural connectivity of the terrestrial landscape.

Natural Ecosystem

Table 1. Landscape types representing Natural Ecosystems in Prince Edward Island (Fulton & Bush, 2020).

Land Use	Sub Use	Cover Type	Extract
Forestry	Clear cut		
	Plantation		
	Wetland		
		All forest cover classes	
Abandoned Land	Shrubs		
Wetland	Forest		

Forestry

Table 2. Landscape types representing Forested areas in Prince Edward Island (Fulton & Bush, 2020).

Land Use	Sub Use	Cover Type	Extract
Forestry	Clear cut		
	Plantation		
	Wetland		
	Trees		
		All forest cover classes	

Mature Forest

Table 3. Landscape types representing Mature Forested areas in Prince Edward Island (Fulton & Bush, 2020).

Land Use	Sub Use	Cover Type	Extract
Forestry	Clear cut		Everything greater than or equal to 15m in height
	Plantation		
	Wetland		
	Trees		
		All forest cover classes	

Determining the Road Effect Zone

The road effect zone (REZ) is defined as the distance from the edge of the road at which significant ecological effects can be detected (Forman & Alexander, 1998). It acts as a threshold at which the landscape changes from areas undisturbed by roads to areas that experience potentially deleterious effects (Fulton & Bush, 2020). The REZ has been demonstrated to influence wildlife behaviour to varying degrees and at varying distances, depending upon their sensitivity to road impacts and their persistence in road-affected terrestrial and aquatic environments (Robinson, 2008). The Prince Edward Island natural landscape is composed of both young and old-growth forests, and is home to a broad range of species. As such, analysis needs to account for the varying impacts of road effects on different species.

A REZ raster was generated to identify areas most/least impacted by the presence of roads. Additionally, to understand the varying impact of roads on different species, the percentage of the province’s land area within a certain distance to the road (between 0.1 km and 6.3 km) was calculated. Distances were selected based on those previously applied by Fulton & Bush (2020).

The REZ was calculated using the Distance Accumulation and Extract by Mask tools in ArcGIS Pro 3.4.0 using the following tools/ inputs:

1. **Distance Accumulation** (Spatial Analyst Tools)

Input raster or feature sources:	NRN24.shp
Output distance accumulation raster:	NRN24_RoadEffectZone.tif
Output cell size:	25 m
Distance method:	Planar

2. **Extract by Mask** (Spatial Analyst Tools)

Input raster:	NRN24_RoadEffectZone.tif
Feature mask data:	PEI.shp
Output raster:	NRN24_RoadEffectZone_ProvinceBoundaries.tif
Extraction area:	Inside

The percentage of the province's land area within certain distances to the road was calculated using the following iterative process:

1. **Pairwise Buffer** (Analysis Tools)

Input features:	NRN24.shp
Output feature class:	NRN24_%BufferDistance%.shp
Distance:	0.1, 0.3, 0.5, 0.8, 1.0, 3.0, 5.0, 6.3 km *(iteratively)*
Method:	Planar
Dissolve type:	Dissolve all output features into a single feature

2. **Pairwise Clip** (Analysis Tools)

Input features:	NRN24_%BufferDistance%.shp
Clip features:	PEI.shp
Output feature class:	NRN24_%BufferDistance%_ProvinceBoundaries.shp

The sum of the area of each clipped buffer vector was used to determine the land area and subsequent percentage of the province within each distance to the road.

ProNet

The Protected Network metric (ProNet) uses graph theory to assess the connectivity of protected area networks. ProNet is one of many available connectivity metrics that aim to distill the complex relationships between protected area size, distance, and clustering into a value that can be easily understood, compared, and communicated to a broader audience (Theobald et al., 2022). ProNet was designed to be a "simple, robust, and extendable metric developed specifically to guide high-level conservation actions and policies" by measuring the efficacy of protected area networks in different regions (Theobald et al., 2022, p. 3).

ProNet is calculated as:

$$ProNet = \sum_{k=1}^{m} \left(\sum_{i=1}^{n} a_{ik}\right)^2 / \left(\sum_{i=1}^{n} a_i\right)^2$$

Where *a* is the size of the patch (protected area), *i* for *n* number of protected areas. Each patch is grouped within cluster *k* of *m* clusters. Essentially, ProNet is calculated as the sum of the squared areas of patches within each cluster, normalized by the square of the sum of areas for all patches. ProNet values can range from 0.0 (unconnected/isolated) to 1.0 (fully connected) (Theobald et al., 2022). Note that patches represent a single polygon of protected area, not the total protected area if it is composed of fragmented patches. For example, if a protected area is comprised of 30 different parcels of land spread out across the province, each is counted as a single "patch" rather than one protected area. ProNet is still a relatively new metric, but it has been employed in a recent study (Poor et al., 2025) and has been proposed for use in aquatic as well as terrestrial environments (Metaxas et al., 2024).

The ProNet metric was calculated using the *terra* package (Hijmans et al., 2025) in RStudio. The script was provided by Theobald et al. (2022) and modified to suit the study area. To calculate ProNet, the user must set two data sources and one parameter, as follows:

1. **d4PAs.path**: a rasterized layer of protected areas, where raster cells with a value of 0 represent protected areas, and cells with a value of 1 represent unprotected areas (source: PEI_CPCAD24, rasterized).
2. **country.path**: a vector layer of the area of interest, either the provincial boundaries or a specific region.
3. **threshold_metres**: half of the distance, in metres, used to define a cluster of protected areas (i.e. if patches within 500 m of one another are considered a cluster, enter 250 m).

These threshold values, also known as dispersal distances (d), were determined based on recorded dispersal distances for common terrestrial species in Prince Edward Island (Prince Edward Island Executive Council Office, 2023). Essentially, the distance that animals can typically travel is used to define a cluster, so patches within that cluster could all be reasonably reached by animals living within those habitats. Figure 2 exemplifies how patches can be considered a cluster.

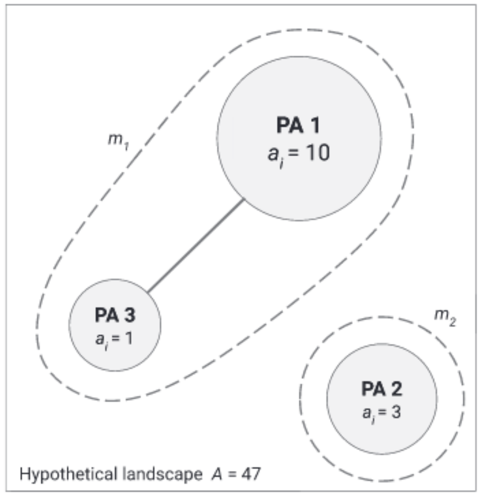


Figure 2. Example of patches and clusters from Theobald et al. (2022). Patches within a certain dispersal distance from one another can be reached back and forth by most species, making them a cluster.

Dispersal distance for common species were obtained from data aggregated by Sutherland et al. (2000). Median and maximum distances were averaged for males and females when necessary. These dispersal distances are intended to represent the general dispersal abilities of terrestrial species common on the island. Any analysis focused on a single species should use dispersal distances specific to that animal.

Table 4. Median and maximum dispersal distances for common species in Prince Edward Island. Adapted from Sutherland et al. (2000).

Species	Median dispersal distance (km)	Maximum dispersal distance (km)
Beavers (*Castor canadensis*)	2.10	
Eastern Coyotes (*Canis latrans x Canis lycaon*)	29.40	
Muskrats (*Ondatra zibethicus*)		3.37
Raccoons (*Procyon lotor*)		265.50
Red Foxes (*Vulpes vulpes*)	10.80	
Red Squirrels (*Sciurus vulgaris*)		3.37
Weasel (*Mustela*)		24.18
Snowshoe hare (*Lepus americanus*)		20.10
Canada Goose (*Branta canadensis*)	1.75	

From this data, dispersal distances of 0.5, 1, 2, 3, 4, 5, 10, 25, and 100 km were chosen to calculate both ProNet and ProtConn metrics. Intermediate distances between 1 km and 10 km were chosen due to the small size of the island; small increases in dispersal distance were shown to have a significant impact on connectivity metrics.

The ProNet metric was calculated for the province as a whole, as well as for the eastern/western region of the province, and for regions created by the divisions imposed by major highways. Regions of Prince Edward Island were arbitrarily divided using the major highways in the NRN_19 roads shapefile layer available from the province. Roads classed as “Highway” in the “CodeForSym” field were used to create regions bounded by major highways.

ProtConn

The Protected Connected (ProtConn) metric is another connectivity metric used to assess connectivity within protected area networks. Like ProNet, ProtConn is based on graph theory (network analysis), and accounts for both the land area that can be reached within protected areas as well as the land area that is reachable by travelling across unprotected areas (Saura et al., 2017). It aims to quantify the relationships between multiple protected areas into an interpretable value; however, it also seeks to provide a more comprehensive assessment of connectivity by identifying different categories of land through which movement between protected areas may occur (see Table 10). The ProtConn metric also has the ability to take into account protected areas that are just outside of the study area, but which may still be used for species movement. This allows for a more realistic portrait of protected area usage, and can improve the overall accuracy of the assessment (Saura et al., 2017).

ProtConn is calculated as:

$$ProtConn = 100\ x\ \frac{ECA}{A_L} = 100\ x\ \frac{\sqrt{\sum_{i=1}^{n+t}\sum_{j=1}^{n+t} a_i a_j p^*{}_{ij}}}{A_L}$$

Where *n* is the number of patches (protected areas) within the region, *t* is the number of patches in the transboundary buffer (i.e. the space outside of the area of interest, if present) outside the region, a_i and a_j are the attribute of patches *i* and *j*, A_L is the maximum landscape attribute (total region area), and p^*_{ij} is the maximum product probability of all paths connecting nodes *i* and *j* (Saura et al., 2017).

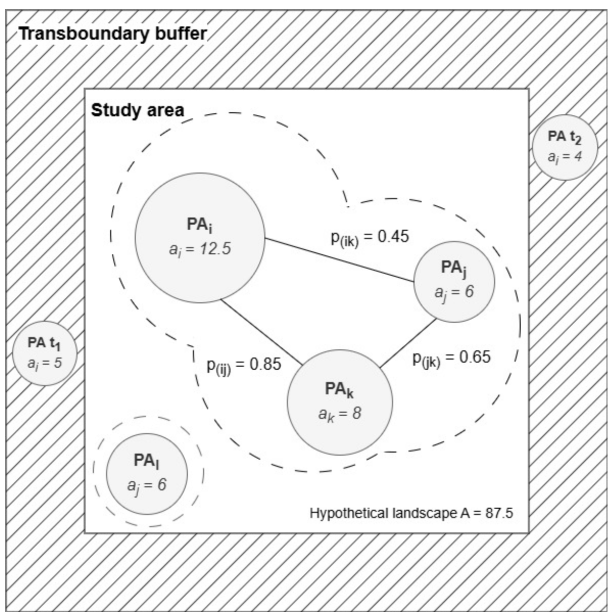


Figure 3. Example of patches and clusters using ProtConn metrics. Patches within a certain dispersal distance from one another can be reached back and forth by most species, making them a cluster (i.e. protected and connected land – ProtConn). Patches within a transboundary buffer zone are also represented.

The full suite of ProtConn indicators (see Table 10 for the full list of indicators and associated definitions) was calculated for Prince Edward Island using the same set of dispersal distances applied to ProNet calculations. These indicators measure how much of the study region is covered by protected areas

(Prot), and how much of the study region is covered by connected protected areas (ProtConn). Protected areas are considered "connected" when, similar to ProNet, the patches of protected land are within the dispersal distance necessary for animals to feasibly move between them. The tool measures how much of the study region is covered by protected areas that are isolated (ProtUnconn), i.e., are not within the dispersal distance necessary for animals to move between them. Several other indicators are also calculated, measuring the ability of animals to move throughout the protected/unprotected landscape.

ProtConn indicators were calculated using the *Makurhini* package (Godínez-Gómez & Correa Ayram, 2020) in RStudio. To calculate the ProtConn indicators, the user must set two data sources and can alter several parameters associated with the tool, as follows:

1. **region**: a vector layer of the area of interest, either the provincial boundaries or a specific region
2. **protected_areas**: a vector layer of protected areas (source: PEI_CPCAD24.shp).
3. **distance_thresholds**: the distance, in metres, used to define a cluster of protected areas – unlike ProNet, a list of distances can be entered in order to calculate ProtConn for multiple dispersal distances at once.
4. **transboundary**: set to TRUE to consider protected areas outside of the study region; this parameter is useful when examining smaller regions which may have neighbouring protected areas.

The ProtConn metric has been more widely applied than ProNet to ecological connectivity studies. Jackson & Fuller (2024) used ProtConn to assess the level of connectivity in the National System of Protected Areas in Chile. Castillo et al. (2020) used data on anthropogenic impacts on landscape connectivity to refine worldwide ProtConn estimations. Bargelt et al. (2020) calculated ProtConn metrics to assess the connectivity of protected area networks in the United States and the contribution of private lands to structural connectivity.

Circuitscape

Circuitscape is an open-source software package that utilizes electronic circuit theory to predict patterns of animal movement, gene flow, and genetic differentiation across heterogeneous landscapes (McRae et al., 2014). Circuit theory is widely employed for analysis of forest connectivity, and its use complements the least-cost path approach by simultaneously considering the effects of all possible pathways across the landscape (Pelletier et al., 2017; Circuitscape, n.d.).

Circuitscape reflects electronic circuit theory by using a resistance surface to measure the flow of electrical current across the surface, indicating a random walker's probability of passing through each cell on its way towards a node, such as a habitat patch (Shah & McRae, 2008). Additionally, voltage maps created by Circuitscape (not used in this analysis) predict whether the "random walker will reach one destination before another" (Shah & McRae, 2008, p. 62). Constricted locations with high current flow passing through them are considered pinch points.

The Circuitscape tools require a raster-based resistance surface with cell values indicative of the relative "cost" for a random walker to cross that cell. Typically, this is represented by a digital elevation model (DEM), where higher elevations represent higher costs for movement. The focal node input is typically associated with the core habitat patches which the animal is moving to and from.

When applying circuit theory to landscape connectivity, natural ecosystems and forest habitats were presumed to be “low-cost” areas for animals to traverse, whereas roads and developed areas are expensive to cross. This analysis replicated research performed by Fulton and Bush (2020) using the following resistance surfaces: Natural Ecosystems (forest and natural ecosystems resistance = 1 and all other land cover, including roads = 1000) and Forests (forest resistance = 1 and all other land cover, including roads = 1000). Cell size was 100 m x 100 m (1 ha). Since circuit flow was used to predict movement through suitable habitat patches, focal nodes were created using a wall-to-wall analysis approach. This approach involved assessing the flow of movement from one side of a resistance surface tile to the other side of the tile wall (from source to ground). Tiles were 25 km x 25 km. This size was chosen based on previous methodology employed by Fulton & Bush (2020), and to allow the whole province to be processed efficiently, given varying computer processing power.

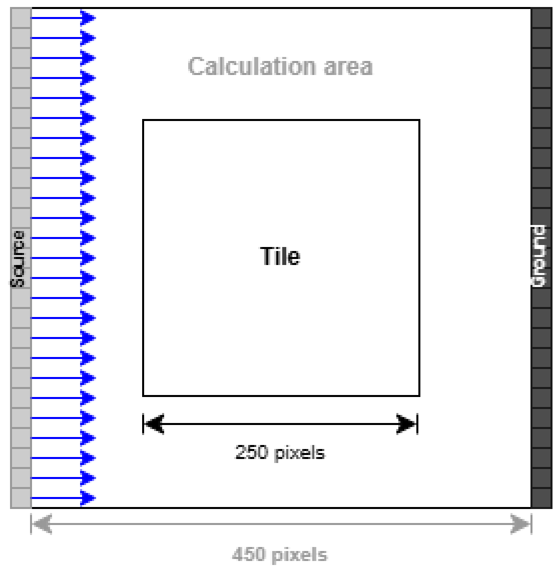


Figure 4. Wall-to-wall directional flow.

When animals move through their environment, they are unlikely to traverse only a single linear path from one cardinal direction to another. In order to approximate multidirectional flow, this study assessed the flow from horizontal nodes (East-West, then West-East) and vertical nodes (North-South and South-North) for each tile (Figure 4). To ensure that the edge of tiles did not influence current movement, a 10 km buffer was created around each target tile to create overlapping calculation areas. Buffers were then removed from each target tile, following wall-to-wall analysis (Fulton & Bush, 2020). The directional tiles (horizontal and vertical) were then combined to create omnidirectional connectivity mosaics.

Tiles were pre-processed using resistance surfaces created from previously identified landscape classifications in order to create appropriately sized tiles with buffers and focal node layers. Pre-processing was performed in ArcGIS Pro v. 3.3 and Python (arcpy package), and this version of the analysis was performed in Circuitscape 5, developed in Julia (Circuitscape, n.d.).

