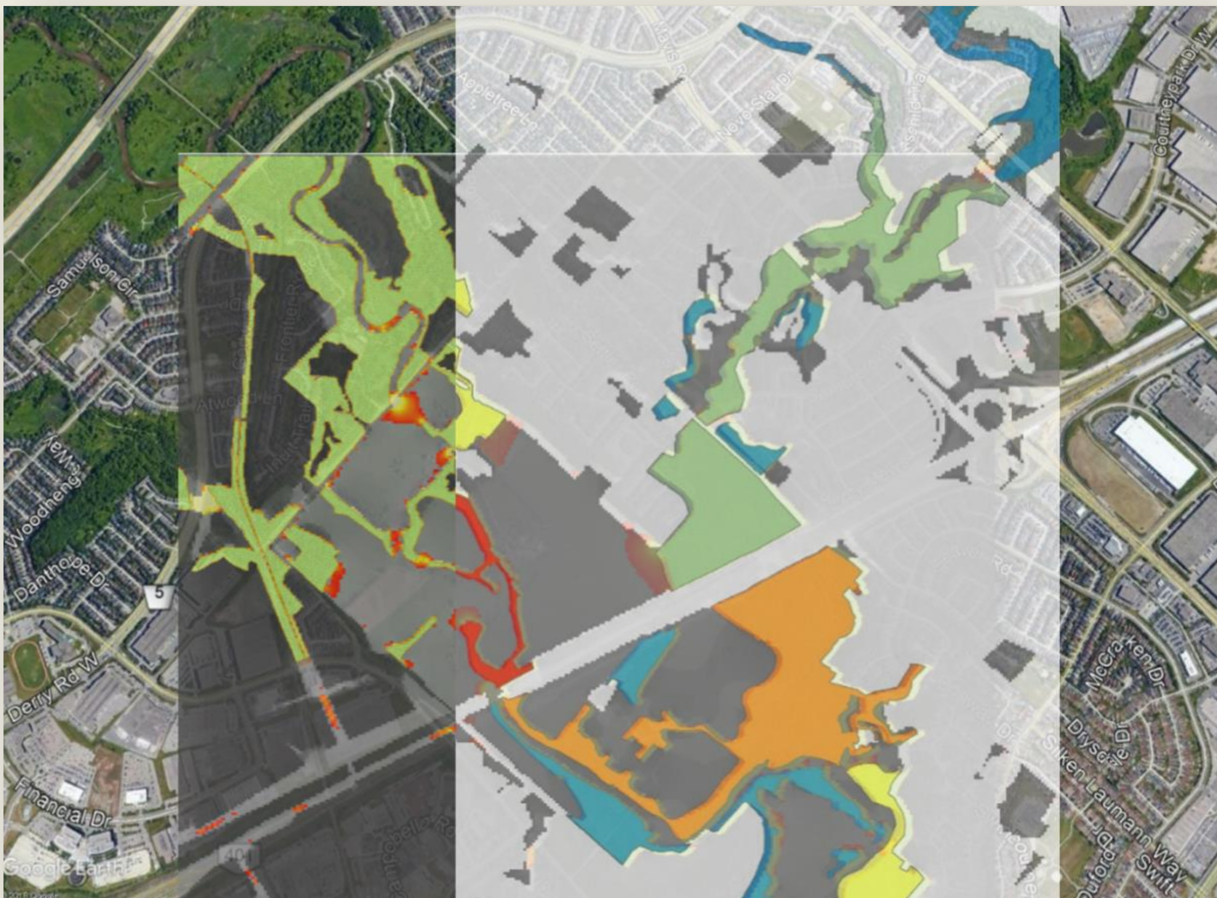
Final Report

Evaluating Natural Heritage Connectivity in the Credit River Watershed



Credit Valley Conservation
inspired by nature

Centre for Urban Environments
Environments
Humans
Cities
CUE
University of Toronto

UNIVERSITY OF TORONTO MISSISSAUGA

TABLE OF CONTENTS

LIST OF FIGURES

1. Acknowledgements

1.1. Partnership

This project is an output of the active ongoing partnership between the University of Toronto-Mississauga (UTM) through the Center for Urban Environment (CUE), and the Credit Valley Conservation Authority (CVC). This established partnership and ongoing collaborative relationship is oriented to understanding ecological processes at the landscape and site scale, communicating these relationships, and providing the science-based knowledge required for watershed management and planning. In this collaborative project, the following roles of the two partners have been developed:

CVC: (1) provide access to existing natural heritage system and other spatial data for the Credit River Watershed; (2) provide expert opinion on the classification of land cover types and assignment of resistance values, and (3) co-supervision of graduate student internship.

UTM-CUE: (1) conduct the landscape connectivity modelling and analyses; (2) provide raster spatial data deliverables including a high-resolution resistance surface and a current density surface (in ESRI format); (3) provide vector data of natural area patches in the watershed attributed with landscape connectivity metrics; (4) submit a final report to CVC; and (5) provide a technical user manual for CVC, outlining detailed spatial analysis steps.

1.2. Steering Committee

Helene Wagner, University of Toronto-Mississauga
Hossam Abdel Moniem, University of Toronto-Mississauga
Aviva Patel, Credit Valley Conservation
Erika Nardone, Credit Valley Conservation

1.3. Funding Resources

UTM provided funding through the Connaught Community Partnership Research Program. The internship of F. Torres was funded through the NSERC CREATE “ADVENT/ENVIRO” program.

CVC provided in-kind resources (data, technical input) and a financial contribution of $5,000 to support project completion (report and technical manual)

1.4. Technical Contributions

Hossam Abdel Moniem, University of Toronto-Mississauga
Felipe Torres-Vanegas, University of Toronto-Mississauga
Helene Wagner, University of Toronto-Mississauga
Aviva Patel, Credit Valley Conservation
Erika Nardone, Credit Valley Conservation
Katherine Robbins, Credit Valley Conservation
Scott Sampson, Credit Valley Conservation
Liam Marray, Credit Valley Conservation
Yvette Roy, Credit Valley Conservation
Kata Bavrlic, Credit Valley Conservation
Laura Timms, Credit Valley Conservation

1.5. Recommended Citation

Abdel Moniem, H. E., Torres-Vanegas, F., and Wagner, H. H. 2020. Evaluating Natural Heritage Connectivity in the Credit River Watershed. Final Report. 75 pp. https://dataverse.scholarsportal.info/dataset.xhtml?persistentId=doi:10.5683/SP2/CMGXZR.

2. Abstract

The Provincial Policy Statement (PPS) (MMAH, 2020) mandates the planning and development of natural heritage systems in order to maintain, restore, or improve biodiversity and connectivity of natural features The Conservation Authorities Act directs conservation authorities to develop programs and services to promote the conservation, restoration and management of natural resources. Credit Valley Conservation (CVC) works with municipalities to develop and manage natural heritage systems within the Credit River Watershed. Therefore, there is an important demand for modeling connectivity and evaluating the importance of natural heritage features within CVC jurisdiction to optimize and prioritize their conservation efforts. In collaboration with CVC, we used a circuit theory approach to model a wall-to-wall, high-resolution current density map to characterize the important connectivity pathways that facilitate the flow of biodiversity across the Credit River Watershed. We then quantified the importance of each natural heritage feature for maintaining the connectivity across the natural heritage system network. This was based on the probability of connectivity index, using a least cost path analysis and four critical Euclidian dispersal thresholds relevant to the dispersal abilities of species in the watershed. Our results illustrate the importance of natural heritage features in maintaining connectivity within the Credit River Watershed. This role was underestimated as modeled, previously, at the provincial scale (Bowman & Cordes, 2015). The implementation of this approach will provide CVC with the knowledge required for prioritizing conservation efforts.

3. Background, Scope, and Objectives

3.1. Background

Progressive anthropogenic activities and socioeconomic impacts of urbanization (e.g. development, land use change, and human footprints) are the main drivers of habitat loss and fragmentation. These impacts have negatively influenced ecological processes and have caused rapid declines in biodiversity (Grimm et al., 2008). Thus, it is essential to protect and maintain the connectivity of the natural heritage system to promote biodiversity and ecosystem services in our urbanizing landscapes (Theobald et al., 2012). To balance increasing socioeconomic demands with connectivity of natural habitats in the landscape, planning authorities should prioritize conservation efforts and management based on an accurate evaluation of landscape connectivity and the importance of natural habitat patches in our natural heritage system.

This project was initiated by the Centre For Urban Environments (CUE), the University of Toronto, Mississauga (UTM) with the support of CVC to create a high-resolution connectivity map modeled to characterize the landscape of the watershed and to quantify the importance of all natural habitat patches within the Credit River Watershed. The resulted connectivity map and network analysis can be assessed and tested with biodiversity data available at CVC. However, this goal is the next logical step after this project. The results of this project can be used to inform the protection and restoration of the Credit River Watershed's natural heritage system. At the larger scale, the project can help planning efforts to accommodate future expansion of urbanization and socioeconomic demands in the area.