Results

Road Effect Zone

Using updated road data from 2024, a REZ raster was generated to visualize the proximity of 25 m^2 tiles of land to the road (figure 5). An analysis of these distances revealed that the maximum distance from the road in any part of the province is 6.243 km, and the median distance is 0.285 km.

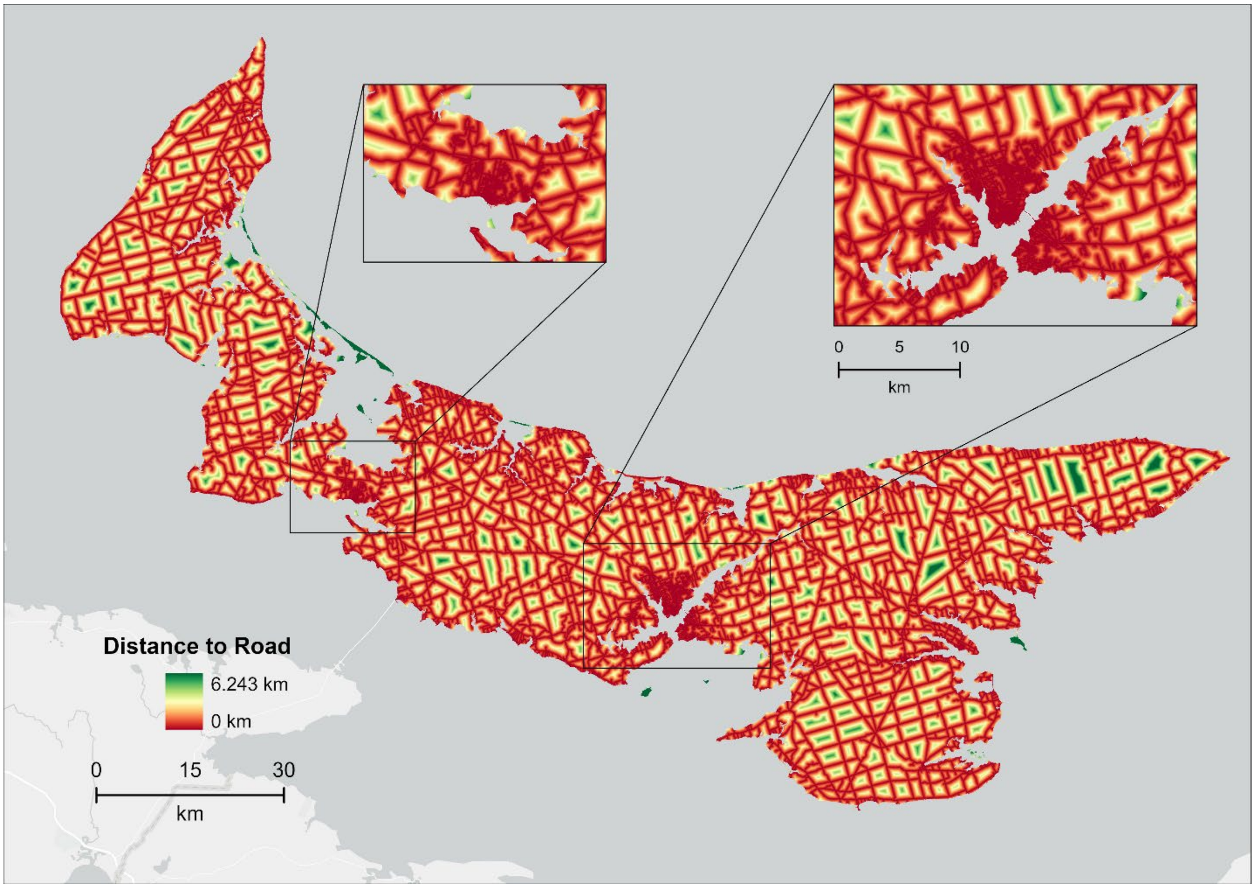


Figure 5. Distance to the road across Prince Edward Island based on a Distance Accumulation analysis.

Table 5 shows the percentage of the province within a series of distances (0.1 km – 6.3 km), and Figure 5 demonstrates landscape classifications (Tables 1-3) and the decreasing area of natural ecosystem, forest, and mature forest when a 300 m and 500 m REZ is applied. A REZ of 300 m and 500 m was selected because they represent approximately 50% and 75% of the provincial land area, respectively (Fulton & Bush, 2020).

Table 5. Percentage of the province within a specified distance from a road. Percentages were calculated using the Pairwise Buffer tool.

Distance (km)	Percentage of Province within Distance to Road
0.1	21.2%
0.3	51.1%
0.5	71.1%
0.8	88.4%
1.0	94.2%
3.0	99.8%
5.0	99.9%
6.3	100.0%

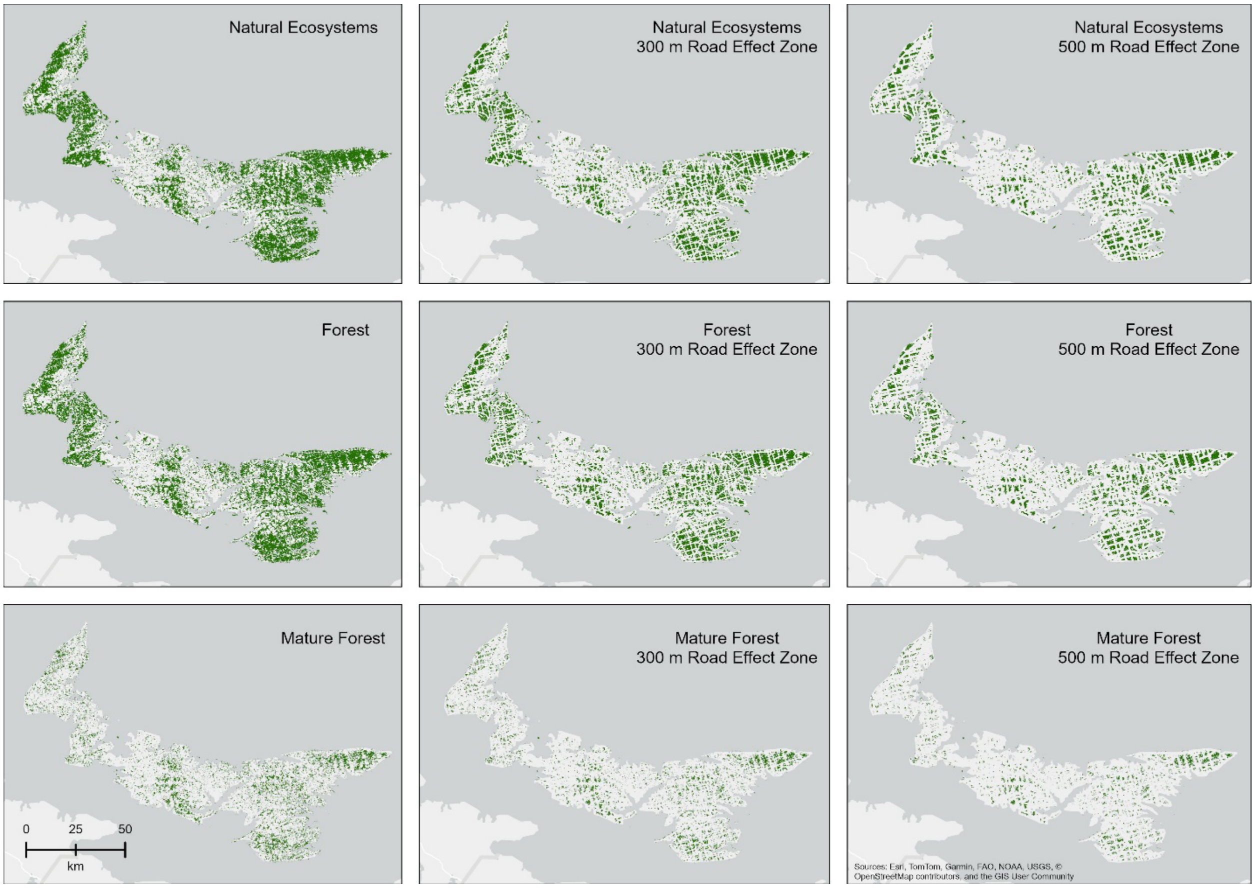


Figure 6. Landscape classifications for this analysis include Natural Ecosystems, Forest, and Mature Forest with a road effect zone (REZ) of 300 m and 500 m.

ProNet

The total amount of protected area calculated by the ProNet tool for Prince Edward Island was 1,729 patches, constituting 282.57 km^2. This represents **4.97%** of the total land area of the province. The ProNet metric was calculated using dispersal distances between 0.5 and 100 km, representing the threshold at which two patches in proximity are considered a cluster. At dispersal distances above 5 km, all patches in the province are considered one single cluster (Figure 7). Distinct clusters of protected areas in the province emerge at the 3 km threshold distance and above. Using a 4 km dispersal distance, most of the patches in eastern Prince Edward Island coalesce into a single cluster (Figure 8, cluster 18). Clusters are sparser across the central area of the province, with another major cluster (cluster 10) in the west.

Table 6. ProNet metric calculations for Prince Edward Island, using dispersal distances between 0.5 km and 100 km based on average dispersal distances for common species in the province.

Dispersal Distance (km)	No. of Clusters	ProNet
0.5	509	0.047
1	344	0.081
2	121	0.193

3	53	0.512
4	18	0.540
5	8	0.899
10	1	1
25	1	1
100	1	1

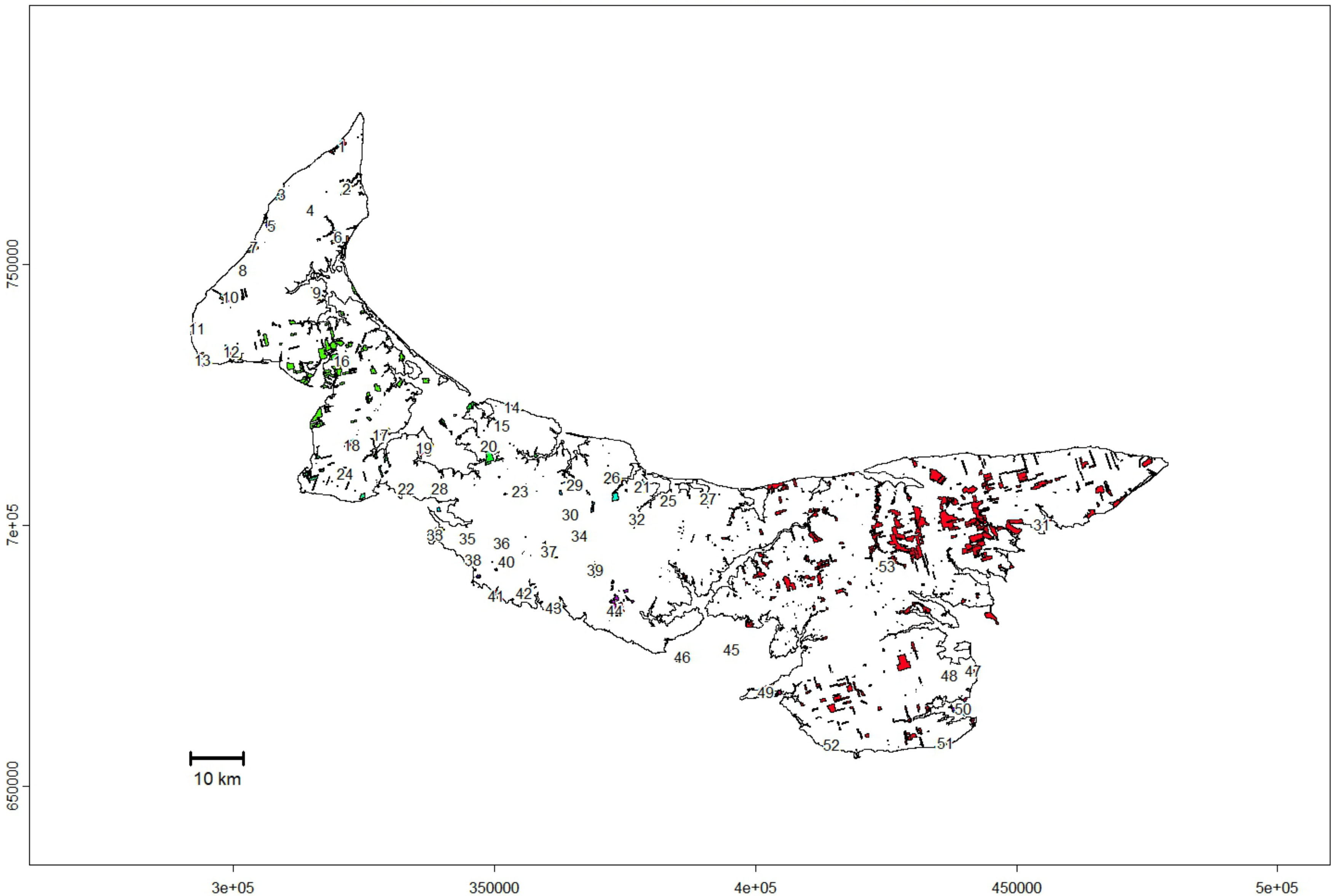


Figure 7. ProNet clusters for Prince Edward Island, using 3 km dispersal distance. 53 total clusters; each cluster is numbered.

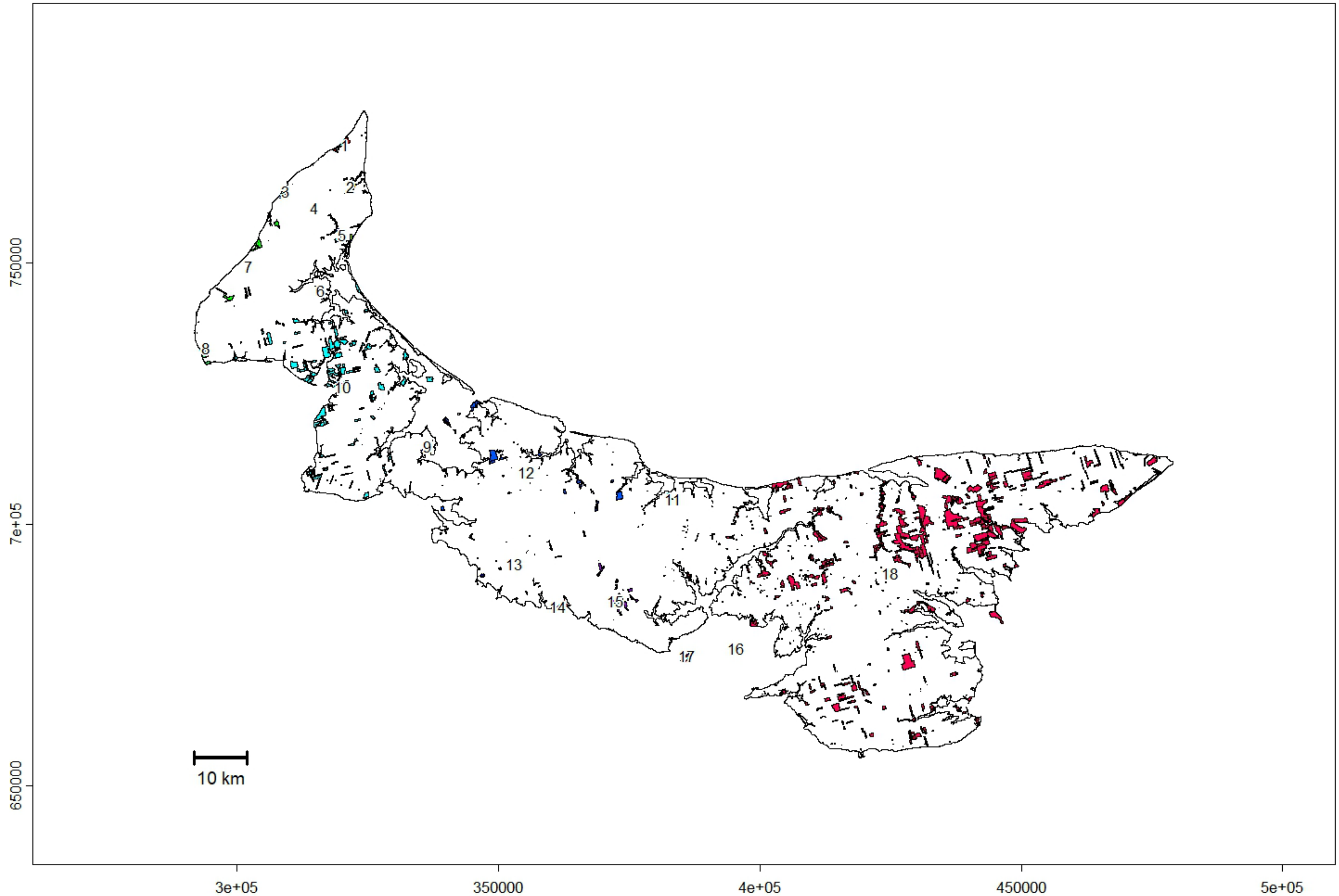


Figure 8. ProNet clusters for Prince Edward Island, using 4 km dispersal distance. 18 total clusters; each cluster is numbered.

Eastern and Western Region

The ProNet metric is useful for comparing connectivity values between different regions (Theobald et al., 2022). Since Prince Edward Island is not divided into distinct ecoregions, the province was divided into eastern and western regions using the centroid of the provincial boundaries (Figure 9). The ProNet metric was calculated at a limited series of dispersal distances (1, 2, and 5 km) for the eastern and western regions. These values can be compared to understand the differences in connectivity between both regions of the province.

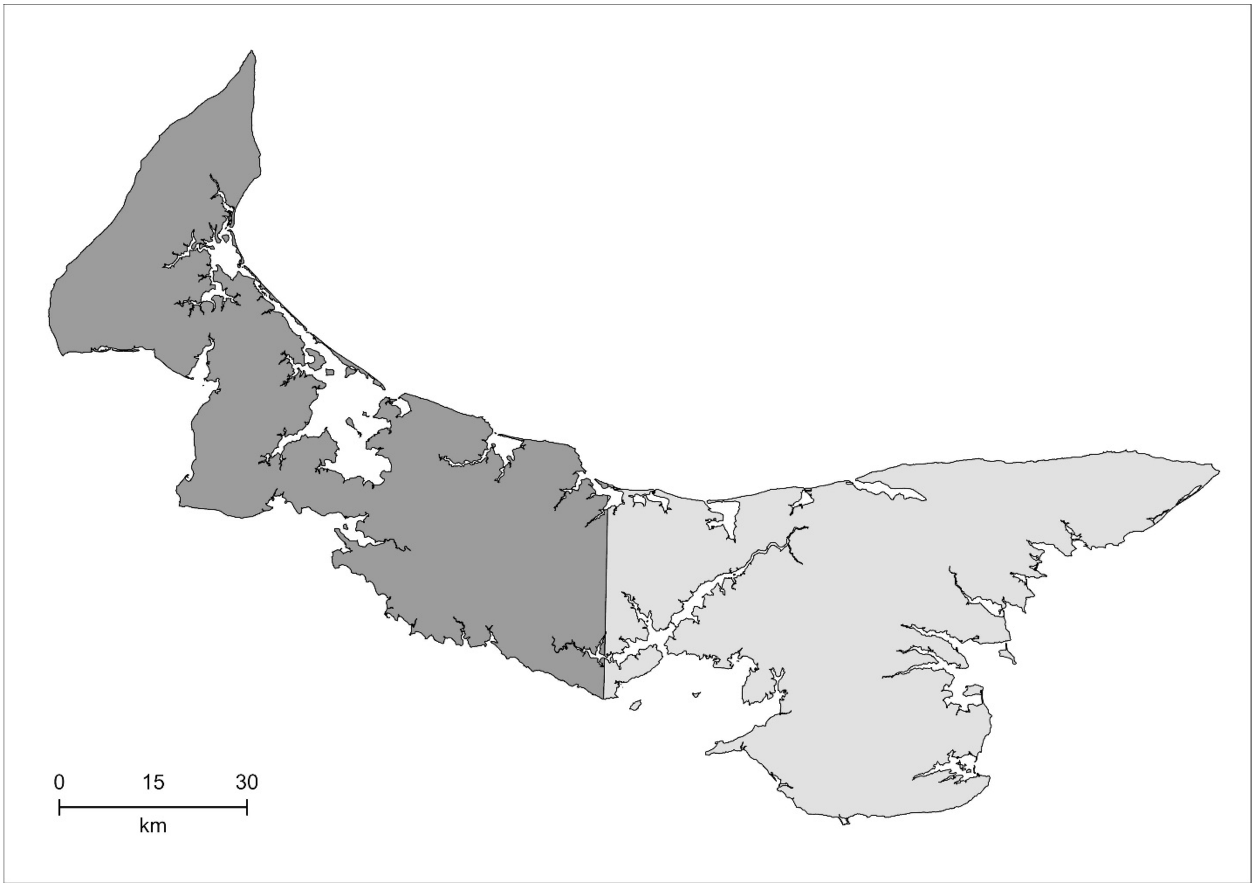


Figure 9. Division of Prince Edward Island into eastern and western ranges based on the calculated centroid of the provincial land area.

Eastern region

The total amount of protected area in the eastern region of Prince Edward Island calculated by the ProNet tool was 1,235 patches, constituting 201.25 km^2. This represents 6.96% of the total land area of the eastern part of the province. Similar to the provincial metrics, ProNet values for the eastern region steadily increased as dispersal distances increased (Table 7). Meaningful clusters start to emerge at 2 km (Figure 10), and the ProNet value reached nearly 1 at a dispersal distance of 5 km.

Western region

The total amount of protected area in the western region of Prince Edward Island calculated by the ProNet tool was 494 patches, constituting 81.32 km^2. This represents 2.90% of the total land area of the western part of the province. The western region of the province exhibited overall lower ProNet values, indicating less connectivity in this area (Table 7). Patches appear to be closer together, as more clusters are created at a dispersal distance of 2 km compared to the eastern region (Figure 11). Even at a dispersal distance of 5 km, connectivity is lower than both the eastern portion and the province in general.

Table 7. Comparison of ProNet metric calculations for the eastern and western regions of the province at a limited set of dispersal distances.

Dispersal Distance (km)	Eastern region		Western region	
	No. of Clusters	ProNet	No. of Clusters	ProNet
1	186	0.149	158	0.065
2	45	0.346	76	0.218
5	2	0.997	7	0.685

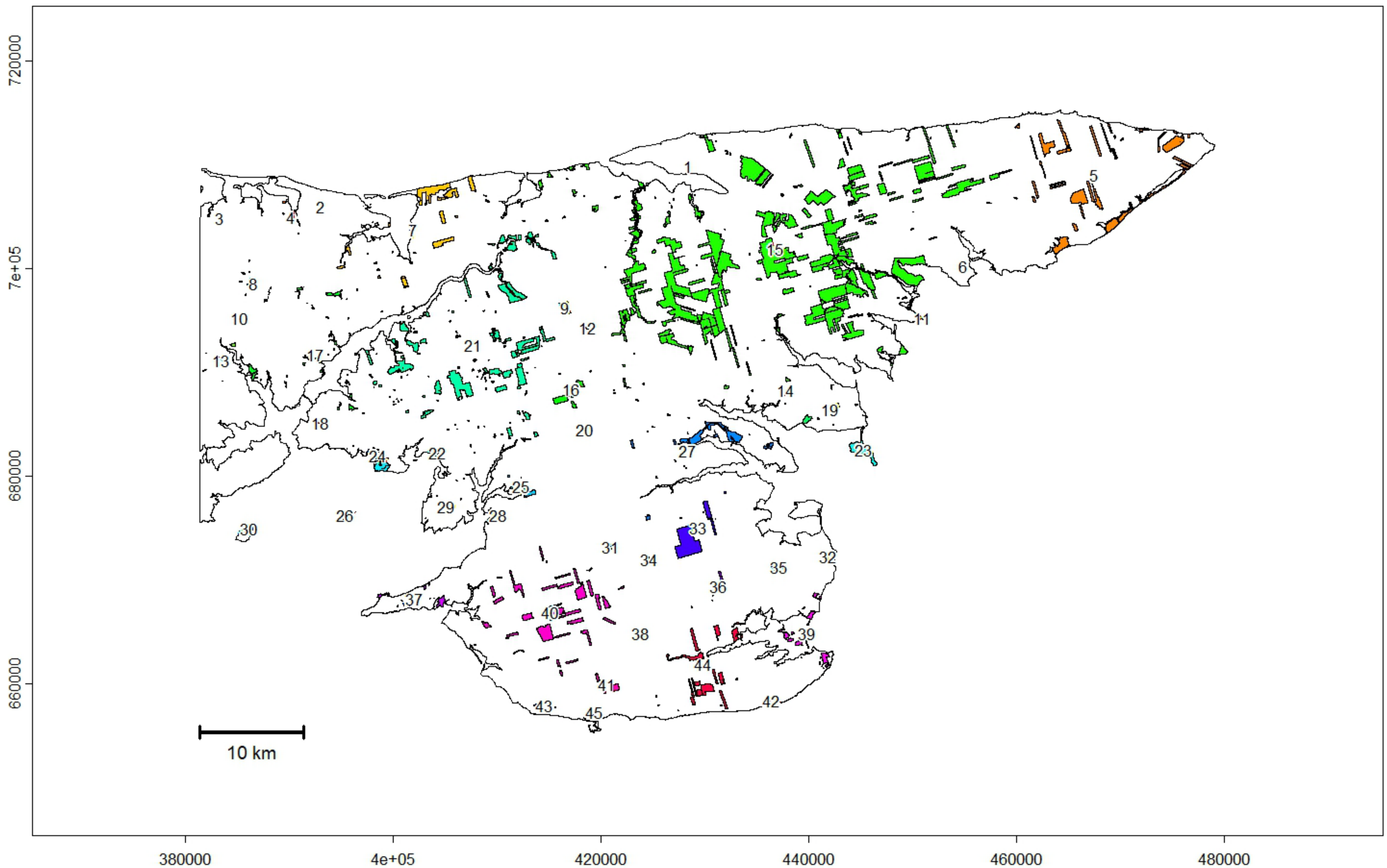


Figure 10. Eastern region protected area clusters, using a 2 km dispersal distance. 45 total clusters; each cluster is numbered

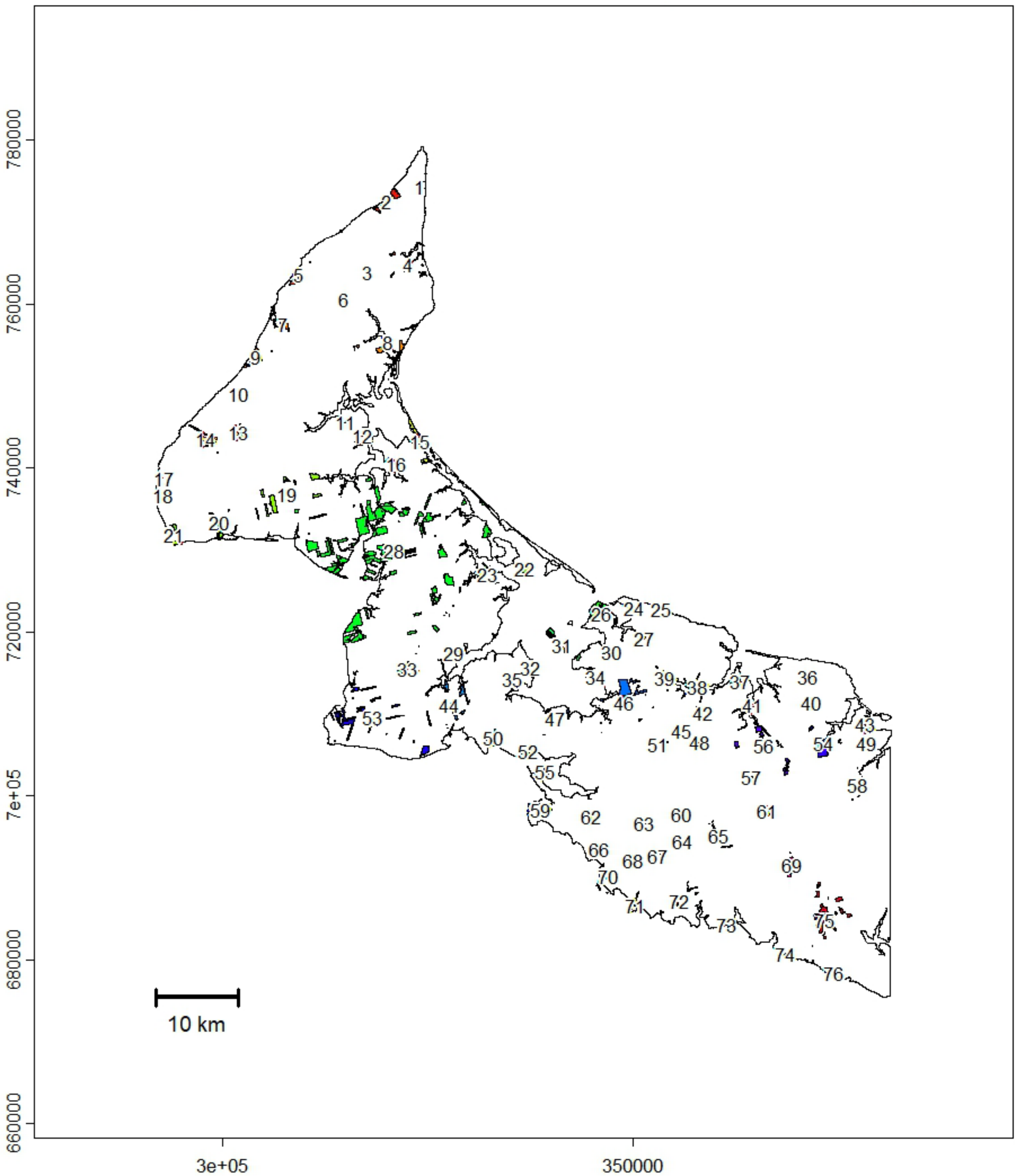


Figure 11. Western region protected area clusters, using a 2 km dispersal distance. 76 total clusters; each cluster is numbered

Regions Divided by Highways

Roads and other infrastructure projects are proven to have significant impacts on animal movement and behaviour (Benítez-López et al., 2020). Highways can be major barriers to terrestrial movement, so it is worthwhile to examine the connectivity of landscapes bounded by highways. To examine connectivity within highway-bounded areas, regions of Prince Edward Island were divided using major highways as boundaries, and ProNet metrics at a dispersal distance of 2 km were calculated for all regions.

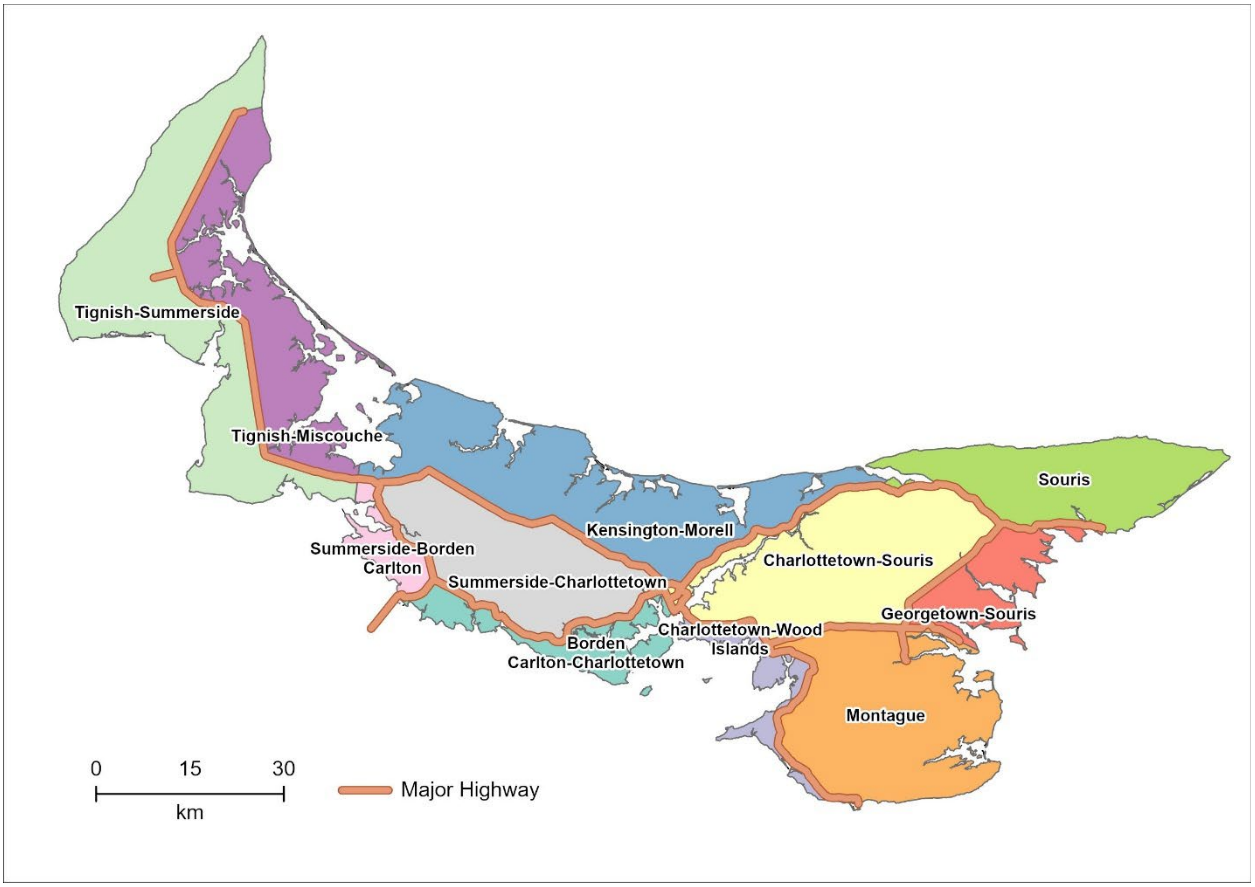


Figure 12. Regions in Prince Edward Island created by major highways. Highways can serve as major barriers to terrestrial movement for certain species.