Landscape connectivity is commonly defined as the degree to which the landscape facilitates or impedes the movement of organisms and their genes among habitat patches (Taylor et al., 1993; Tischendorf & Fahrig, 2001). There are three main approaches for quantifying landscape connectivity: structural connectivity, potential functional connectivity, and actual functional connectivity (Calabrese & Fagan, 2004). Structural landscape connectivity can be determined from physical attributes in the landscape, based on maps alone (i.e. without reference to organism movement behaviour). Potential functional connectivity uses assumptions on organismal movement behaviour, e.g. by mapping a species' habitat and setting dispersal thresholds. Finally, actual functional connectivity refers to observed data (e.g., species occupancy, radio tracking, mark-recapture, or molecular genetic data), which reflect actual rates of the exchange of organisms (or genes) among habitat patches (natural heritage features). Because of these characteristics and functions of connectivity, its decline is a major concern for wildlife population survival, species diversity, and ecosystem services (Damschen et al., 2006; Kramer-Schadt et al., 2004; Mitchell et al., 2013, 2015). Thus, quantifying landscape connectivity is a crucial component for any land-use planning and conservation management (Lechner et al., 2015).

Understanding our different perspectives on the landscape can clarify conceptual differences, guide researchers in making decisions about how to model connectivity and inform practitioners about the potential and limitations of resulting maps. At the conceptual level, there are two axes of our perspective on the landscape: The first distinction occurs when we come from a species conservation perspective, or a land-use planning perspective. For example, conservation studies are often based on organism perspective. This bottom up perspective is compatible with the modelling of connectivity based on the biology and ecology of species and results in models of potential and actual functional connectivity. In contrast, land-use planning focuses on the sustainable development of multi-functional landscapes. This top down perspective is highly compatible with the modelling of connectivity based on human modification, which will result in a model of structural landscape connectivity. In between, the ecological communities' perspective can be placed. Since species within communities share common biological, ecological and sometimes dispersal characteristics, these models could be built by overlaying multiple species-specific models.

The second distinction occurs at the policy and ecology perspectives. While ecology mainly considers natural processes, policy addresses human values and actions. Both perspectives meet in the consideration of the human impact on ecosystems. Along this axis, connectivity models quantify how human actions and their manifestation as non-natural landscape features constrain ecological flow across the underlying natural fabric of the landscape with the goal of maintaining ecosystem services and biodiversity in the context of sustainable development (Fig. 1).

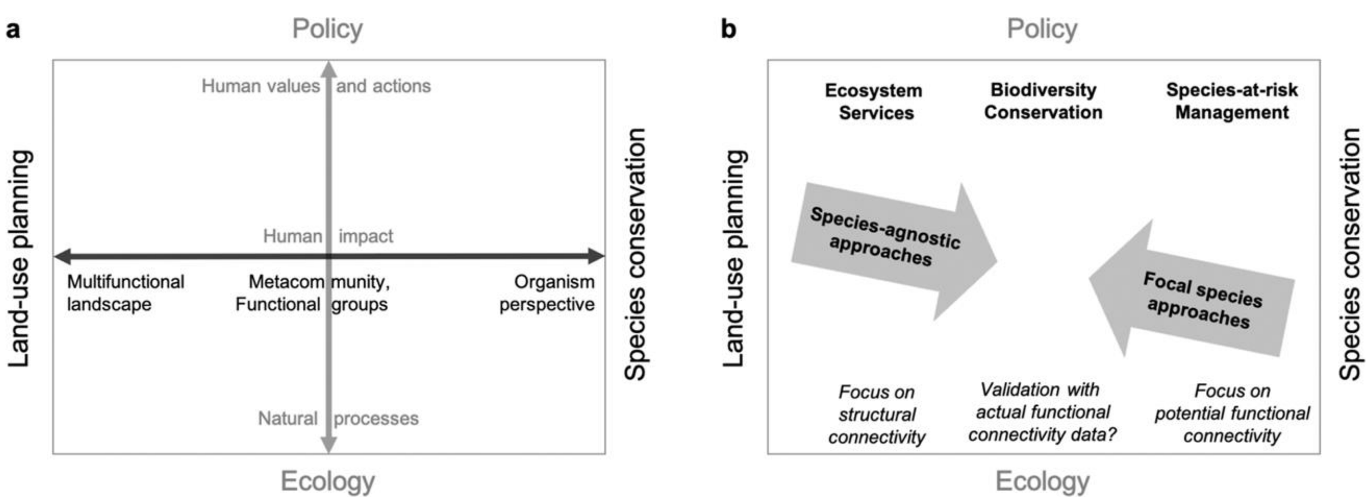


Figure 1. Conceptual framework: different perspectives on the landscape (a) and corresponding goals and approaches to connectivity modelling (b) from Marrec et al. (2020).

In this project, we are adopting the species-agnostic (top-down) approach that focus on structural connectivity, and not on a species specific/multispecies approaches that focus on potential functional connectivity.

From a practical perspective, developing a large-scale natural heritage system connectivity model that is suitable for a wide range of species without the need for extensive information on species-specific habitat requirements is challenging. While species-specific and multispecies models provide an accurate and realistic basis for modelling connectivity (at least for the selected species), in practice, developing these models can be very time-consuming and costly (Dilkina et al., 2017). In this project, we adopted a species-agnostic approach that relies on modelling connectivity based on the degree of non-naturalness in the landscape (Dickson et al., 2017; Theobald, 2013). In species-agnostic models, human footprints (i.e., land-use feature classes) are used as a proxy to develop a resistance layer that represents a gradient of barriers to organismal movement and dispersal across the landscape. This resistance layer is then used to model connectivity as current density (representing the flow of organismal and their genes) within a circuit theory framework. Species-agnostic connectivity models have been tested and validated with actual functional connectivity data (Koen et al., 2014) and were found to be efficient and cost-effective in predicting landscape connectivity for multiple species.

In Ontario, the Provincial Policy Statement (PPS) (MMAH, 2020) and the Growth Plan for the Greater Golden Horseshoe (MMAH, 2019) mandate the planning and development of natural heritage systems. The PPS also states, "Natural heritage systems shall be identified in Ecoregions 6E & 7E1, recognizing that natural heritage systems will vary in size and form in settlement areas, rural areas, and prime agricultural areas." It explicitly stated that "The diversity and connectivity of natural features in an area, and the long-term ecological function and biodiversity of natural heritage systems, should be maintained, restored or, where possible, improved, recognizing linkages between and among natural heritage features and areas, surface water features and ground water features."

Although there have been efforts to model landscape connectivity across Ontario (Bowman & Cordes, 2015; Koen et al., 2014), these studies lack the fine-scale spatial resolution necessary to model connectivity across a single watershed (Fig. 2). Moreover, these efforts have catalogued urbanized watersheds as areas of very low connectivity and ecological value. However, the presence of small natural areas and farming land be important for the conservation of landscape connectivity in urbanized watersheds such as (the Southern parts of) the Credit Valley Watershed.

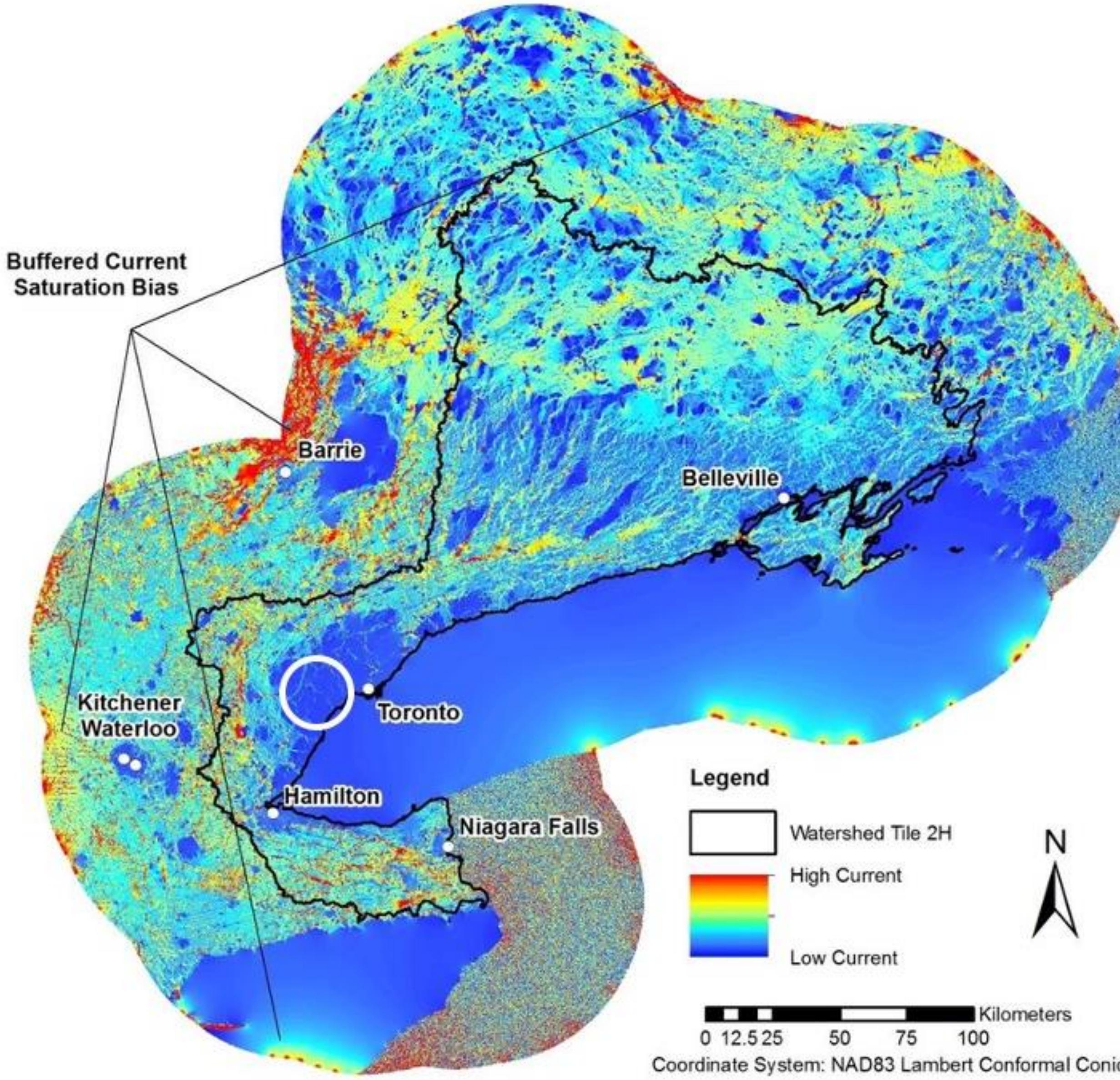


Figure 2: A current density map of southern Ontario from Bowman & Cordes, 2015 indicating patterns of high-to-low current flow (red-to-blue). Due to extent and spatial resolution of the map, and the assumption that large waterbodies act as a barrier, most current is channeled through the Greenbelt and deviated around Lake Ontario, showing large parts of the Credit River Watershed as having little or no importance for maintaining connectivity across the Golden Horseshoe area (e.g. Mississauga area in the white circle).

3.2. Scope

The scope of this project was to provide an initial assessment of landscape connectivity across the Credit River Watershed to identify natural habitat areas in the watershed that are important for landscape connectivity.

3.3. Objectives

Our main objectives included:

1. Assess existing natural heritage system and expert opinion data to classify landcover types and assign resistance values to organism movement.
2. Develop a high-resolution landscape resistance surface to produce a current density map that models landscape connectivity as current density.
3. Quantify the contribution of natural areas to the overall connectivity of the natural heritage system network to help prioritize conservation efforts.

3.4. Analyzing Landscape Connectivity

This project followed a standardized protocol (Bowman & Cordes, 2015) to quantify landscape connectivity in the Credit River Watershed. Leveraging existing CVC spatial data, we categorized landcover types into three policy-relevant groups: (1) natural and permeable – low resistance (e.g. forest patches); (2) non-natural but permeable – medium resistance (e.g. agriculture and open spaces); and (3) non-natural and impermeable – high resistance (e.g. urban development). Then, we used a circuit theory approach as implemented in Circuitscape v4.0.5 (www.circuitscape.org) (McRae, 2006; McRae et al., 2008) to model a wall-to-wall landscape current density map. This map represents landscape connectivity as a continuous function of permeability values across the Credit River Watershed. In addition, we use a graph theory approach as implemented in Conefor v2.6 (www.conefor.org) (Saura & Rubio, 2010) to assess the connectivity of the entire natural heritage system as a network of all natural features within CVC's jurisdiction, and quantify the importance of each natural feature for the maintenance of connectivity. This project provides science-based decision-making support for conservation planning in the Credit River Watershed based on the identification and prioritization of critical habitat patches.

3.5. Study Area: The Credit River Watershed

The Credit River Watershed encompasses 950 km^2 of land within the Greater Golden Horseshoe area, the most rapidly urbanizing region of Ontario. The Credit River flows southeast for nearly 100 km from its headwaters near Orangeville to Lake Ontario. Twenty-one subwatersheds have been identified within the watershed, as well as approximately 14 creeks located within the City of Mississauga that drain directly into Lake Ontario.

Land cover in the Credit River Watershed consists of roughly equal parts natural cover (35%), agriculture and open space (34%) and urban land use (31%) (Fig. 2). Natural land cover in the watershed is made up of upland forests (12%), wetlands (7%) and a small proportion of aquatic habitat and other natural cover such as beaches and bluffs (1%). It also includes cultural forest (6%) or successional communities (9%) that have a history of human origin. These include agricultural fields that have been allowed to naturalize or undergo natural succession (cultural meadows, cultural thickets, cultural savannahs and cultural woodlands), plantations that are being allowed to undergo natural processes (cultural plantations) and forests that have undergone non-natural thinning in the form of selective logging (cultural woodlands) (Fig. 3; Lee et al., 1998).

Natural, agricultural and urban land cover types are unevenly distributed across the watershed. In the upper portion of the watershed, above the Niagara escarpment, land use is dominated by agriculture and natural cover types. The middle portion of the watershed contains the Niagara Escarpment and the western edge of the Oak Ridges Moraine. Together, the upper and middle zones contain the majority of wetland and woodland cover in the watershed. The lower portion of the watershed is home to 87% of the watershed's population and includes most of the City of Mississauga, the western half of the City of Brampton and the eastern portions of the Town of Oakville and Town of Milton. Natural cover in the lower watershed is low, with few remaining forests and wetlands.

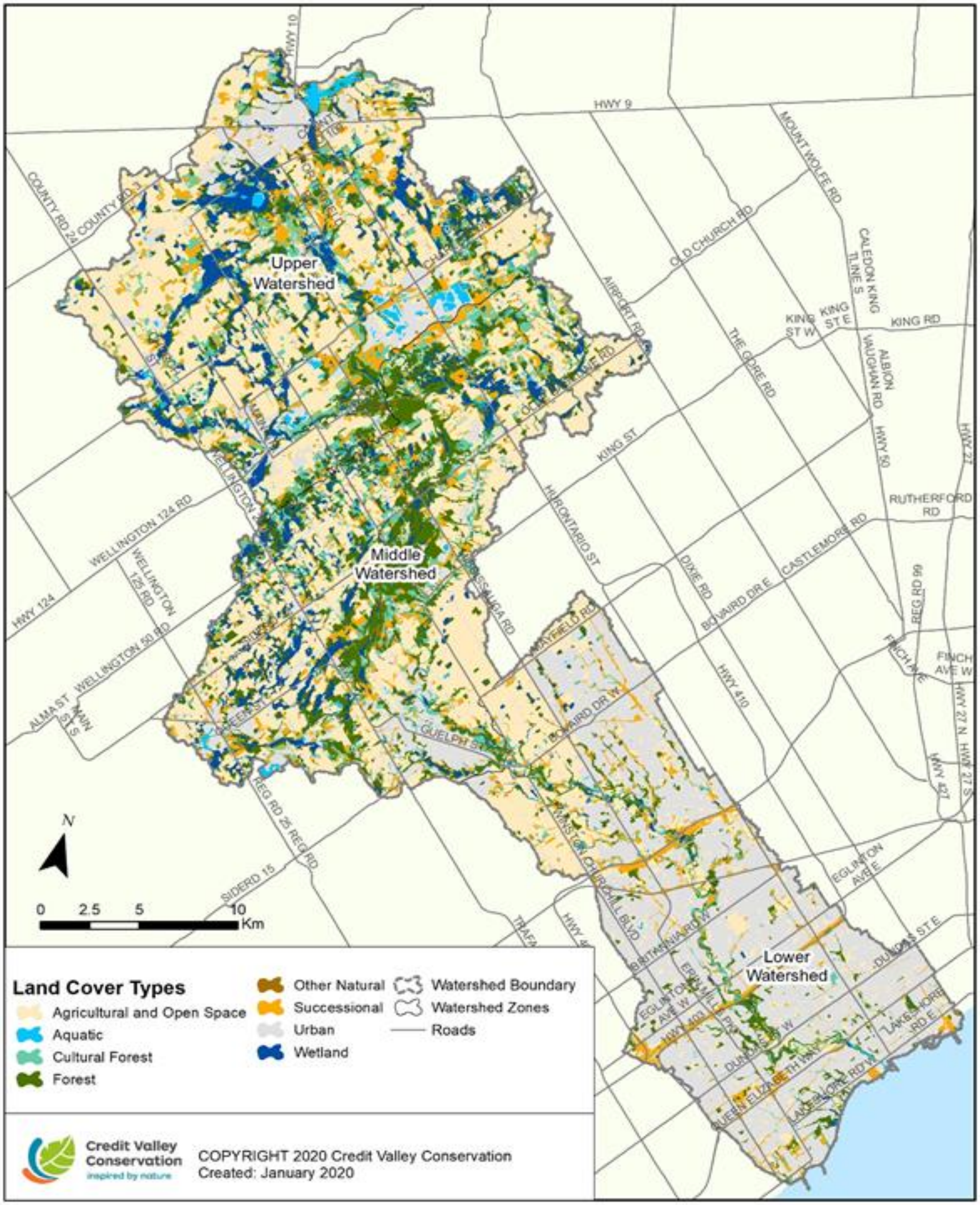


Figure 3: Land cover in the Credit River Watershed based on 2017 Ecological Land Classification (ELC) and land use data.

4. Methodology

For detailed systematic notes on the methodology, please refer to the project user manual prepared specifically for this project. The manual explains all steps to build the wall-to-wall connectivity map and resistance surface. It also provides exhaustive details on connectivity network analysis. The project user manual complements this report and can be found at:
https://dataverse.scholarsportal.info/dataset.xhtml?persistentId=doi:10.5683/SP2/CMGXZR

4.1. Methodology Overview:

In this project, we modeled landscape connectivity in two complementary ways. *Firstly*, we adopted a species agnostic approach, following the protocol of Bowman and Cordes (2015), who reclassified landcover types into three policy relevant groups: (1) natural and permeable – low resistance (10); (2) non-natural but permeable – medium resistance (100); and (3) non-natural and impermeable – high resistance (1000). We mapped all feature types of CVC's spatial data to these categories. Landscape connectivity was then modelled as electric current moving across the estimated landscape resistance surface (McRae et al., 2008). The resulting current density map represents the contribution of each raster cell to connectivity across the Credit River Watershed as a continuous function of resistance values. The circuit theory approach thus enabled us to produce a wall-to-wall (full extent map based on CVC boundary polygon) current density map for CVC that shows important routes of ecological flow across the Credit River Watershed.