Table 8. ProNet calculations for regions divided by major highways in Prince Edward Island. Dispersal distance of 2 km.

Region	Dispersal Distance (km)	No. of Protected Areas	No. of Clusters	ProNet	Protected Area (km^2)	Percentage of total area protected
Georgetown-Souris	**2**	**71**	**7**	**0.733**	**30.40**	**12.93%**
Souris	2	250	4	0.559	45.90	8.73%
Charlottetown-Souris	2	273	7	0.556	81.81	10.56%
Summerside-Charlottetown	**2**	**52**	**14**	**0.359**	**5.48**	**0.92%**
Tignish-Summerside	2	184	23	0.342	43.47	4.84%
Tignish-Miscouche	2	186	16	0.319	19.84	3.46%
Borden Carlton-Charlottetown	2	92	8	0.305	2.08	0.95%

Charlottetown-Wood Islands	2	60	11	0.304	2.92	2.11%
Montague	2	227	19	0.217	31.58	4.07%
Summerside-Borden Carlton	2	11	6	0.211	1.36	1.26%
Kensington-Morell	2	184	36	0.185	19.56	2.20%

The most connected region bounded by major highways in the province was **Georgetown-Souris** (Figure 14); the area also had the highest proportion of protected land compared to other regions. The **Georgetown-Souris, Souris** and **Charlottetown-Souris** regions, located in the eastern part of the province (Figure 13), also had the highest landscape connectivity (0.733, 0.559, and 0.556 respectively). On the contrary, Montague, Summerside-Borden Carlton, and Kensington-Morell regions had the lowest landscape connectivity (0.217, 0.211, 0.185 respectively). The median ProNet value for all eleven regions was 0.319.

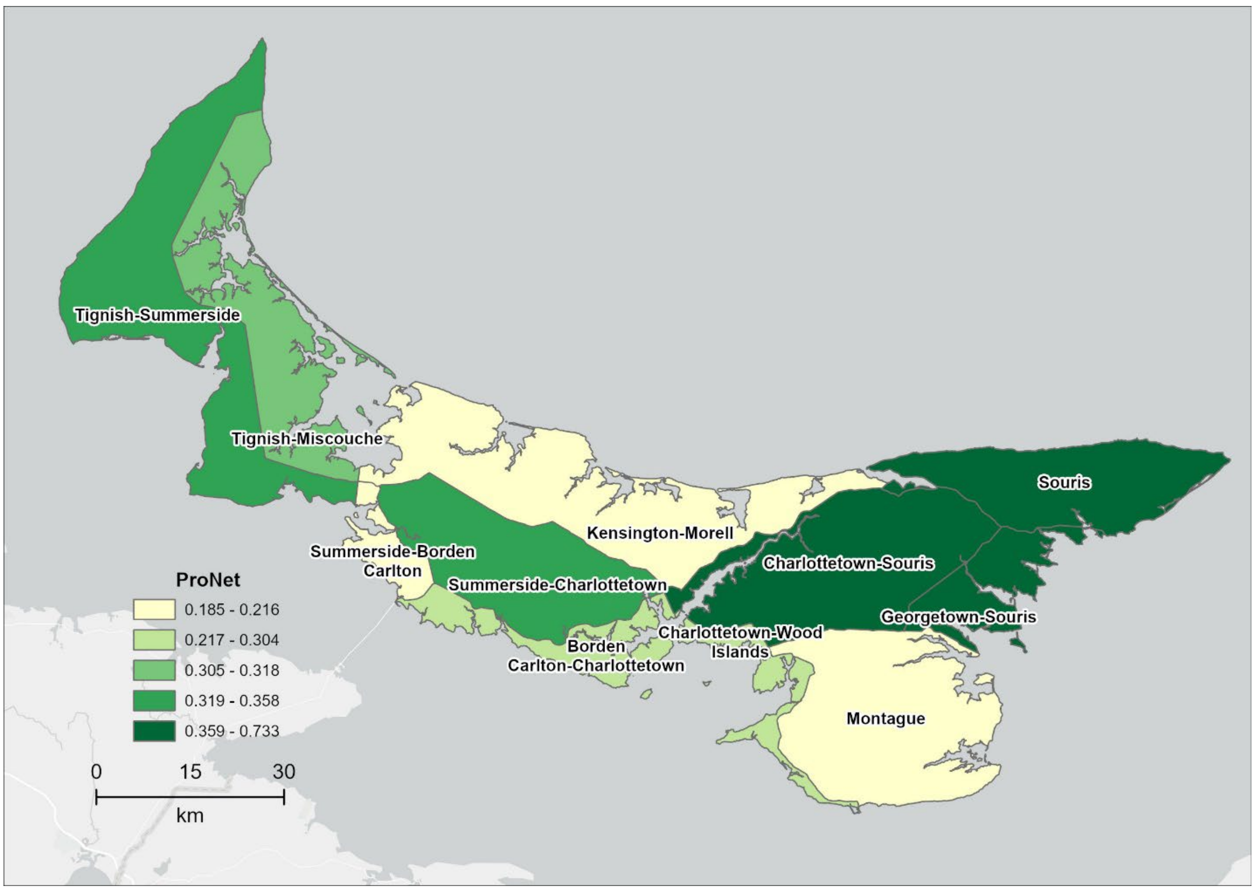


Figure 13. Distribution of ProNet values for regions divided by major highways in Prince Edward Island.

Georgetown-Souris

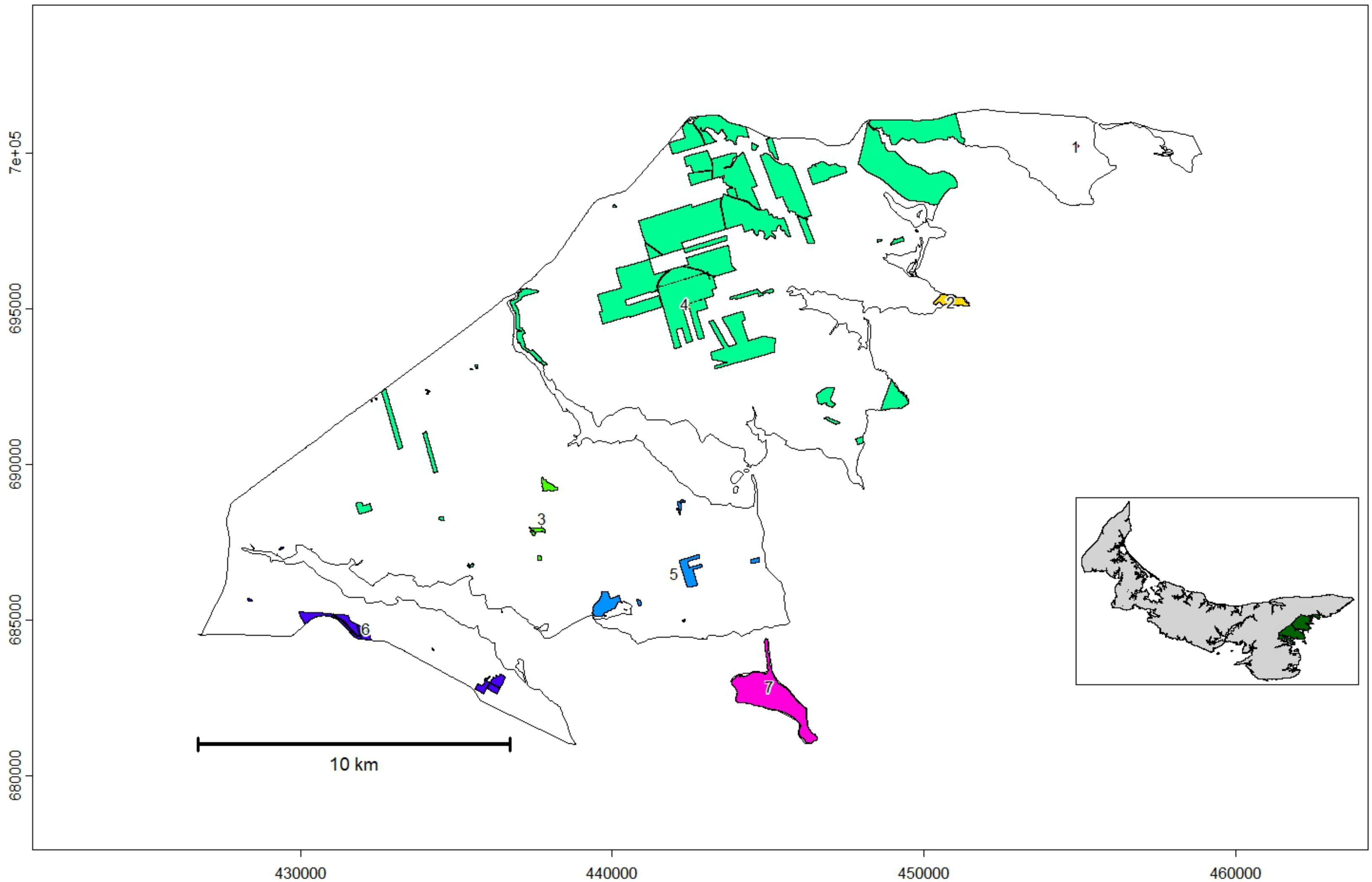
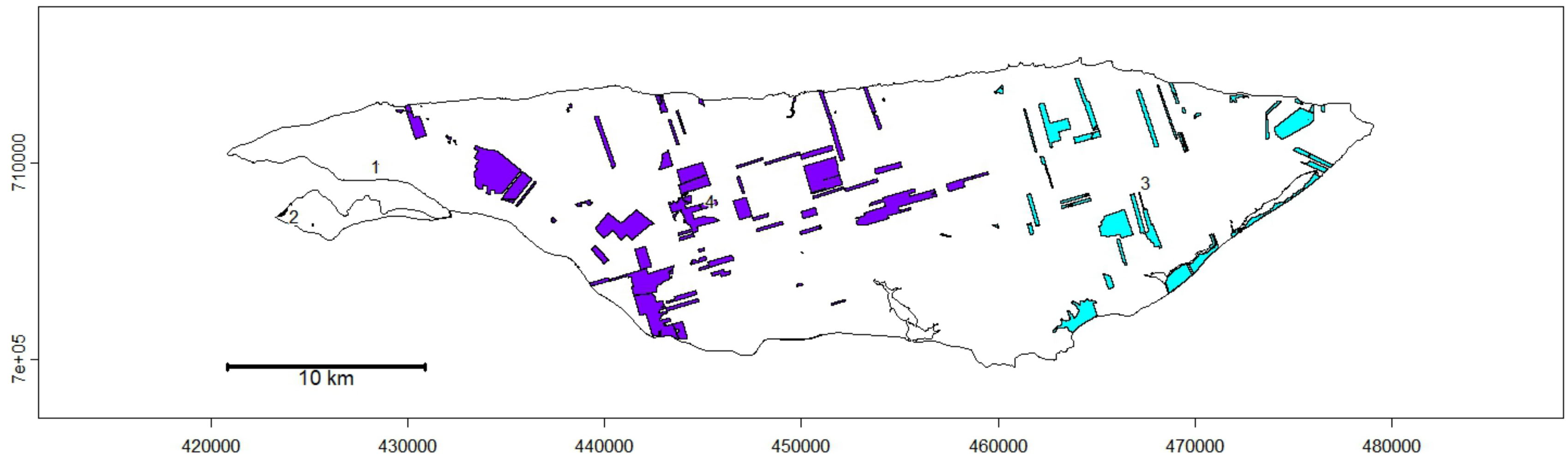


Figure 14. ProNet clusters for Georgetown-Souris region. Dispersal distance of 2 km.

Souris



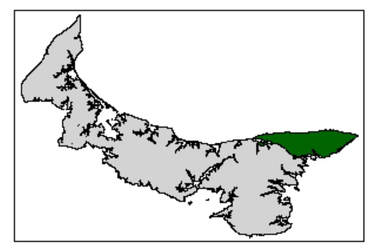


Figure 15. ProNet clusters for Souris region. Dispersal distance of 2 km.

Additional Protected Areas

Previous calculations of ProNet (both for the whole province and for specific regions) have been completed using the existing protected area network for Prince Edward Island (Figure 16). However, one of the benefits of using a metric like ProNet to measure connectivity is that it can be compared between existing and future protected areas networks to determine how the addition of a protected area (patch) could potentially increase the connectivity of the network.

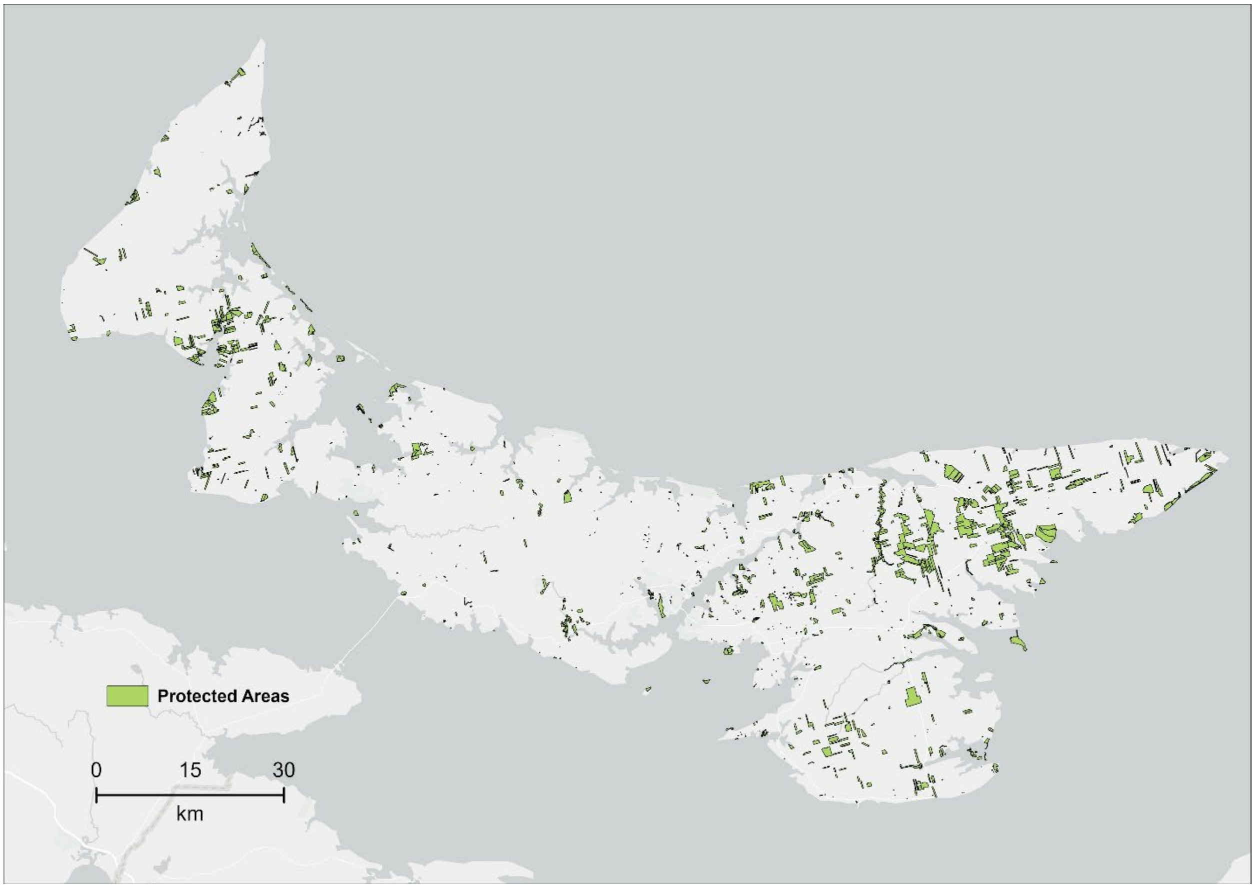


Figure 16. Existing protected areas network in Prince Edward Island. Data from Canadian Protected and Conserved Areas Database.

To demonstrate the use of these metrics for this case, nine theoretical additional protected areas between 550 and 600 ha (0.1% of total provincial area – approximately 570,000 ha) were selected from the 2020 PEI Corporate Land Use Inventory to represent hypothetical additional protected areas added to the province's protected areas network. These land parcels met the criteria for "natural ecosystems" (Table 1), ensuring that hypothetical areas were not agricultural or urban land. Land parcels that overlapped with existing protected areas were also not selected. Land parcels were selected manually in ArcGIS Pro based on the described criteria. Figure 17 shows the resulting nine theoretical additions to the protected area network.