This approach is based on circuit theory and its widely recognized applications in landscape ecology and conservation biology (McRae, 2006; McRae et al., 2008). It uses a resistance surface that represents a gradient of barriers to the movement of terrestrial organisms across the landscape. This resistance surface is then used to model the flow of random walking electrons (organisms and their genes) across this resistance surface (the landscape). The resulting current density maps (organismal movement and gene flow) is used as a proxy of landscape connectivity. Current density is an estimate of the net electron flow (representing ecological flow, or the movement of individuals and their genes) through resistance surface cells. This approach provides a robust way of quantifying all possible paths of movement and dispersal of organisms in the landscape in contrast to the traditional analysis method of least-cost paths, which estimate a single lowest-cost pathway between any two points based on the resistance surface. Current density maps can characterize three distinctive patterns: (1) *Barriers*: areas of low current density, due to high resistance; (2) *Pinch-points* (bottlenecks): areas with high current density and low or intermediate resistance (e.g., culverts), where flow is diverted and funneled due to nearby strong barriers; and (3) *Diffused* current flow areas with low current flow and low resistance that mark large connected areas with few barriers (Anderson et al., 2012).

Secondly, we conducted a network analysis by quantifying three fractions that measure the different ways in which each natural heritage feature (natural areas) contributes to connectivity of the network of all features in the natural heritage system (Saura & Rubio, 2010). Natural areas were characterized by: (1) size of the natural area – *Intra*; (2) direct connections to nearby natural areas – *Flux*; and (3) indirect connections between other natural areas – *Connector* (also for linkages between natural areas). This analysis enabled us to quantify the relative importance of each natural habitat patch in the Credit River Watershed, for maintaining the connectivity of the entire natural heritage system.

This approach is based on Graph theory and spatial networks (Dale & Fortin, 2010) and relies on the concept reachability of natural areas, irrespective of their habitat quality. Reachability is quantified by the probability of connectivity, which is the probability that two points (organisms) that are randomly placed in the landscape (inside or outside of natural areas) will fall into natural areas that are connected (Saura & Pascual-Hortal, 2007). The change in the overall probability of connectivity due to the removal of one natural area at the time quantifies the contribution of the area to network connectivity and can be decomposed into the three aspects of Intra, Flow and Connector functions described above.

4.2. Base Data and Data Preparation

Data inputs for the current density modeling with Circuitscape v4.0.5 (McRae, 2006; McRae et al., 2008) and the network analysis with Conefor v2.6 (Saura & Rubio, 2010) were developed using the 2018 CVC's Ecological Land Classification (ELC) system for southern Ontario (Lee et al., 1998) and Land use shapefile as base data. Land cover types were identified through a combination of orthophoto interpretation and fieldwork done at the CVC. Specifically, these data include an inventory of culverts, which can mitigate the barrier effect of roads. This base data provided the best available data at the time of analysis. The spatial extent of the data encompasses a two-kilometer buffer around the Credit River Watershed and the entirety of the Region of Peel. Urban, agricultural and open space areas are classified using CVC-defined land use categories, and natural areas are classified based on the ELC. A table listing all cover types in CVC's 2018 ELC and land Use shapefile can be found in Appendix A.

4.3. Resistance Surface Development

The input resistance raster layer used to model the wall-to-wall current density map in Circuitscape was created using CVC's 2018 ELC and Land Use shapefile as follows:

Step 1: Updating and modifying CVC's 2018 ELC and Land Use map for terrestrial species movement

Three new land cover types were added:

- *Open aquatic river*: CVC's ELC and Land use shapefile delineates open aquatic habitat (OAO) and includes waterbodies, and some wide rivers (generally, sections of the Credit river which are >20 m wide). The ELC and land use shapefile was edited to separate waterbody polygons from wide river polygons in order to consider them separately for resistance classification.
- *Gravel roads*: CVC's ELC and Land use shapefile delineates all roads and classifies them as either highway, regional road, collector or general urban. The project team was interested in distinguishing roads with lower traffic volume in order to consider them separately for resistance classification. In lieu of available traffic volume data from CVC, gravel roads were chosen as a reasonable proxy for low-traffic roads. The ELC and Land use shapefile was edited to separate segments of road that were identified as gravel using a combination of orthophoto interpretation and Google street view.
- *Wildlife passage*: The Credit River Watershed contains many bridges and culverts that provide wildlife passage underneath roads. CVC's Road and Valley Crossings shapefile is a point dataset that that characterizes opportunities for fish and wildlife passage at municipal road-stream crossings in the watershed. Wildlife passage polygons were added to the ELC and Land use shapefile at 63 crossings characterized by the Road and Valley Crossings dataset as likely passable by all wildlife. Wildlife passages polygons were mapped by buffering the Road and Valley Crossing point, bridging the land use types on either side of the road.

Step 2: Reclassifying land cover types based on degree of naturalness:

The updated land cover map was reclassified into three categories (Fig. 4) that represents the degree of the non-naturalness in the landscape according to Bowman and Cordes (2015), and resistance values were attributed as follows (*Detailed in Appendix 9.1*):

- *Low resistance (value = 10)*: includes natural cover types that are permeable to the movement of terrestrial species.
- *Medium resistance (value = 100)*: includes land cover types that are permeable but discourage movement in some way. This includes some land use types that discourage movement for anthropogenic reasons (e.g., noise, lack of cover from predators), as well as some natural land cover types that discourage movement due to the presence of natural barriers (e.g., rivers, bluffs).

- *High resistance (value = 1000)*: includes non-natural cover types that are assumed impermeable to the movement of terrestrial species.

Step 3: Rasterizing the resistance values of the reclassified land cover map.

The resistance values associated with the reclassified land cover map were converted to a high-resolution raster map with 10m cell size to serve as the resistance surface for modelling connectivity in Circuitscape. Measures were taken to avoid artificial gaps or fractures in linear features, a problem that can occur during the rasterization process. To avoid this issue, cells containing more than one resistance class (e.g., part highway, part cultural meadow), were classified with the highest resistance level. This conservative approach reduces the likelihood of underestimating resistance for movement across the landscape.

Step 4: Establishing a 25% buffer around the watershed.

The resistance surface was extended with a 25% larger buffer than the total area of CVC polygon in the watershed, following Koen *et al*. (2014). Any areas within this buffer that had not yet received a resistance classification (i.e. any areas beyond the extent of CVC's ELC and land use shapefile) were classified as medium resistance (assigned a value of 100).

The function of this buffer is to avoid bias related to the placement of current sources when modeling current density. Current sources are placed along the outside of the buffer (*see project user manual of this project for details*) (Fig. 5).

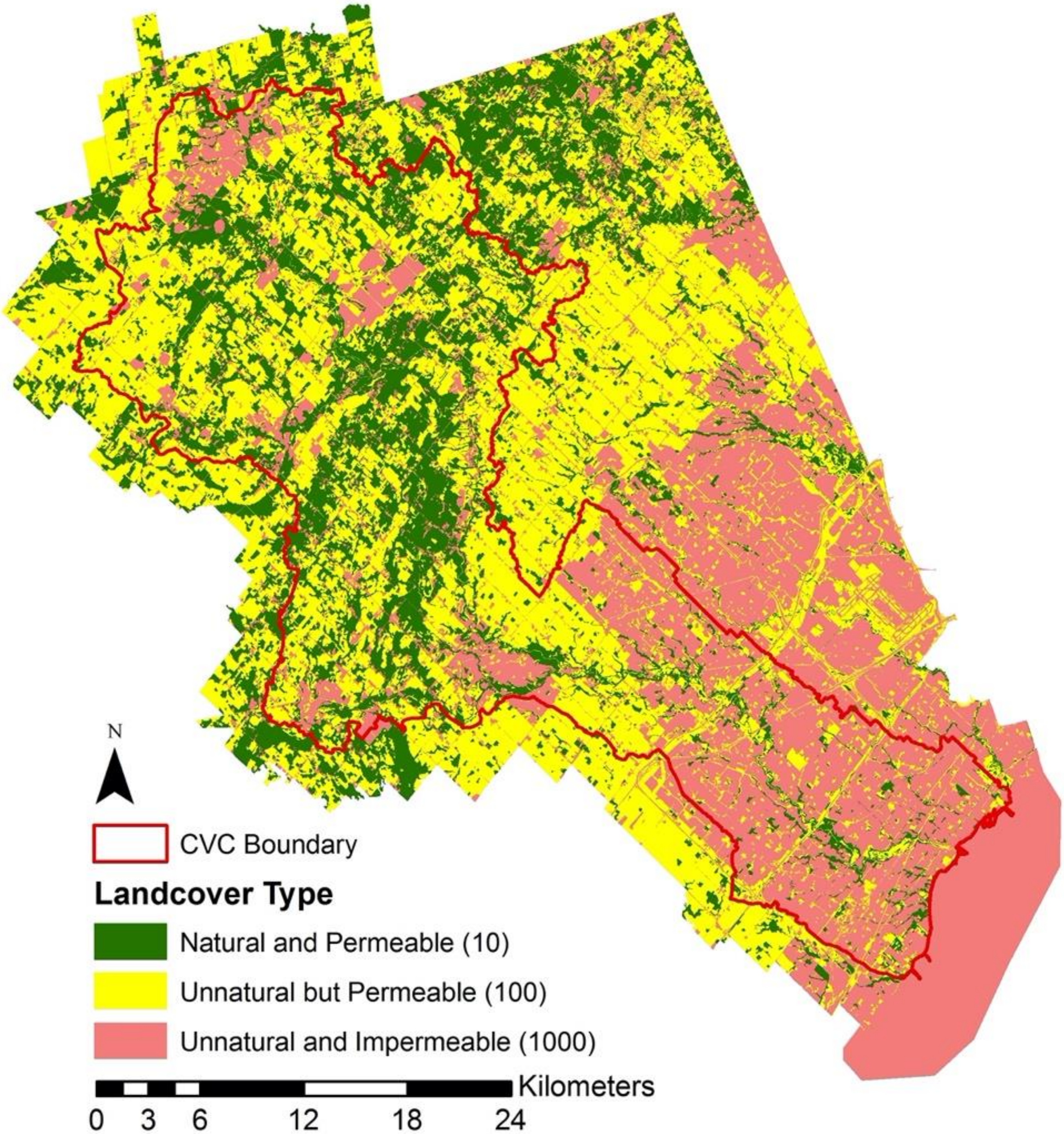


Figure 4: Reclassified land cover map for the Credit River Watershed, with three categories following Bowman & Cordes (2015).

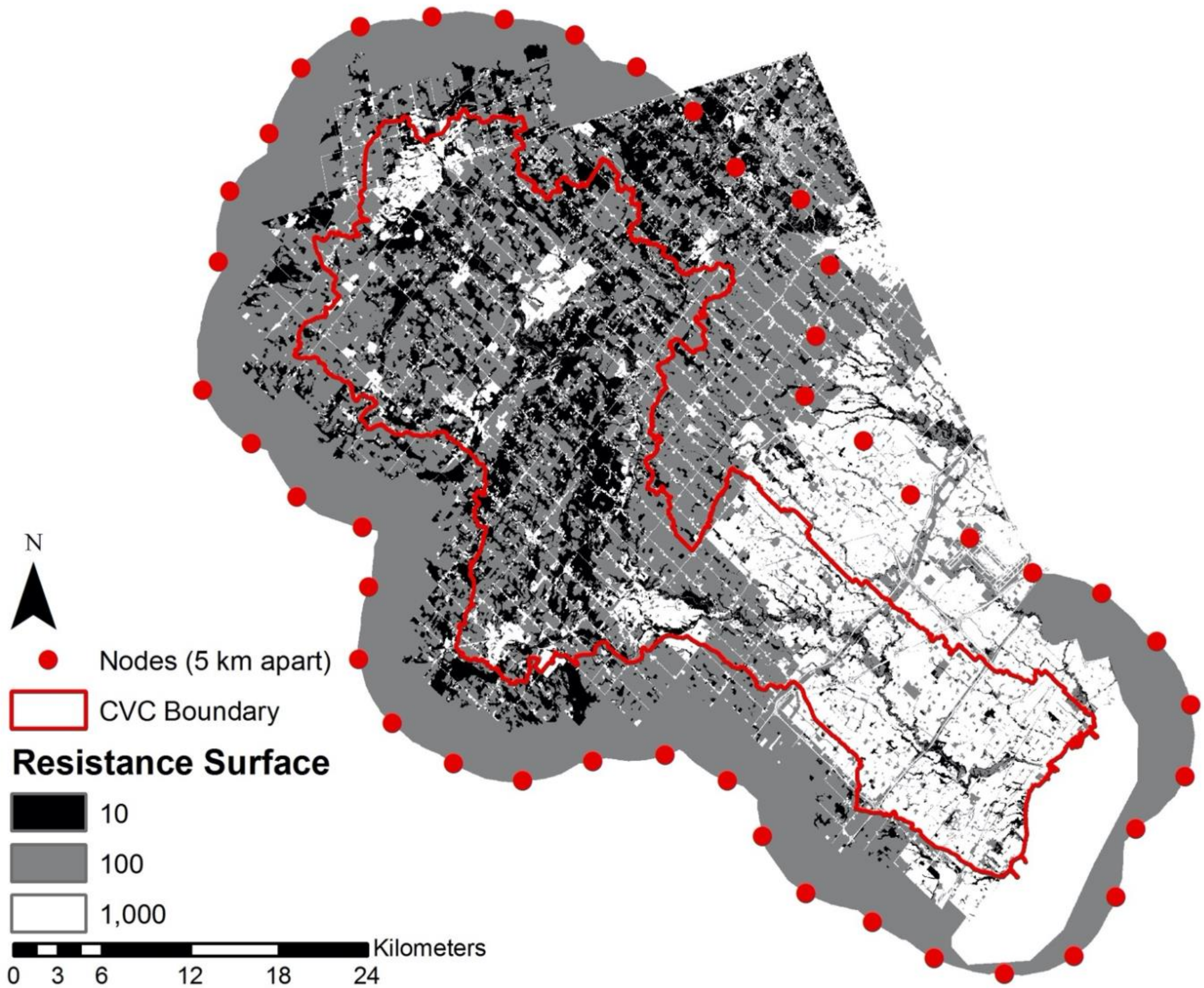


Figure 5: Resistance surface for the Credit River Watershed. The CVC boundary is surrounded by a 25% buffer zone, which was used to place the current sources (nodes).

4.1. Modeling Current Density

To model current density across the Credit River Watershed, we placed current sources with 5 km distance along the outer boundary of the buffer area. We used Circuitscape v4.0.5 (McRae, 2006; McRae et al., 2008) to assess how much current flows through each raster cell when any two current sources are connected. This was repeated for all possible combinations of current sources, and current density was calculated for each cell as the sum of the flow accumulated across all pairs. In order to visualize and contrast important ecological flow routs in the current density map, we standardized current density values as *z*-scores by subtracting the map mean and dividing by the standard deviation for all cells. Values above a *z*-score of 1 are considered to be important ecological flow routs in the map (personal communication with J. Bowman).

For more details on how Circuitscape was implemented in this project (e.g. calculation mode, resistance format, current source placements, and selected outputs) please refer to the project user manual.

4.2. Network of Natural Areas

The natural area polygon input file required for the network analysis with Conefor was also created using CVC's 2018 ELC and Land Use shapefile, after land cover classes were reclassified into resistance categories. We included 2181 natural patches within or intersecting with the Credit River Watershed's polygon in the network analysis (Fig. 6). These patches are contiguous areas of natural cover types of low resistance (value=10). Patches were considered distinct if separated by land cover types of medium (value = 100) or high resistance (value = 1000) (Appendix A).

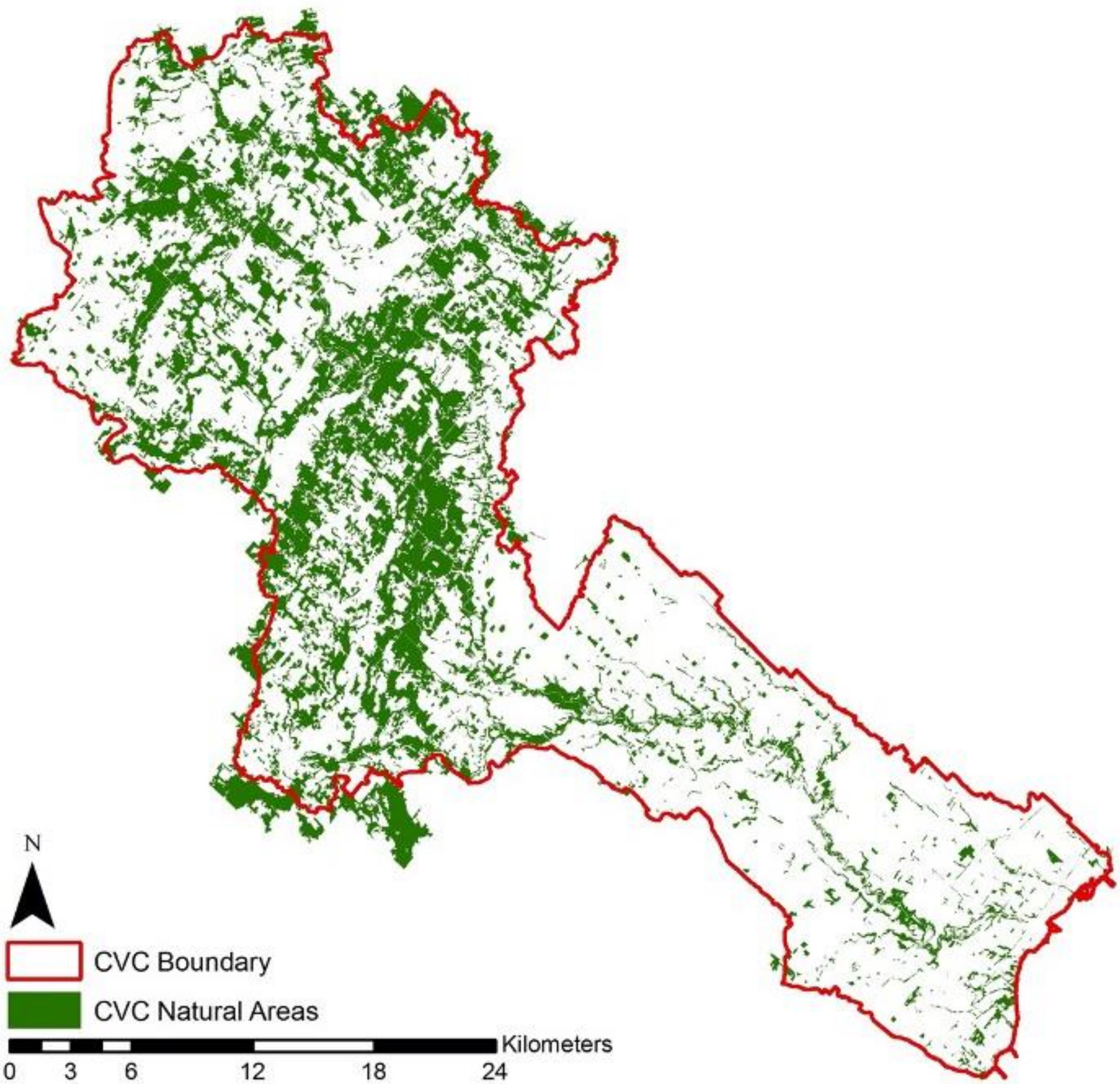


Figure 6: Natural area polygons within and intersecting with the boundary polygon of the Credit Valley Conservation Jurisdiction in the Credit River Watershed.