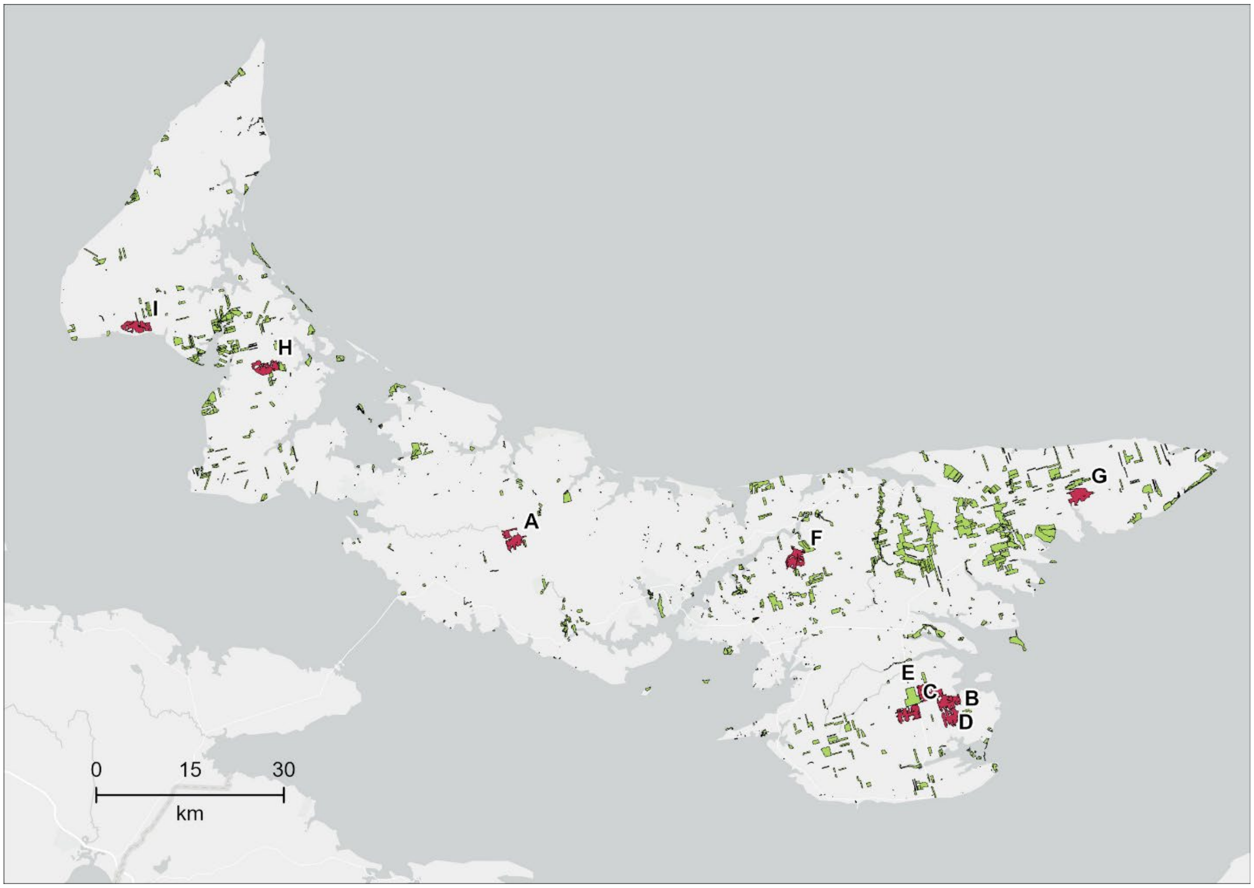


Figure 17. Existing and hypothetical protected areas network in Prince Edward Island. Existing data from Canadian Protected and Conserved Areas Database; hypothetical areas are used as proof-of-concept.

To quantify the impact of potential additions to the protected area network, ProNet values (with a dispersal distance of 2 km) were calculated for the province with the sequential addition of each proposed protected area. Each protected area was added to the protected area network layer one at a time (then altogether – see line 10, Table 9), and the updated layer was used as input for the ProNet tool. These values can be compared to the ProNet value (d = 2 km) for the current protected areas network (0.193), as shown in Table 6.

Table 9. ProNet calculations for Prince Edward Island with the addition of each protected area to the existing protected area network. These values represent the addition of a single protected area to the network, not any combination of selected areas. Dispersal distance of 2 km.

Hypothetical area (see Figure 17)	No. of Protected Areas	No. of Clusters	ProNet	Hypothetical Protected Area (km^2)	Protected Area Total (km^2)	Percentage of total province protected
A	1731	120	0.186	5.59	288.16	5.06%
B	1730	120	0.186	5.64	288.21	5.07%
C	1730	119	0.187	5.88	288.45	5.07%
D	1731	119	0.187	5.78	288.35	5.07%
E	1734	121	0.187	5.60	288.17	5.06%
F	1742	121	0.189	5.92	288.49	5.07%

G	**1731**	**121**	**0.202**	**6.00**	**288.56**	**5.07%**
H	1732	121	0.191	5.76	288.33	5.07%
I	1734	120	0.187	5.78	288.35	5.07%
ALL AREAS	1763	116	0.166	51.95	334.50	5.87%

Interestingly, adding a new hypothetical protected area to the network often caused the ProNet value to decrease below the current network value for a dispersal distance of 2 km (0.193), previously calculated. This is the case even when the metric is calculated with all hypothetical protected areas added at once (line 10, Table 9). Only the addition of proposed area **G** led to an increase in the overall ProNet value. Theobald et al. (2022) suggest that this decrease is due to the fact that while adding patches to the protected network increases the overall amount of protected area, adding more elements that are isolated from one another (i.e., proposed areas that do not overlap with the existing protected network) causes the ProNet value to decrease. As such, the proximity of the hypothetical area to existing protected areas likely has an impact on whether the overall ProNet metric will increase, and potential additions to the network should be considered in the context of their connection to other protected areas. This is where pinch point analysis from Circuitscape can prove useful for protected area selection.

ProtConn

The full suite of ProtConn indicators was calculated for the province of Prince Edward Island using the same set of dispersal distances applied to ProNet calculations. For the eastern and western regions of the province, and for the regions created by major highways, a truncated set of indicators (Prot, ProtConn, ProtUnconn, RelConn) was calculated for ease of comparison.

Table 10. ProtConn indicators for Prince Edward Island using dispersal distances between 0.5 km and 100 km.

ProtConn Indicator	**Description** (Saura et al., 2017)	**Dispersal distance (km)**								
		0.5	**1**	**2**	**3**	**4**	**5**	**10**	**25**	**100**
Prot	Percentage of the study region covered by protected areas (PA)	4.95	4.95	4.95	4.95	4.95	4.95	4.95	4.95	4.95
Unprotected	Percentage of the study region not covered by PAs.	95.05	95.05	95.05	95.05	95.05	95.05	95.05	95.05	95.05
ProtConn	Percentage of the study **region covered by connected protected lands**.	0.44	0.52	0.74	0.95	1.13	1.30	1.92	2.85	4.10
ProtUnconn	Percentage of the **study region covered by protected lands that are isolated**. Calculated as the difference between Prot and ProtConn.	4.51	4.43	4.21	4.00	3.81	3.65	3.03	2.10	0.85
RelConn	**Percentage of the protected lands within the study region that are connected**. It is calculated as the ratio between ProtConn and the PA coverage (Prot), multiplied by 100.	8.84	10.53	14.89	19.12	22.92	26.30	38.82	57.52	82.76
ProtConn_Prot	**Percentage of the Protected Connected land (ProtConn) that can be reached by moving only through protected lands, without traversing unprotected lands**. This indicator can be partitioned in two subindicators, ProtConn[Prot] = ProtConn[Within] + ProtConn[Contig], which are described next.	94.02	78.94	55.80	43.46	36.26	31.59	21.40	14.45	10.04
ProtConn_Trans	Percentage of the Protected Connected land within the study region (ProtConn) that can be reached by moving through PAs located outside the region boundaries. It includes the effect of both transboundary PAs in the strict sense (i.e. individual PAs that extend across region boundaries) as well as of other PAs that, located outside the region, promote the connectivity	0	0	0	0	0	0	0	0	0

	between PAs within the region by acting as stepping stones between them.									
ProtConn_Unprot	**Percentage of the Protected Connected land (ProtConn) that can be reached by moving through unprotected areas**. It includes movements between PAs that entirely happen through unprotected lands and others that traverse unprotected lands in the initial and final stretches but that may use some protected land in between. The value of this fraction will be lower when PAs are separated by larger tracts of unprotected lands, making inter-PA movements less likely, particularly when the distances that need to be traversed through unprotected lands are large compared to the species dispersal distance.	5.98	21.06	44.20	56.54	63.74	68.41	78.60	85.55	89.96
ProtConn_Within	**Percentage of the Protected Connected land (ProtConn) that can be reached by moving only within individual PAs**, i.e. how much land can be accessed by species if they move only within the limits of individual PAs.	70.22	58.96	41.67	32.46	27.08	23.59	15.98	10.79	7.50
ProtConn_Contig	**Percentage of the Protected Connected land (ProtConn) that can be reached by moving through sets of immediately adjacent (contiguous) PAs**, without traversing any unprotected lands. This percentage excludes the protected land that can be reached by moving within a single PA, which is given by ProtConn[Within].	29.78	41.04	58.33	67.54	72.92	76.41	84.02	89.21	92.50

ProtConn indicators estimated that 4.95% of the total provincial area was covered by protected areas, a slightly lower estimate than the protected area coverage determined by ProNet (4.97%). As the dispersal distance increased, the percentage of the total provincial area covered by connected protected lands (ProtConn) increased to a maximum of 4.10% for a dispersal distance of 100 km. This appears to be approaching the maximum coverage of protected connected land, since 82.76% of all protected areas are considered "connected" at this distance. At lower dispersal distances (1, 2, and 5 km), the percentage of protected areas considered "connected" is much lower (between 10.53% and 26.30%). The associated ProtConn values are correspondingly lower at these distances.

Eastern and Western Region

For the eastern and western regions of the province, a truncated set of indicators (Prot, ProtConn, ProtUnconn, RelConn) was calculated for ease of comparison.

ProtConn indicators estimated that 6.94% of the eastern region of the province and 2.89% of the western region of the province were covered by protected areas (compared to an estimate of 6.96% and 2.90% respectively by ProNet tools).

Table 11. Comparison of the truncated list of ProtConn indicators for the eastern and western regions of the province at a limited set of dispersal distances.

Dispersal Distance (km)	Eastern region			Western region		
	ProtConn	ProtUnconn	RelConn	ProtConn	ProtUnconn	RelConn
1	0.943	5.998	13.581	0.417	2.476	14.411
2	1.333	5.608	19.207	0.591	2.302	20.417
5	2.368	4.573	34.119	1.004	1.888	34.727

Similar to the ProNet metrics, ProtConn metrics suggest that the eastern region of the province is overall more connected, and that connectivity metrics increase for both regions as dispersal distance is increased. Notably, however, RelConn (percentage of the protected lands within the study region that are connected) is almost exactly the same for the eastern and western regions of the province, indicating that the ratio of connected protected land to total protected land is similar in both regions. As such, the differences in ProtConn values may be due to the varying areas of the eastern and western regions (the eastern region is slightly larger than the western region).

Regions Divided by Highways

Prot, ProtConn, ProtUnconn, and RelConn were calculated at a dispersal distance of 2 km for the same highway-divided regions used to compare ProNet metrics.

Table 12. ProtConn metrics for regions divided by major highways in Prince Edward Island with a dispersal distance of 2 km.

Region	Prot	ProtConn	ProtUnconn	RelConn
Georgetown-Souris	**12.888**	**6.241**	**6.647**	**48.423**
Souris	8.708	2.735	5.973	31.409
Charlottetown-Souris	10.549	3.539	7.010	33.549
Summerside-Charlottetown	**0.917**	**0.464**	**0.453**	**50.615**
Tignish-Summerside	4.829	1.425	3.404	29.509
Tignish-Miscouche	3.421	1.059	2.362	30.950

Borden Carlton-Charlottetown	0.938	0.438	0.500	46.746
Charlottetown-Wood Islands	1.833	1.043	0.789	56.925
Montague	4.002	1.272	2.730	31.788
Summerside-Borden Carlton	1.253	0.650	0.604	51.848
Kensington-Morell	2.191	0.700	1.491	31.945

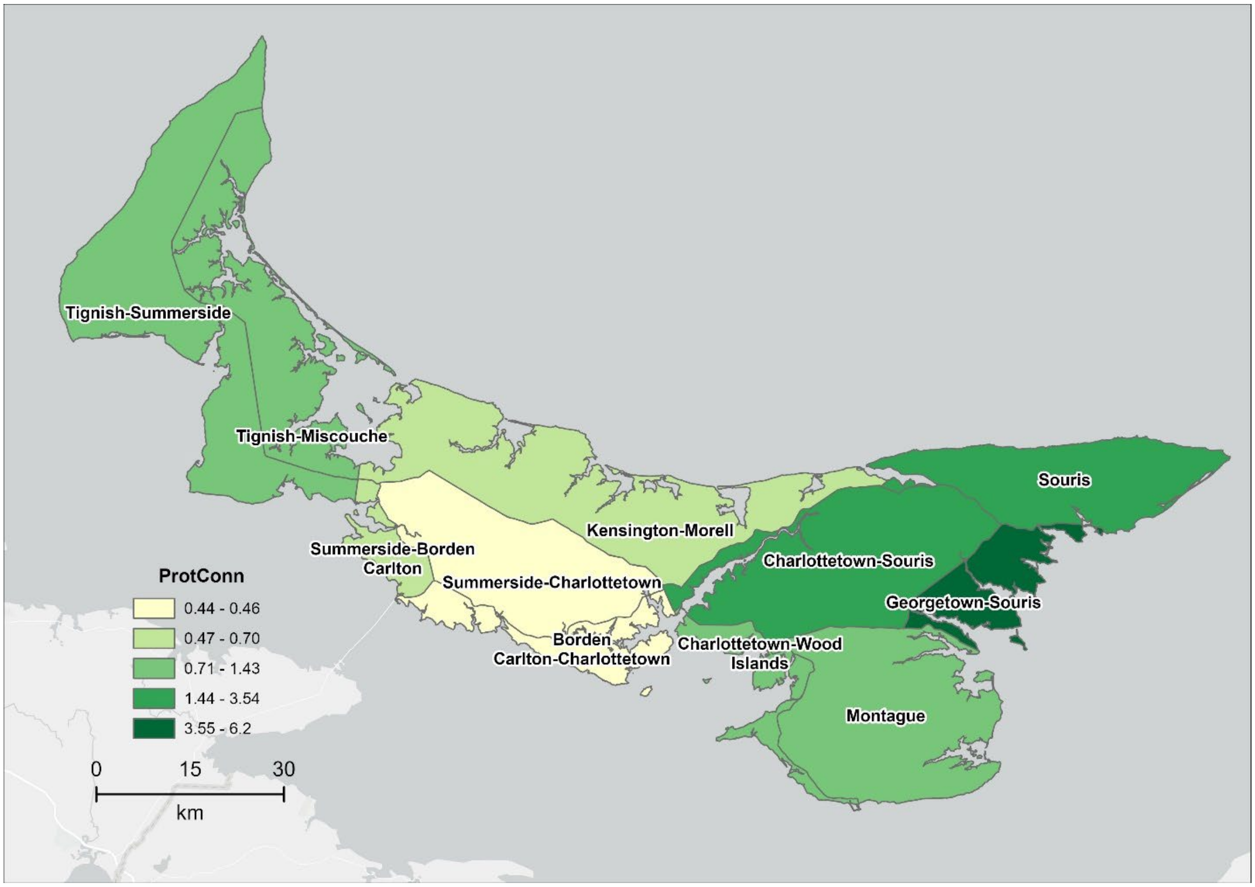


Figure 18. Distribution of ProtConn values for regions divided by major highways in Prince Edward Island.

Similar to values produced by ProNet analysis, the Georgetown-Souris, Charlottetown-Souris, and Souris regions had the highest ProtConn values, suggesting overall high connectivity in those three regions, while Summerside-Borden Carlton, Kensington-Morell, and Borden Carlton-Charlottetown had the lowest connectivity in the province.

Additional Protected Areas

The addition of each hypothetical protected area naturally led to an increase in the percentage of protected land across the landscape (from the existing network baseline of 4.95% at a dispersal distance of 2 km). Hypothetical additions led to small increases (between 0.04 and 0.14, from 0.74% for the existing network) in the ProtConn value, indicating that the proportion of protected connected land across the land area increased overall. Adding all the hypothetical protected areas to the network at once led to the greatest increase in the ProtConn value (line 10, Table 13).

Table 13. ProtConn calculations for Prince Edward Island with the addition of each protected area to the existing protected area network. These values represent the addition of a single protected area to the network, not any combination of selected areas. Dispersal distance of 2 km.