4.3. Quantifying the Relative Importance of Natural Areas

We used Conefor v2.6 (Saura & Rubio, 2010) to quantify the relative importance of each patch for maintaining connectivity in the network of natural areas in the Credit River Watershed. This involves calculating pairwise distances between all patches in the network and specifying a median dispersal threshold (Fig. 7). We calculated two types of distances that can provide useful information for conservation practices. First, we used the edge-to-edge Euclidian (i.e., straight-line) distance between natural areas. Euclidian distance is the easiest for interpretation as it is informed with some ecologically meaningful median dispersal distances for a group of terrestrial organisms with different dispersal capacities (see below). However, it does not take into account the heterogeneity of the intervening landscape and the ability of these organisms to move across different features types. Therefore, we considered also the least-cost distance derived from the resistance map defined above.

Dispersal ability is inherently a species-specific trait. Rather than selecting the median dispersal distance of a single focal species, we used four median dispersal distances (300 m, 1750 m, 8200 m, and 15,700 m) representing species with short, medium, large and very large dispersal abilities. These dispersal distances were suggested by CVC based on an internal literature review and analysis of available dispersal distance measures for native mammals and herpetiles in the watershed (CVC, 2019). In a review of 63 primary scientific articles, CVC identified dispersal distances for 13 of 27 herptile species and 18 of 39 mammal species confirmed in the watershed. The average dispersal distance for each species was used in a cluster analysis (Jenks Natural Breaks optimization) to form six functional groups with different characteristic dispersal abilities. To focus on the functional groups most vulnerable to landscape connectivity, we excluded the two groups with the highest dispersal distances (this excluded *Ursus americanus* (American black bear), *Neovison vison* (Americal mink), *Martes americana* (American marten), *Lynx rufus* (Bobcat), and *Canis latrans* (Coyote)). The average median

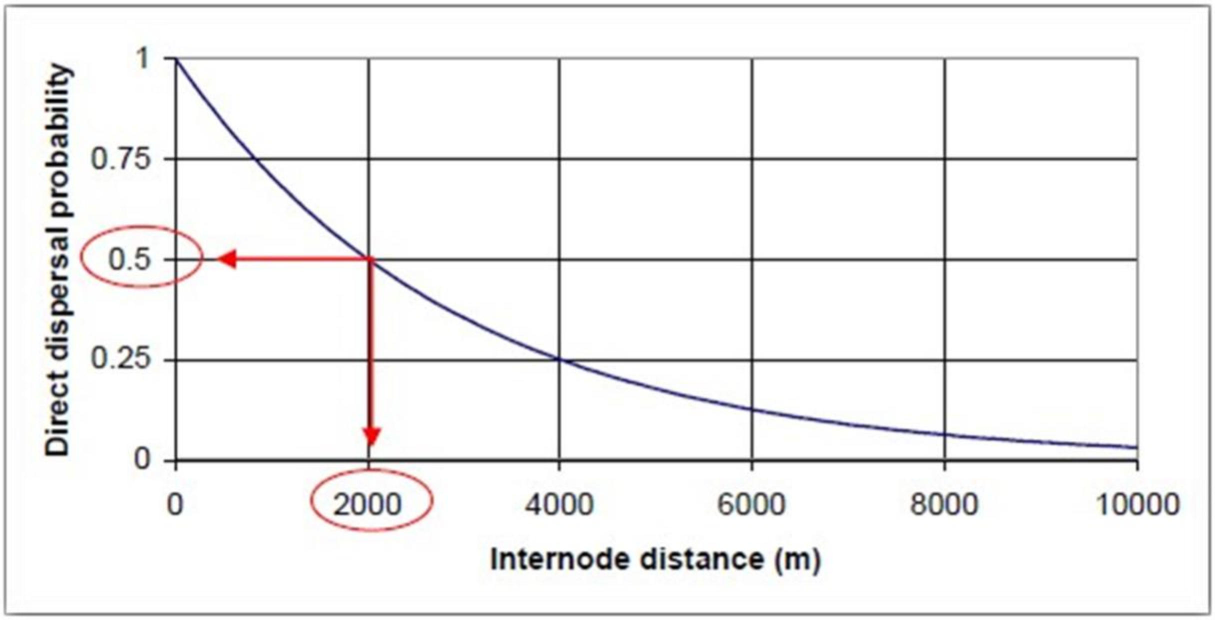


Figure 7: Illustration of the calculation of the probability of direct dispersal between nodes as an exponential decay function of the internodal distance. This example indicates that a distance of 2 km between two patches (internodal distance) will correspond to 50% dispersal probability (Saura & Torné, 2008).

When using least-cost distances (i.e., the cost accumulated along the least cost path between two patches), it becomes necessary to rescale the median dispersal distance (or connectivity would break down in the network) so that dispersal ability is expressed in cost units rather than meters. Following Gurrutxaga *et al*. (2011), we rescaled the dispersal threshold by multiplying the median dispersal distance (in meters) by the median resistance value for the study area (here: median resistance = 100). This rescaled the negative exponential function so that a cost of 100 * median Euclidean dispersal distance corresponded to a 50% probability that two patches are directly connected. Therefore, the median dispersal distances associated with the least-cost approach could be interpreted as the effective capacity of the species to move between patches assuming that they can cross the non-natural but permeable features between natural areas. E.g., with this rescaling, a species with a 300 m median dispersal threshold (Euclidean) would have a 50% probability to disperse 3000 m through natural areas, or 300 m through non-natural but permeable areas, or 30 m through non-permeable areas, which may not be a realistic set of assumptions. Compared to the Euclidean distance approach, the least-cost approach is more biologically relevant as it takes into account the resistance of the intervening landscape, but this comes at a cost of interpretability and justification of the median dispersal threshold.

The metric that is used in Conefor to quantify the overall network connectivity is called PC, the probability of connectivity, (Pascula-Hortal & Saura, 2007). It is the probability that if two points that are randomly placed within the landscape will fall into patches that are connected (i.e., reachable from each other, either directly or through other patches). The change in this probability, referred to as *dPC* (*Equation 1*), is a probability-based quantitative measure of the overall change in connectivity of the network of natural areas when a single patch is removed. The metric dPC thus quantifies the relative importance of each natural area in the network. It can be decomposed into three additive fractions, each indicating a different aspect of contribution to connectivity (*Equation 2*):

1. *dPCintra*: Quantifies the contribution of each patch based on available area only (intrapatch connectivity). For patch C in Fig. 8, this is a function of the probability that two random points are in the same patch C.
2. *dPCflux*: Quantifies the contribution of each patch as a direct connection with other patches in the network. For patch C, this is a function of the probability that one random point is in patch C and one in another patch, B or D, that is directly linked to C.
3. *dPCconnector*: Quantifies the contribution of each patch as a connector between other patches (stepping stone function) For patch C, this is a function of the probability that two random points are in two patches B and D for which the shortest path goes through C.

$$dPC_k = 100 \cdot \frac{PC - PC_{remove,k}}{PC} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.\ldots\ldots\ldots\ldots\ldots\ldots Equation\ 1$$

$$dPC_k = dPC_{intra,k} + dPC_{flux,k} + dPC_{connector,k} \ldots\ldots\ldots\ldots\ldots..Equation\ 2$$

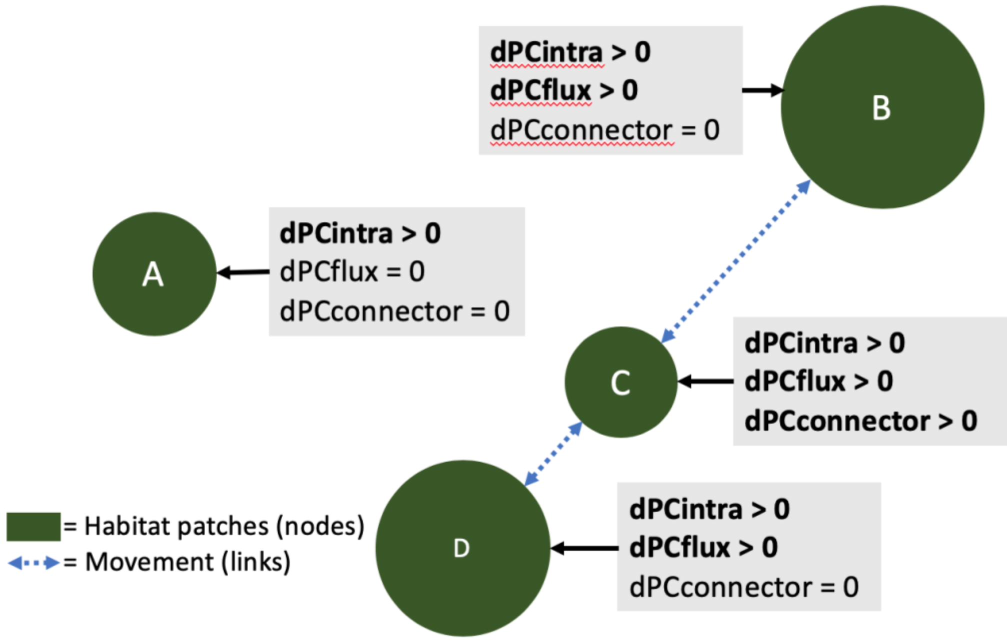


Figure 8: Implementation of graph theory in Conefor to assess the network connectivity and the relative contributions of patches (A-D) and linkages, expressed in terms of three additive fractions of dPC; modified from Saura and Rubio (2010).

For more details on how Conefor was implemented in this project (e.g. calculation mode, probabilistic function, calculated indices, and outputs) please refer to the project user manual.

4.4. Identifying the Most Sensitive Dispersal Distance

For species with a very limited dispersal ability, connected habitat is mostly within the same patch (*dPCintra*) or among neighboring patches that are directly linked (*dPCflux*), with short distances between them. Hence, a very low median dispersal threshold, e.g. lower than the average distance between nearby patches in the network, leads to a break-down of the network into many unconnected components, with single patches or small clusters of nearby patches that lack connections with other parts of the network. In such a situation, connectivity is largely due to the *dPCintra* fraction, with some *dPCflux* within local clusters, and little *dPCconnector* (stepping-stone function). On the other hand, species with very high dispersal ability will be able to reach most patches and are less dependent on stepping-stone patches. Hence, very high median dispersal distances result in a network where most patches are directly linked (*dPCflux*), so that the stepping-stone function (*dPCconnector*) is less important. As a result, the *dPC*connector fraction, summed across the entire network, tends to peak at intermediate median dispersal distances, and the median dispersal distance with the maximum *dPCconnector* function can be interpreted as the dispersal threshold with the highest sensitivity for network connectivity (Gurrutxaga et al., 2011). It is important to note that total network connectivity consists of all three fractions, where *dPCintra* does not depend on the distance threshold at all, *dPCflux* is to some degree affected by it, and *dPCconnector* is the most sensitive.

To identify the most sensitive median dispersal distance, we compared the *dPCconnector* fraction between all median dispersal thresholds for each approach. We included additional thresholds, so that we assessed the sum of the *dPCconnector* function over all patches in the network for each of nine median dispersal thresholds for Euclidean distances (100 m, 200 m, 300 m, 500 m, 1000 m, 1750 m, 3000 m 8200 m, and 15,700) and eleven for least-cost distances (10000, 20000, 30000, 50000, 100000, 175000, 300000, 820000, 1570000, 2000000, 8000000).

5. Results and Discussion

5.1. Resistance Map

We developed a high-resolution (10m×10m) resistance surface for the entire Credit River Watershed (Fig. 5). The three values of resistance (10, 100, and 1000) were used to characterize the reclassified land cover types: natural and permeable, non-natural but permeable, and impermeable land covers in the area. The high-resolution resistance map delineated fine landscape features and important elements for connectivity (e.g., such as underpasses, dirt roads, and residential backyards) that are at least 100 m^2, which is equivalent to the grain size of the resistance map (10m x 10m resolution). For features with smaller size than the raster grain, we assigned the maximum value of the pixel they fall into to be more conservative. Therefore, we were able to produce a high-resolution connectivity map at a relevant scale for conservation practices for the Credit Valley Watershed (Fig. 9 and 10), compared to the outputs from the previous efforts for modelling connectivity in southern Ontario (Bowman & Cordes, 2015). Notably, the input data included a field-based inventory of culverts and underpasses (CVC's Road and Valley Crossing Data), which was not considered in the previous, larger-scale analysis.

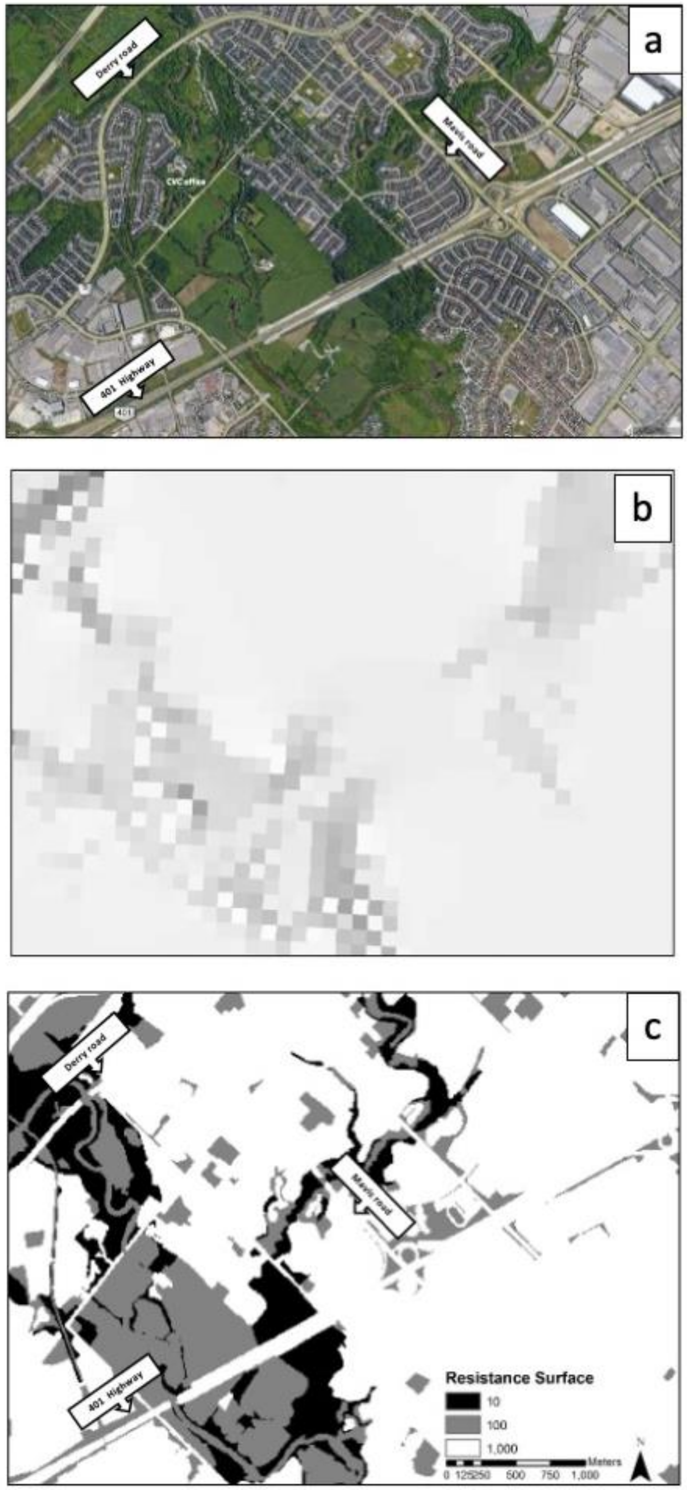


Figure 9: Illustration of high-resolution resistance map for a heterogenous landscape within the Credit River Watershed. a) Google Earth satellite image of the area, b) resistance map at 100 m resolution (Bowman & Cordes, 2015), and c) high-resolution resistance map (10m) with fine details of landscape elements, including an underpass under Highway 401.