Hypothetical area (see Figure 17)	Prot	ProtConn	ProtUnconn	RelConn
A	5.047	0.744	4.302	14.749
B	5.048	0.747	4.301	14.789
C	5.052	0.751	4.301	14.865
D	5.050	0.747	4.303	14.795
E	5.047	0.752	4.295	14.902
F	**5.053**	**0.754**	**4.299**	**14.916**
G	5.054	0.753	4.301	14.890
H	5.050	0.751	4.299	14.872
I	5.050	0.747	4.303	14.792
ALL AREAS	5.8614	0.863	4.998	14.728

However, it is notable that the addition of these hypothetical protected areas also led to an increase in the ProtUnconn value, or the percentage of the study region covered by protected lands that are isolated (4.21% for the existing network). This indicates that these hypothetical protected areas are introducing more patches that are isolated from the rest of the network, rather than patches that bridge between other areas and increase connectivity. This is also reflected in RelConn values (percentage of the protected lands that are connected). The RelConn value for the existing protected area network is 14.89%; in all but two cases (areas E and F), the addition of the hypothetical protected areas led to a decrease in the RelConn value, indicating an overall decrease in connectivity throughout the protected area network.

These findings are consistent with conclusions drawn from the associated ProNet values; however, the calculation of additional metrics (ProtUnconn, RelConn) makes it easier to understand the changes occurring as a result of the hypothetical additions.

Like ProNet, the results underscore the need for potential new protected areas to be considered in relation to the rest of the network.

Circuitscape

Circuitscape analysis was applied to different resistance landscape classifications (natural ecosystems and forests). Fulton & Bush (2020) applied Circuitscape tools to natural ecosystems and forests, as well as both landscape classifications with an inbuilt road effect zone of 300 m. However, they noted that resistance layers with included REZs were difficult to interpret, as the ubiquitous presence of roads across the province created a silo effect wherein circuit flow was unlikely to cross roads. Circuitscape analysis using 300 m REZs for natural ecosystems and forests was performed in this study, and confirmed the findings outlined in Fulton & Bush (2020). As such, REZ layers are excluded from this analysis. The resulting maps illustrate current flow across natural ecosystem and forest landscape classifications.

Overall, updated Circuitscape analysis utilizing Corporate Land Use Inventory data from 2020 produced similar current flow maps to previous analyses completed with 2010 data (Fulton & Bush, 2020). Specific changes between 2010 and 2020 are detailed in the Discussion section of the report.

Natural Ecosystems

Natural ecosystems landscape classifications assign equally low resistance for wetlands and all types of forests, with barriers for roads, developments, non-natural land cover, and natural water bodies (Fulton & Bush, 2020). Circuitscape analysis revealed possible pinch points in the eastern, central, and northwestern portions of the province (highlighted in greater detail in Figure 19). The western region of the province appears to have more pinch points overall, suggesting it may be more difficult for animals to move throughout that region compared to the eastern region of the province.

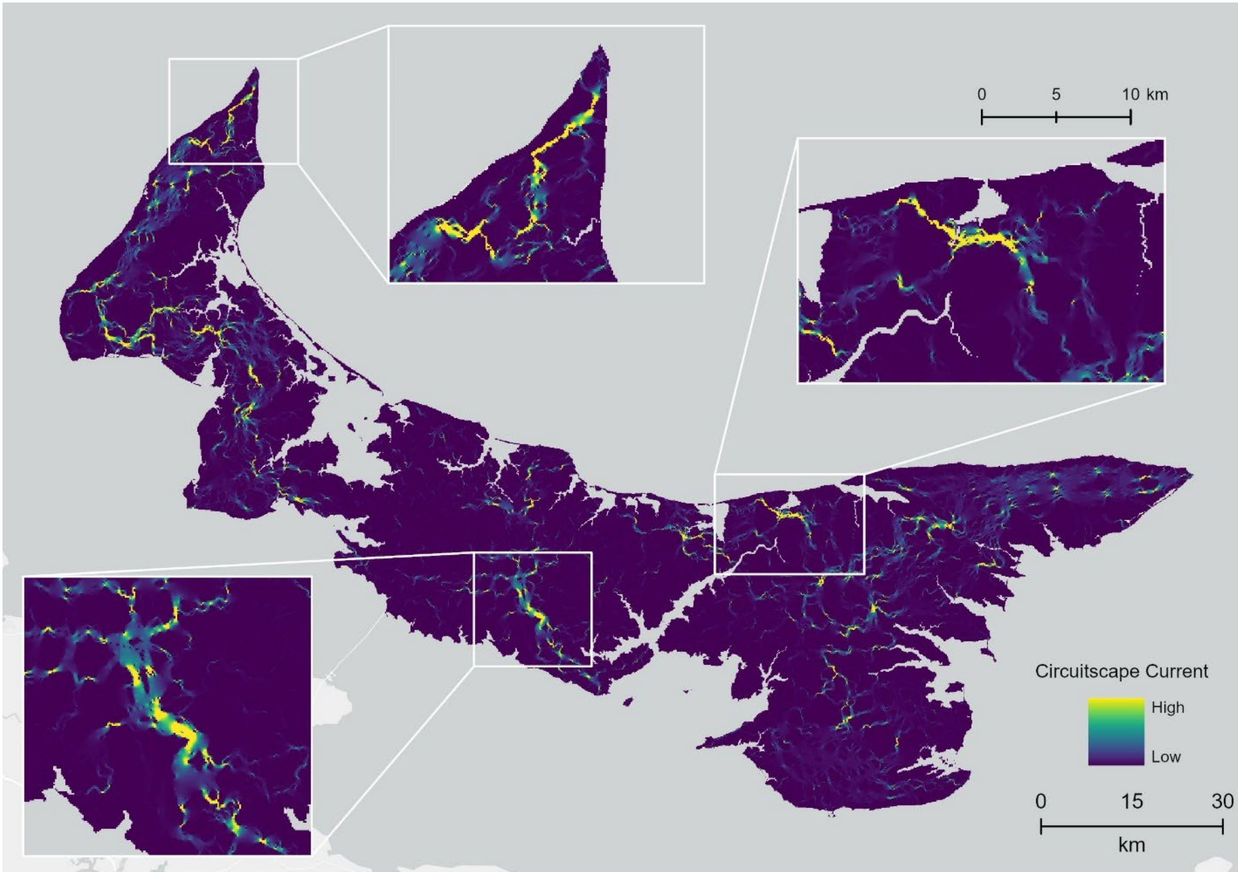


Figure 19. Circuitscape current map for natural ecosystems in 2020.

Forests

Forested landscape classifications assign low resistance only to forests. Analysis of the forested landscape revealed similar potential pinch points in the central and northwestern portions of the province; however, it also showed more pronounced pinch points farther east in the province, highlighted in Figure 20.

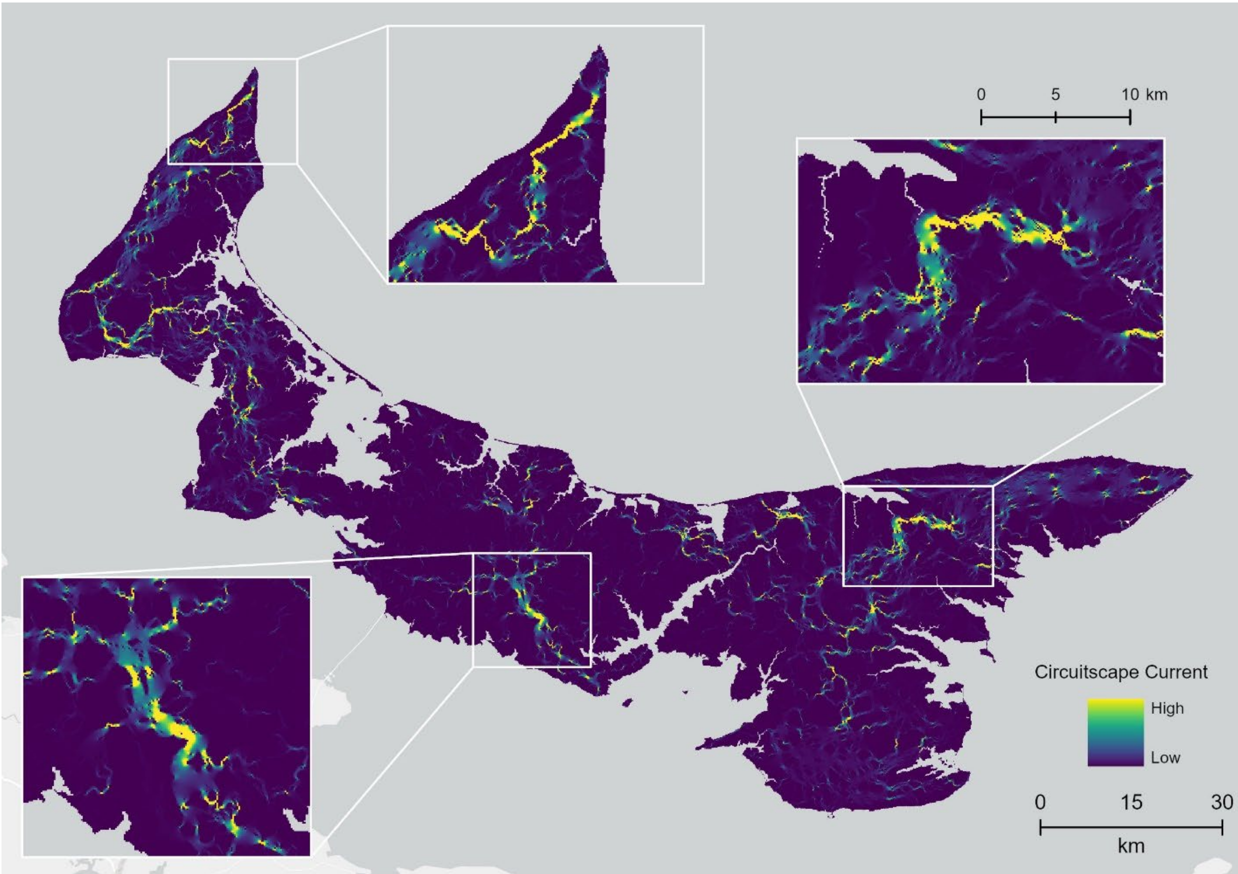


Figure 20. Circuitscape current map for forest ecosystems in 2020.

Pinch points

The Circuitscape analysis highlighted constricted areas with high current flow passing through them, also known as pinch points. These areas (highlighted in yellow in the maps above) are important to recognize, as they may represent important areas for conservation aimed at maintaining connectivity throughout the landscape.

To highlight these pinch points so that they are actionable for land managers, the current maps presented above were segmented into 4 classes using the Geometric Interval algorithm in ArcGIS Pro. This algorithm is designed to highlight uniquely high values in datasets with skewed data and repeated values (as is the case in this dataset). The top two sets of classes in this dataset (class 4, and classes 3 and 4) were highlighted and vectorized (i.e. reclassified and transformed into vector format) to provide actionable pinch point land parcels that can support decision-making and inform conservation strategies (see Appendix). Pinch points were filtered to display only those greater than 1 hectare.

Discussion

Road Effect Zone

The maximum distance from the road in any part of the province is 6.243 km, and the median distance is 0.285 km. This represents a decrease in the maximum and median distance from the road compared to 2019 values of 6.289 km and 0.328 km, respectively. This indicates that overall, land is closer to roads in 2024 than it was in 2019. Land in Prince Edward Island is significantly closer to roads than in Nova Scotia, where the maximum distance from roads is 25.6 km, and the mean distance is 1.8 km (Cunningham, 2020).

The persistence of species in habitats that are increasingly encroached upon by roads suggests that wildlife in the province has adapted to living within these distances from roads. However, habitat conditions may be deteriorating the closer they are to the road. Road effect zones can differ based on road type, and estimates of the average cumulative effects of roads range from 300 m from the road edge up to 5 km (Stewart & Neily, 2008; Benítez-López et al., 2010). As such, it is important to understand how much of the provincial land area lies within this range of distances from roads. The percentage of the province within 100 m of the road saw the largest increase between 2019 and 2024, a 1.1% increase from 20.1% to 21.2%, indicating that roads are generally encroaching further into the provincial landscape (Fulton & Bush, 2020). The percentage of the province within 5 km of a road has remained the same from 2019 to 2024, at 99.9%. Considering the maximum REZ for mammals determined by Benítez-López et al. (2010), 5 km, virtually all mammals on the island will have their habitats impacted by road effects to some degree.

Table 14. Percentage of the province within a specified distance from the road.

Distance (km)	Percentage of Province within Distance to Road (2019)*	Percentage of Province within Distance to Road (2024)
0.1	20.1%	21.2%
0.3	50.8%	51.1%
0.5	71.0%	71.1%
0.8	88.5%	88.4%
1.0	94.3%	94.2%
3.0	99.8%	99.8%
5.0	99.9%	99.9%
6.3	100.0%	100.0%

*Data published by Fulton & Bush (2020).

ProNet vs. ProtConn

In other jurisdictions, ProNet and ProtConn metrics have been calculated for the same protected areas to compare the relative values of the metrics and examine their strengths and weaknesses (Theobald et al., 2022). In this case, the two metrics can be compared at the provincial level (d = 0.5 – 100 km, Table 15), as well as for the eastern and western regions (d = 1, 2, 5 km, Table 16), and between regions divided by highways (d = 2 km, Table 17).

When directly comparing these two metrics, it is most prudent to compare the ProNet metric to the RelConn indicator produced by the ProtConn tools. This is because both the ProNet and RelConn metrics generally represent the portion of the total amount of protected area that is included in a cluster (i.e. protected connected land). Comparing these two metrics allows us to evaluate the effectiveness of ProNet and ProtConn while comparing indicators that represent the same measure of connectivity. ProNet is measured as a value between 0 and 1, while RelConn is given as a percentage between 0 and 100.

Province

Table 15. Comparison between ProNet and RelConn metrics for Prince Edward Island. Dispersal distances range 0.5 km - 100 km.

Dispersal Distance (km)	ProNet	RelConn
0.5	0.047	8.84
1	0.081	10.53
2	0.193	14.89
3	0.512	19.12
4	0.540	22.92
5	0.899	26.30
10	1	38.82
25	1	57.52
100	1	82.76

If RelConn values are normalized to values between 0 and 1, the two metrics can be graphically compared, as shown in Figure 21.

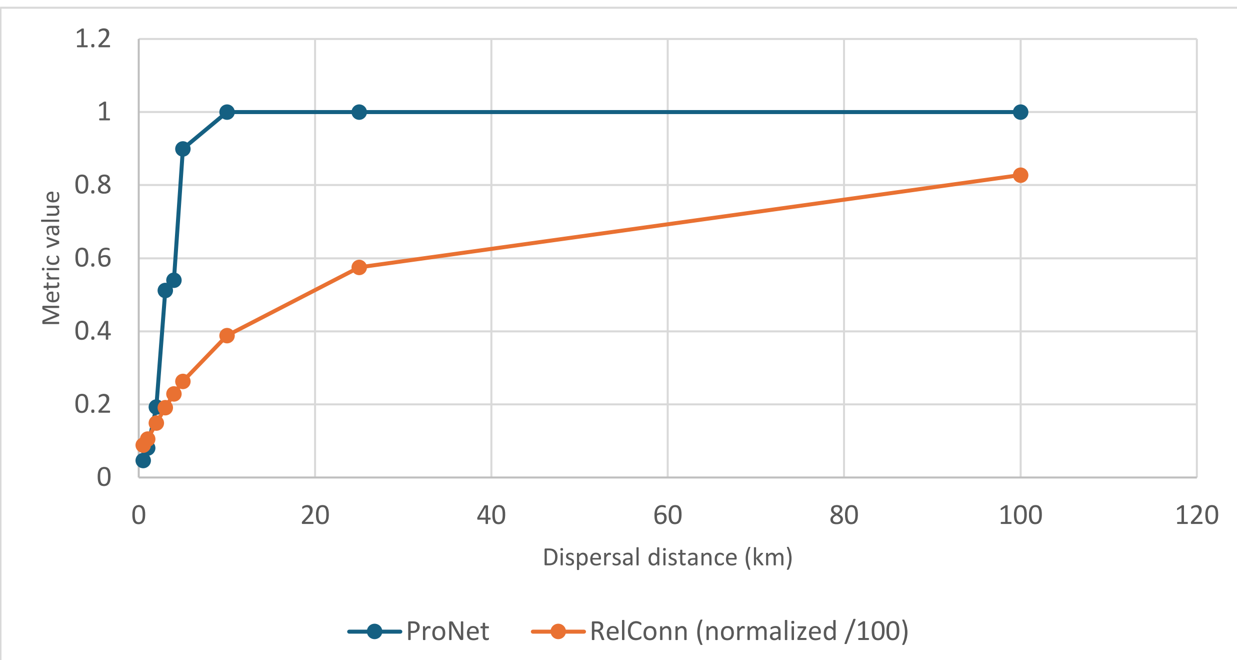


Figure 21. Graphical comparison between ProNet and RelConn metrics for Prince Edward Island. Dispersal distances range 0.5 km - 100 km.

Eastern and Western Region

Similar trends can be observed when comparing ProNet and RelConn indicators between the eastern and western regions of the province.

Table 16. Comparison between ProNet and RelConn metrics for eastern and western regions of Prince Edward Island. Dispersal distances range 1 km - 5 km.

Dispersal Distance (km)	Eastern region		Western region	
	ProNet	RelConn	ProNet	RelConn
1	0.149	13.581	0.065	14.411
2	0.346	19.207	0.218	20.417
5	0.997	34.119	0.685	34.727

Regions Divided by Highways

When comparing regions divided by highways, trends in ProNet and RelConn values were not always similar. This is demonstrated in Figure 22, where RelConn values are normalized to values between 0 and 1 (similar to Figure 21). This mostly occurred in regions along the coast with complex geographies that could naturally limit the movement of animals; as such, the differences in ProNet/RelConn values relative to one another are likely a result of differences in the algorithms used to determine clusters in both tools.

Table 17. Comparison between ProNet and RelConn metrics for regions divided by highways in Prince Edward Island. Dispersal distance of 2 km.

Region	ProNet	RelConn
Georgetown-Souris	0.733	48.42
Souris	0.559	31.41
Charlottetown-Souris	0.556	33.55
Summerside-Charlottetown	0.359	50.62
Tignish-Summerside	0.342	29.51
Tignish-Miscouche	0.319	30.95
Borden Carlton-Charlottetown	0.305	46.75
Charlottetown-Wood Islands	0.304	56.93
Montague	0.217	31.79
Summerside-Borden Carlton	0.211	51.85
Kensington-Morell	0.185	31.95

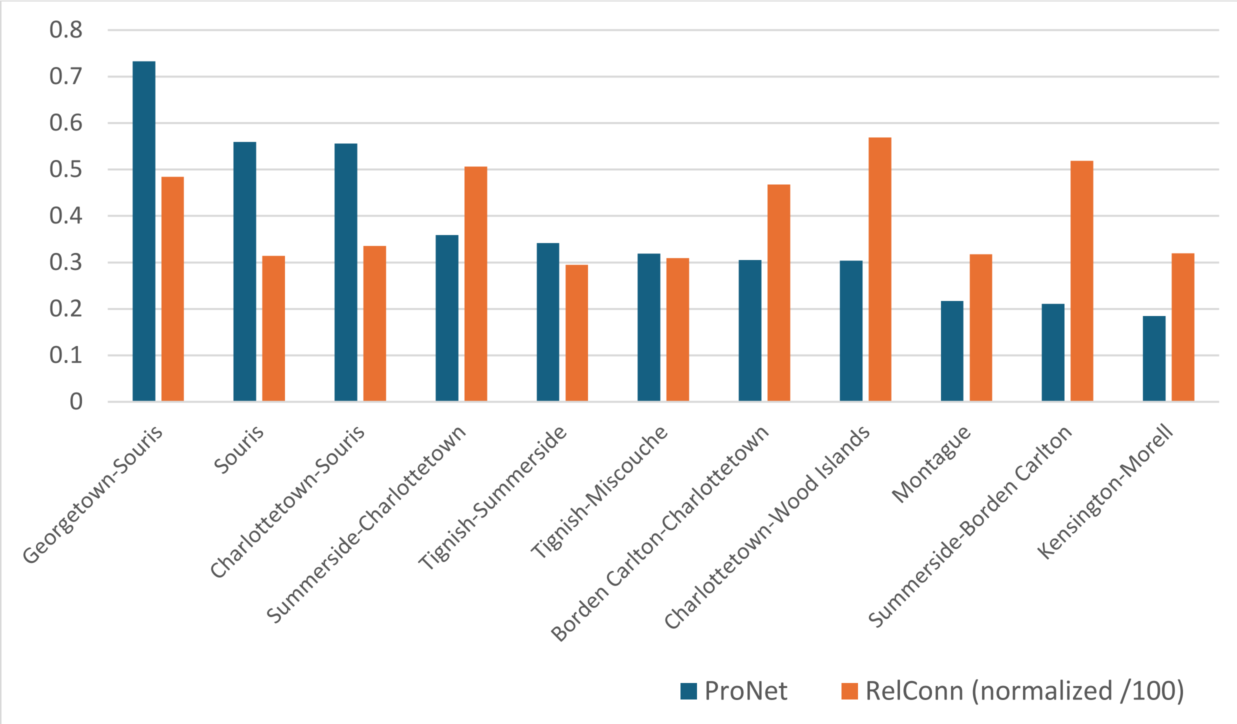


Figure 22. Graphical comparison between ProNet and RelConn metrics for regions divided by highways in Prince Edward Island. Dispersal distance of 2 km.

Use of Protected Area Metrics

This analysis has demonstrated a use case for the ProNet and ProtConn metrics for measuring the connectivity of the protected areas network in Prince Edward Island. Both ProNet and ProtConn metrics can be useful for measuring connectivity on a provincial and regional scale. ProNet provides just one metric, which can be easier to present and understand for a wider audience. The ProNet tool more readily provides information about the number of clusters and the total protected area, information which could be valuable to the province in connectivity assessments.

On the other hand, ProtConn offers a larger suite of indicators that allow land managers to glean more information about different facets of connectivity. For example, using the ProtConn indicator can help land managers understand how connected a whole region is, as it measures the amount of connected protected land in the entire study area (i.e., the province). RelConn may be more useful when managers want to compare connectivity between regions, as it measures the amount of connected protected land within the protected area network. The ProtConn metrics also take into account additional connectivity information to make the assessment more realistic – while it was not included in this analysis, there is an option to provide a set of "buffer" protected areas outside the region of interest (e.g., protected areas just outside of the borders of the eastern region) that the tool will consider when measuring connectivity, as animals might still be able to move through those areas even if they are not technically within the study region boundaries. While the standard ProtConn tools do not automatically map clusters, the script could likely be altered to do so.

When comparing ProNet and RelConn values (metrics which are most comparable to one another), it is notable that increasing dispersal distances cause the ProNet value to reach 1 sooner than the RelConn value reaches 100. This may reflect the sensitivity of these algorithms in terms of assessing the impact of these different factors on connectivity; ProtConn indicators may allow for finer precision when trying to understand how changing aspects of animal movement and the protected areas network impact connectivity.

Which metric is more useful for Prince Edward Island?

The decision to use one metric over another will depend on the aims and interests of those studying or analyzing landscape connectivity; however, based on the above analysis, our recommendation is to use the **ProtConn** suite of indicators to assess landscape connectivity in Prince Edward Island. The broader set of metrics provides more information, and the metrics appear to be more sensitive to change, allowing for finer comparisons of changing systems. Overall, ProtConn tools appear to be more flexible and robust for use in Prince Edward Island.

What regions are more appropriate for applying these tools?

We have presented analysis for the province as a whole, the eastern and western regions, regions divided by highways, and the addition of hypothetical protected areas. These metrics are best used as a **comparative** tool, either spatially or temporally. We identified that landscape connectivity can be further analyzed when the metrics are applied to smaller regions (such as those divided by major highways), allowing for further comparison and assessment of connectivity in one region relative to another. This can also be applied to other study regions of interest.

What dispersal distances should be used?

A variety of dispersal distances, from 0.5 km to 100 km, were presented in this analysis. These distances were chosen based on the recorded dispersal distances of common animals on Prince Edward Island and the geography of the island. Generally, **2 km** appears to be the most appropriate dispersal distance for animals on the island. While many species have much higher recorded dispersal distances, the unique island geography of Prince Edward Island practically limits their movement, reducing their ability to move with ocean and river boundaries, as well as natural bottlenecks. Using a dispersal distance of 2 km allows for sufficiently sensitive analysis of connectivity while accounting for realistic animal movement patterns.

Circuitscape

The Circuitscape analysis performed with Corporate Land Use Inventory (CLUI) data from 2020 was compared to the previous analysis performed with 2010 data. Generally, results were similar between the two analyses; however, some key differences can be noted.

Natural ecosystems

Changes in connectivity in natural ecosystems are generally underpinned by an overall decrease in natural land across the province between 2010 and 2020. In 2010, there were 251,193 ha of land under the natural ecosystem classification; in 2020, this decreased to 246,823 ha (according to CLUI data). This is a decrease of 1.74% (4,370 ha).

The description of changes presented below moves in an east-west direction. The intensity of pinch points on the eastern tip of the island (near Elmira) was reduced from one major pinch point to two, moving horizontally on the northern and southern sides of Elmira. This was likely due to the loss of natural habitat in what was once a main corridor between 2010 and 2020, leading to less current flow through that area and causing it to diffuse over the two corridors instead.

The two major pinch points south of Hermanville, highlighted by Fulton & Bush (2020), are still present. The loss of a larger parcel of natural land north of Farmington created an additional pinch point in that area. The loss of forested/natural land between Cardigan Head and Cardcross led to an increased funnel of current into the patch of land at Cardigan head, creating a more pronounced pinch point. The coastal area north of Fanning Brook remains a key pinch point.

The most significant pinch points remain on the western side of the province. The major pinch point between Crapaud and New Haven – highlighted both in this report and by Fulton & Bush (2020) – remains significant. West of Ellerslie, pinch points have become more severe. This is likely due to a slight decrease in natural ecosystems south of that area (west of Springhill) that funneled more current into that region rather than splitting it evenly amongst adjacent natural areas. Pinch points remain similar around Portage, Dunblane, and Tignish.

Forest

There has also been a reduction (4,170 ha, 1.67%) in forested land across Prince Edward Island between 2010 and 2020 – from 250,047 ha to 245,877 ha. There has been little change in major eastern pinch points north of Forest Hill. The loss of forested land between Cardigan Head and Cardcross, mentioned above, again led to a more pronounced pinch point. There was a slight reduction in pinch points between Glenroy and Saint Andrews, likely due to differences in forest boundary placement between the 2010 and 2020 CLUI.

Similar to the natural ecosystems, the major pinch point between Crapaud and New Haven remains the same. The loss of peripheral forests along the edges of land parcels north of Tignish has reduced the overall width of the corridor available for current to flow through, increasing the intensity of the pinch point.

Overall, the loss of forested and natural ecosystems between 2010 and 2020 has led to more intense pinch points. This increases their importance for conservation, as more animals now depend on these small areas to move throughout the landscape.

Conclusion

The structural connectivity of Prince Edward Island's protected areas remains limited due to its highly fragmented network. It has been posited that connectivity has been limited due to increased pressure from agriculture and development (Silva et al., 2005). The use of recommended connectivity metrics, such as ProNet and ProtConn, can help land managers understand and compare connectivity of spatially and temporally different regions in Prince Edward Island.

Analysis of road effect zones indicates further encroachment of roads into provincial land, with an increased proportion of the province within closer distances to roads in 2024 compared to 2019. Circuitscape analysis also reveals more flow and pinch points, leading to increased pressure on smaller areas of land to support species movement throughout the landscape. During a decade of change (2010-2020) marked by increased urbanization, industrialization and housing development, it is important to continue assessing connectivity; continued monitoring helps to maintain biodiversity, promote ecosystem health, and achieve provincial and national conservation targets.

Future Research and Recommendations

This report builds upon previous analysis of landscape connectivity and habitat fragmentation in Prince Edward Island. The results from the analysis and the geodatabase can be used for provincial-level planning and conservation efforts. This research highlights key areas in the province where protected areas, management, and restoration can be targeted. It also provides tools for assessing and comparing connectivity between regions on the island.

In future updates of this research, it is recommended to use the Omniscape tool to understand currents of species movement – this tool builds upon the capabilities of Circuitscape and provides more comprehensive movement analysis. It produces current maps similar to the Circuitscape tools. Additionally, it would be highly useful to apply the connectivity metrics described in the "Additional Protected Areas" section above to test the effectiveness of proposed protected areas in improving structural connectivity. This could be combined with the provided pinch point polygons to search for potential protected areas that would have a maximum impact on maintaining and improving connectivity.

Lastly, it is possible to create more dynamic assessments of road effect zones in Prince Edward Island by employing tools that consider not only the presence of roads in the natural environment, but the types of roads and the impact they confer on their surroundings. Nova Scotia is currently testing a Road Index tool that uses the provincial road network and associated road types to help understand how and where major/minor roads influence the landscape. This tool could be adapted to perform similar assessments in Prince Edward Island.

References

Bargelt, L., Fortin, M. J., & Murray, D. L. (2020). Assessing connectivity and the contribution of private lands to protected area networks in the United States. *PLoS ONE, 15*(3): e0228946. https://doi.org/10.1371/journal.pone.0228946

Benítez-López, A., Alkemade, R., & Verweij, P. (2010). The impacts of roads and other infrastructure on mammal and bird populations: A meta-analysis. *Biological Conservation, 143*, 1307-1316.

Brooks, C. P. (2003, July 4). A scalar analysis of landscape connectivity. *Synthesising Ecology, 102*(2), 433439.

Canadian Intergovernmental Conference Secretariat (CICS). (2016). Resolution 40-3 – Resolution on ecological connectivity, adaptation to climate change, and biodiversity conservation. 40th Conference of New England Governors and Eastern Canadian Premiers. Boston, MA. https://scics.ca/en/product-produit/resolution-40-3-resolution-on-ecological-connectivity-adaptation-to-climate-change-and-biodiversity-conservation/

Castillo, L. S., Ayram, C. A. C., Matallana Tobon, C. L., Corzo, G., Areiza, A., Gonzalez-M, R., Serrano, F., Briceno, L. C., Puertas, F. S., More, A., Franco, O., Bloomfield, H., Orrury, V. L. A., Canedo, C. R., Moron-Zambrano, V., Yerena, E., Papadakis, J., Cardenas, J. J., Golden Kroner, R. E., & Godinez-Gomez, O. (2020). Connectivity of protected areas: effect of human pressure and subnational contributions in the ecoregions of tropical Andean Countries. *Land, 9*(8), 239. https://doi.org/10.3390/land9080239

Circuitscape. (n.d.). Circuitscape. Retrieved from https://circuitscape.org/

Cunningham, C., Beazley, K., Bush, P., & Brazner, J. (2020). *Assessing Forest Connectivity in Nova Scotia*. Unpublished.

Environment Canda (2024, November 18). *Conserving 30% of Canada by 2030: Vision for the future.* Government of Canada. https://www.canada.ca/en/services/environment/conservation/conserving-30-by-2030.html

Forman, R. T. T., & Alexander, L. E. (1998). Roads and their major ecological effects. Annual Review of Ecology and Systematics, 29, 207-231. https://www.jstor.org/stable/221707

Fulton, L., & Bush, P. (2020). Current state of landscape connectivity and structural fragmentation in Prince Edward Island. Report submitted to PEI Forests, Fish and Wildlife Division.

Godínez-Gómez, O., & Correa Ayram, C.A. (2020). Makurhini: Analyzing landscape connectivity. https://github.com/connectscape/Makurhini

Government of Prince Edward Island. (2013). 2010 State of the Forest Report. Government of Prince Edward Island, Department of Agriculture and Forestry. Government of Prince Edward Island.

Government of Prince Edward Island. (2023, August 24). *Land conservation*. Government of Prince Edward Island. https://www.princeedwardisland.ca/en/information/land-conservation

Government of Prince Edward Island. (2025, April 30). *Agriculture on PEI*. Government of Prince Edward Island. https://www.princeedwardisland.ca/en/information/agriculture/agriculture-on-pei

Hijmans, R. J., Barbosa, M., Bivand, R., Brown, A., Chirico, M., Cordano, E., Dyba, K., Pebesma, E., Rowlingson, B., & Sumner, M. D. (2025). Package 'terra'. https://rspatial.github.io/terra/

Jackson, A. F. E., & Fuller, R. A. (2024). Private protected areas and ecological connectivity in Chile. *Conservation Science and Practice, 6*(12): e13257. https://doi.org/10.1111/csp2.13257

Laliberté, J., & St-Laurent, M.H. (2020). Validation of functional connectivity modeling: The Achilles' heel of landscape connectivity mapping. *Landscape and Urban Planning, 202*, 103878-. https://doi.org/10.1016/j.landurbplan.2020.103878

McRae, B. H., Shah, V. B., & Mohapatra, T. K. (2014). Circuitscape 4 User Guide. The Nature Conservancy. http://www.circuitscape.org.

Metaxas, A., Harrison, A. L., & Dunn, D. (2024). From oceans apart to the global ocean: Including marine connectivity in global conservation targets. *npj Ocean Sustainability, 3*(40). https://doi.org/10.1038/s44183-024-00079-1

Nature Conservancy of Canada. 2019. Ecoregional summary – Prince Edward Island. Nature Conservancy of Canada, Toronto.

Paterson, J. E., Baxter-Gilbert, J., Beaudry, F., Carstairs, S., Chow-Fraser, P., Edge, C. B., Lentini, A. M., Litzgus, J. D., Markle, C. E., McKeown, K., Moore, J. A., Refsnider, J. M., Riley, J. L., Rouse, J. D., Seburn, D. C., Zimmerling, J. R., & Davy, C. M. (2019). Road avoidance and its energetic consequence for reptiles. *Ecology and Evolution, 9*(17), 9794-9803. https://doi.org/10.1002/ece3.5515

Prince Edward Island Executive Council Office. (2023, March 22). Island nature and fauna. Government of Prince Edward Island. https://www.princeedwardisland.ca/en/information/executive-council-office/island-nature-and-fauna

Pelletier, D., Lapointe, M.-É., Wulder, M. A., White, J. C., & Cardile, J. A. (2017). Forest Connectivity Regions of Canada Using Circuit Theory and Image Analysis. 12(2).

Poor, E., Hall, K., Anderson, J., Clark, M., Jones, A., Kennedy, C., Schloss, C., Theobald, D., Burbano-Giron, J., Cook-Patton, S., Drever, R., Fargione, J., Fitzsimons, J., Nunez-Regueiro, M., Rosenfield, M., & Masuda, Y. (2025). Global whole landscape connectivity to complement protected area connectivity. *Nature Portfolio*. Under Review.

Saura, S., Bastin, L., Battistella, L., Mandrici, A., & Dubois, G. (2017). Protected areas in the world's ecoregions: How well connected are they? *Ecological Indicators, 76*, 144–158. https://doi.org/10.1016/j.ecolind.2016.12.047

Shah, V. B., & McRae, B. (2008). Circuitscape: A Tool for Landscape Ecology. 7th Python in Science Conference , (pp. 62-66).

Silva, M., Hartling, L., & Opps, S. B. (2005). Small mammals in agricultural landscapes of Prince Edward Island (Canada): Effects of habitat characteristics at three different spatial scales. *Biological Conservation, 126*, 556–568.

Stewart, B., & Neily, P. (2008). A Procedural Guide For Ecological Landscape Analysis: An Ecosystem Based Approach to Landscape Level Planning in Nova Scotia (2008-2). Nova Scotia Department of Natural Resources. Retrieved November 30, 2024, from https://novascotia.ca/natr/library/publications/forestry-general.asp

Sutherland, G. D., Harestad, A. S., Price, K., & Lertzman, K. P. (2000). Scaling of natal dispersal distances in terrestrial birds and mammals. *Conservation Ecology 4*(1): 16. http://www.consecol.org/vol4/iss1/art16/

Taylor, P. D., Fahrig, L., Henein, K., & Merriam, G. (1993). Connectivity Is a Vital Element of Landscape Structure. *Nordic Society Oikos, 68*(3), 571-573.

Theobald, D. M., Keeley, A. T. H., Laur, A., & Tabor, G. (2022). A simple and practical measure of the connectivity of protected area networks: The ProNet metric. *Conservation Science and Practice, 4*(11), e12823. https://doi.org/10.1111/csp2.12823

Appendix 1: Pinch points

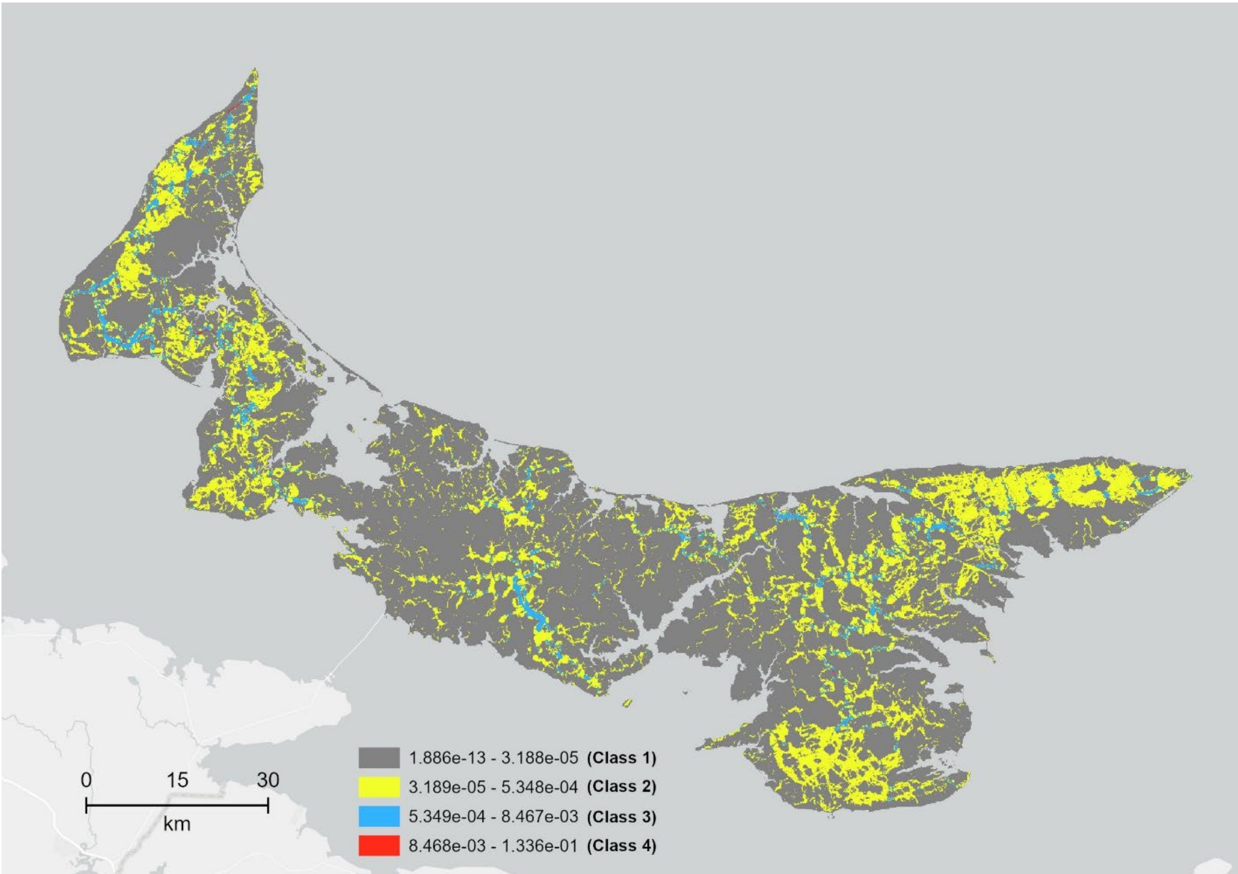


Figure A23. Circuitscape current map for natural ecosystem land classification divided into four classes using the Geometric Interval algorithm in ArcGIS Pro.

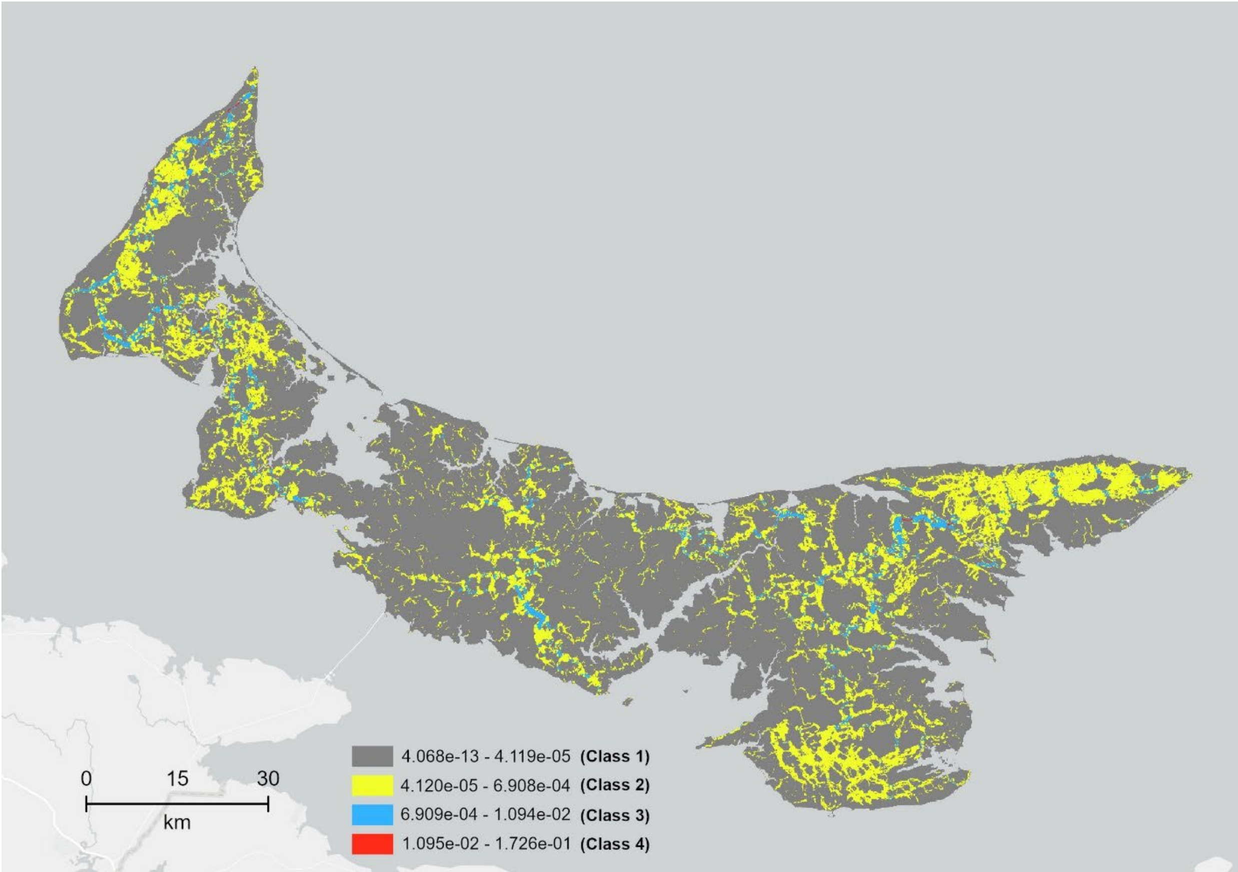


Figure A24. Circuitscape current map for forest land classification, divided into four classes using the Geometric Interval algorithm in ArcGIS Pro.

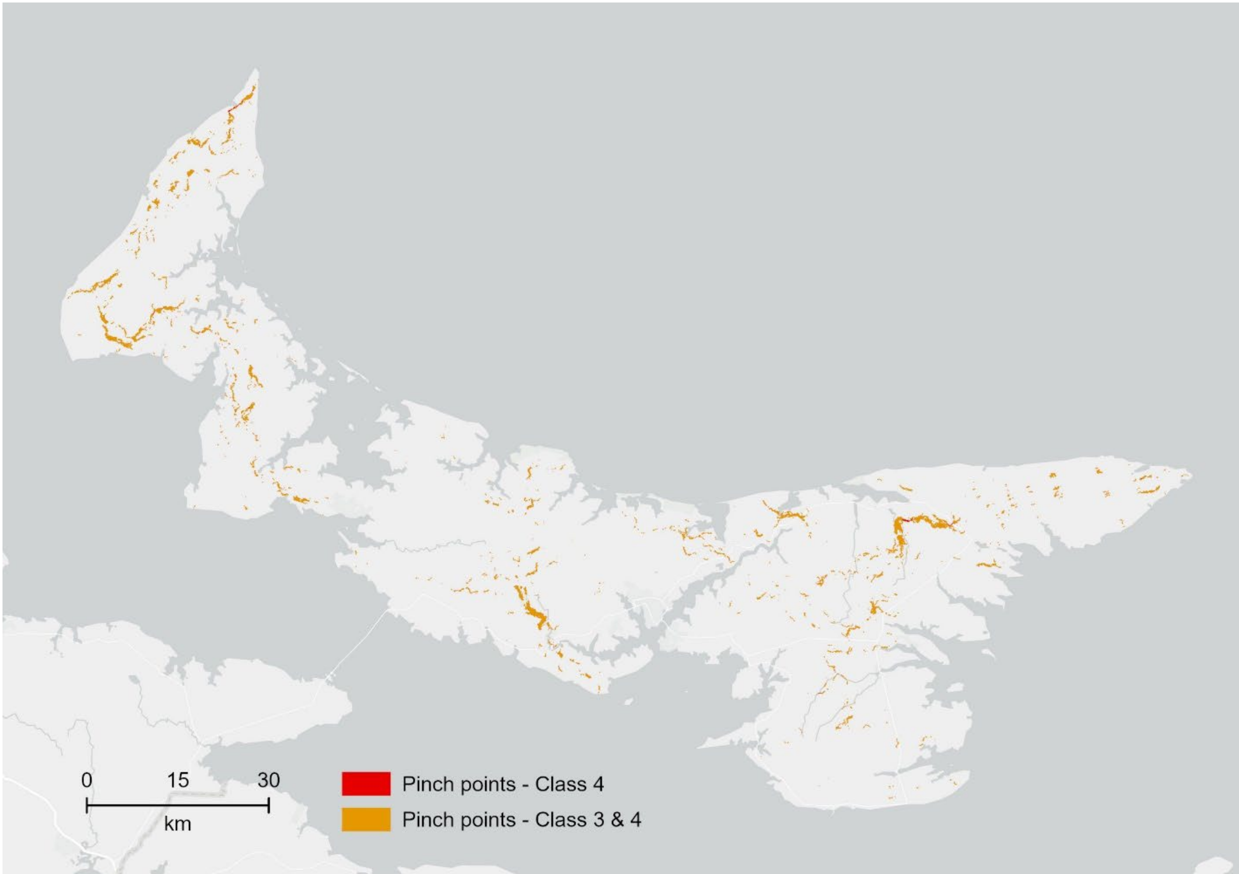


Figure A25. Top two classes of Circuitscape current map pinch points for the natural ecosystem classification.

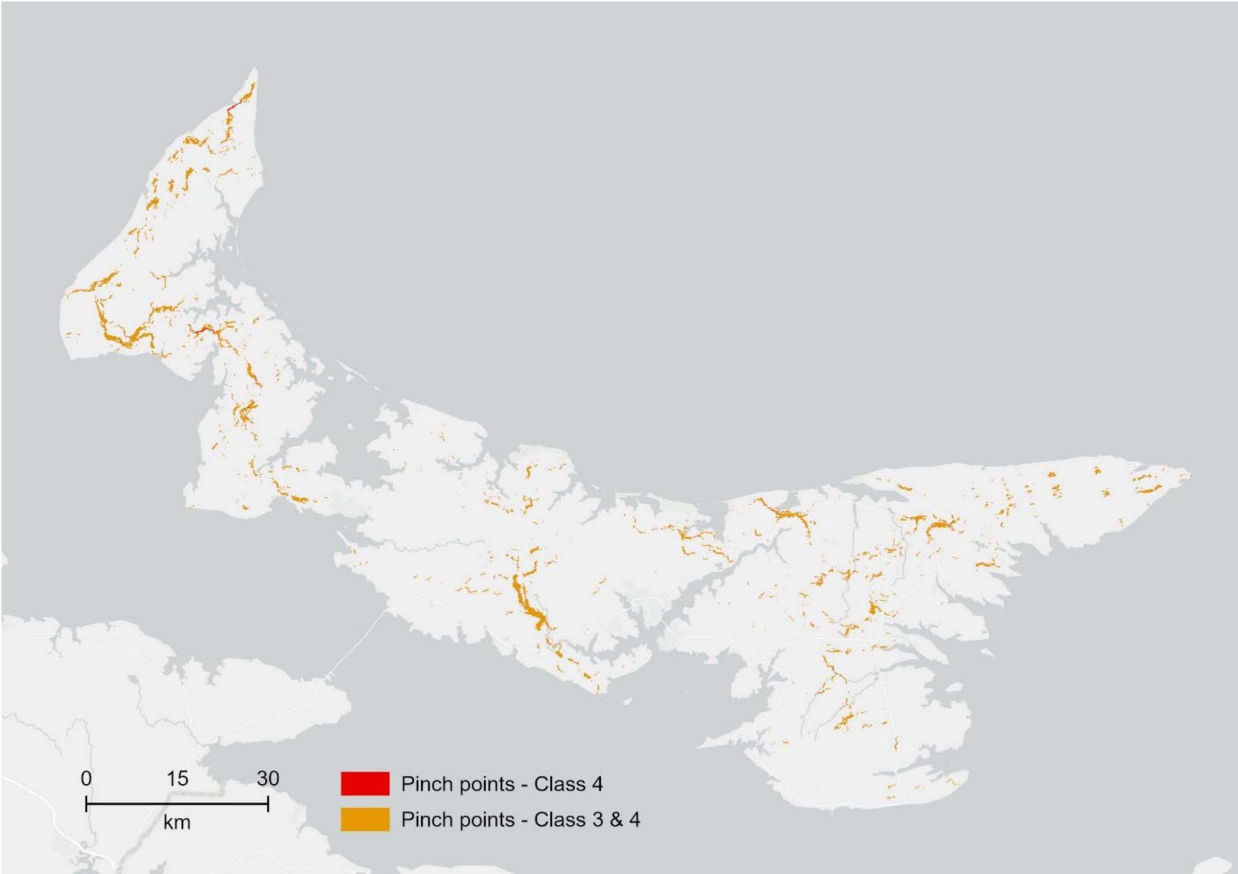


Figure A26. Top two classes of Circuitscape current map pinch points for the forest land classification.