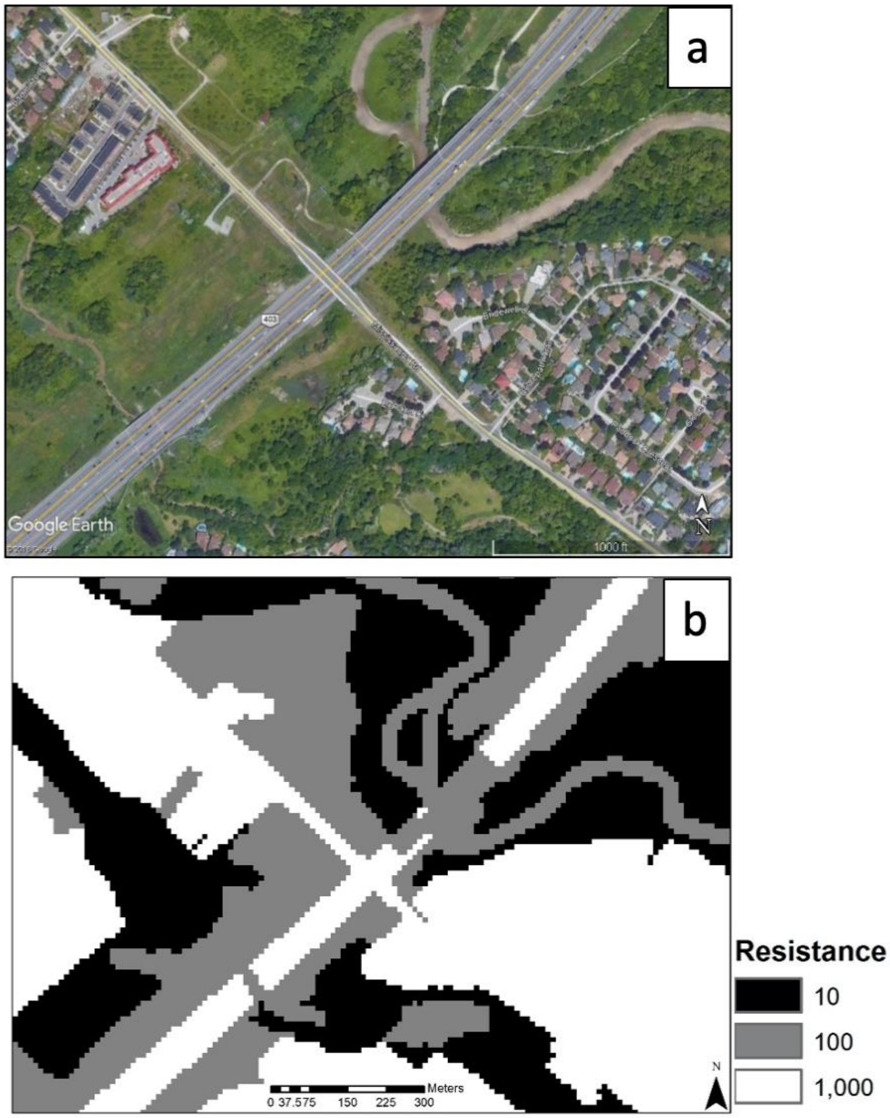


Figure 10: A close-up demonstration of the high-resolution resistance map for a heterogenous landscape within the Credit River Watershed. The area is at the intersection of Highway 403, and Mississauga Road. It includes natural underpasses of the Credit River to the northeast, and Mullet Creek to the southwest. a) Google Earth satellite image of the area, b) high-resolution resistance map (10m).

5.2. Current Density Map

Circuitscape analysis of the resistance map resulted in a high-resolution, wall-to-wall current density map for the Credit River Watershed. While resistance values reflect the cover type of each pixel (100 m^2), current density values indicate the contribution of each pixel to connectivity across the watershed. Hence, it is important to consider the spatial context within the watershed when interpreting current density values. Broadly speaking, the current density map shows three general patterns of current flow:

1. *Areas with high current flow (pinch-points):* These are areas of high current density representing natural and permeable, and non-natural but permeable elements that are bounded by barriers of current flow in the landscape. These areas are important biodiversity movement corridors that support the dispersal of terrestrial organisms through areas that are difficult to traverse otherwise, with few or no alternative pathways available. Therefore, conservation efforts should prioritize these areas as their loss due to future urban development will likely threaten the biological sustainability of terrestrial wildlife populations. The patterns of high-flow or 'biodiversity highways' are concentrated along the Credit River running from the southeast to the northwest of the watershed.

   More pronounced patterns of these pinch-points and high current density areas are noticed in the area that connects the upper and lower watersheds. This central area, located in the middle of the Credit River Watershed, is of special importance for maintaining connectivity across the entire watershed, as in can be considered as a biodiversity traffic hub for organisms to move across the Credit River Watershed (Fig. 11). In practical terms, it will be important not to block flow along the main direction of flow and to maintain multiple routes to create some redundancy.

2. *Areas with low current flow*: These areas were found in urban centers, mainly represented by Mississauga and Brampton in the lower watershed, south of the Greenbelt. In these areas, current flow is restricted by large areas dominated by residential areas and anthropogenic barriers (Fig. 11).

3. *Areas with diffuse current flow*: These areas tend to occur in large, intact areas of natural and semi-natural land covers where current flow can spread anywhere. This is due to a high availability of permeable (low resistance) habitats that facilitate the movement of terrestrial wildlife in the Credit River Watershed. Such areas are abundant in the upper watershed and in the Greenbelt area (Fig. 11). Note that such diffuse flow, and thus low current density, does not indicate an absence of connectivity but a low contribution,

per unit area (pixel), to the maintenance of larger-scale connectivity, as there are many alternative routes available.

A pixel with low resistance (natural area) can thus have low current density if flow is unrestricted in its surrounding landscape (diffused current). Or it can have high current density if it forms part of a 'biodiversity highway', an important connection across the watershed where the current is funneled through pinch points due to barriers to movement on either side (bottleneck). A pixel with medium or high resistance (non-natural area) can have low current density because current flow is diverted by a continuous barrier of non-natural features. Or it can have high current density because the best way leads through that pixel. This is often the case for pixels adjacent to natural areas that lie along the shortest path from one natural area to the next, where these natural areas are part of a main connection ('biodiversity highway') across the watershed. This creates a 'halo' effect as can be seen in Fig. 12. In such situations, it will be important to avoid breaking the flow between these natural areas with impermeable structures, or to mitigate them e.g. with underpasses.

Another type of halo effect occurs around blocks of impermeable features, such as buildings, parking lots, etc. that lie in areas that are important for connectivity across the watershed (Fig. 13, a). The current flow is diverted around the obstacle, with high current density right adjacent to the impermeable structure. What is important here is to recognize the diversion, not the actual pixels that have the highest current density. It is likely that many organisms would keep a larger distance to such structures, rather than follow their edge very closely. The diversion effect will be stronger if the structure lies orthogonal to the main direction of flow. Thus, new development plans may consider constructing new elements parallel to the flow direction instead of interrupting it (Fig. 13, b). At the larger scale, development plans should also consider maintaining multiple routes of biodiversity flow and not only focus on (avoiding or mitigating) pinch-points at the local scale (Gurrutxaga et al., 2010).

Modelling such a high-resolution connectivity map allowed us to demonstrate the importance of fine natural habitat elements in the Credit River Watershed that are crucial for maintaining the connectivity of this unique natural heritage system at the watershed scale (Fig. 11). The previous modeling of current density for southern Ontario by (Bowman & Cordes, 2015) showed the southern part of the watershed as a connectivity desert, whereas the upper Credit watershed (Greenbelt) formed part of a main biodiversity highway connecting the Niagara peninsula and SW Ontario to the Canadian Shield. This important value of the Credit River Watershed in maintaining the connectivity of natural heritage system in southern Ontario was underestimated in the previous efforts done by which represented the area as a connectivity desert (Figure 1). This underestimation was mainly due to the spatial resolution at which resistance was modelled (Fig. 9 for a contrast between studies) and the placement of the current sources, which forced the current to deviate around the Greenbelt and to dissolve in the large water body of Lake Ontario. In the larger spatial context of the Golden Horseshoe area, most flow runs through the greenbelt in a SW – NE direction (Fig. 2).

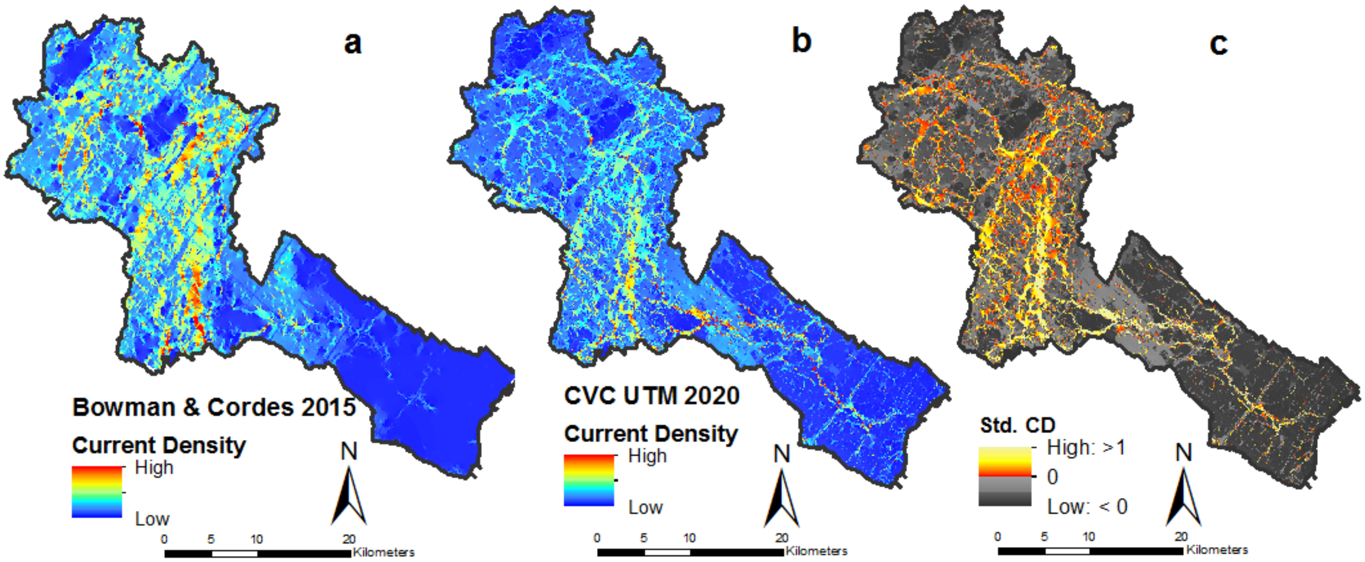


Figure 11: Wall-to-wall current density maps illustrating patterns of current density across the Credit River Watershed. a) Current density map from Bowman and Cordes 2015 showing high current flow in the middle watershed, diffused current flow in the upper watershed, and low current flow in the lower watershed mainly in Mississauga and Brampton urban centers; b) Current density map this project showing more defined and important current flow in the lower watershed compared to the map in a; c) Standardized current density map from this project that contrasts high current flow and biodiversity highways (heat color ramp, SD>0) to the diffused and low current density areas (grey scale areas, SD<0).

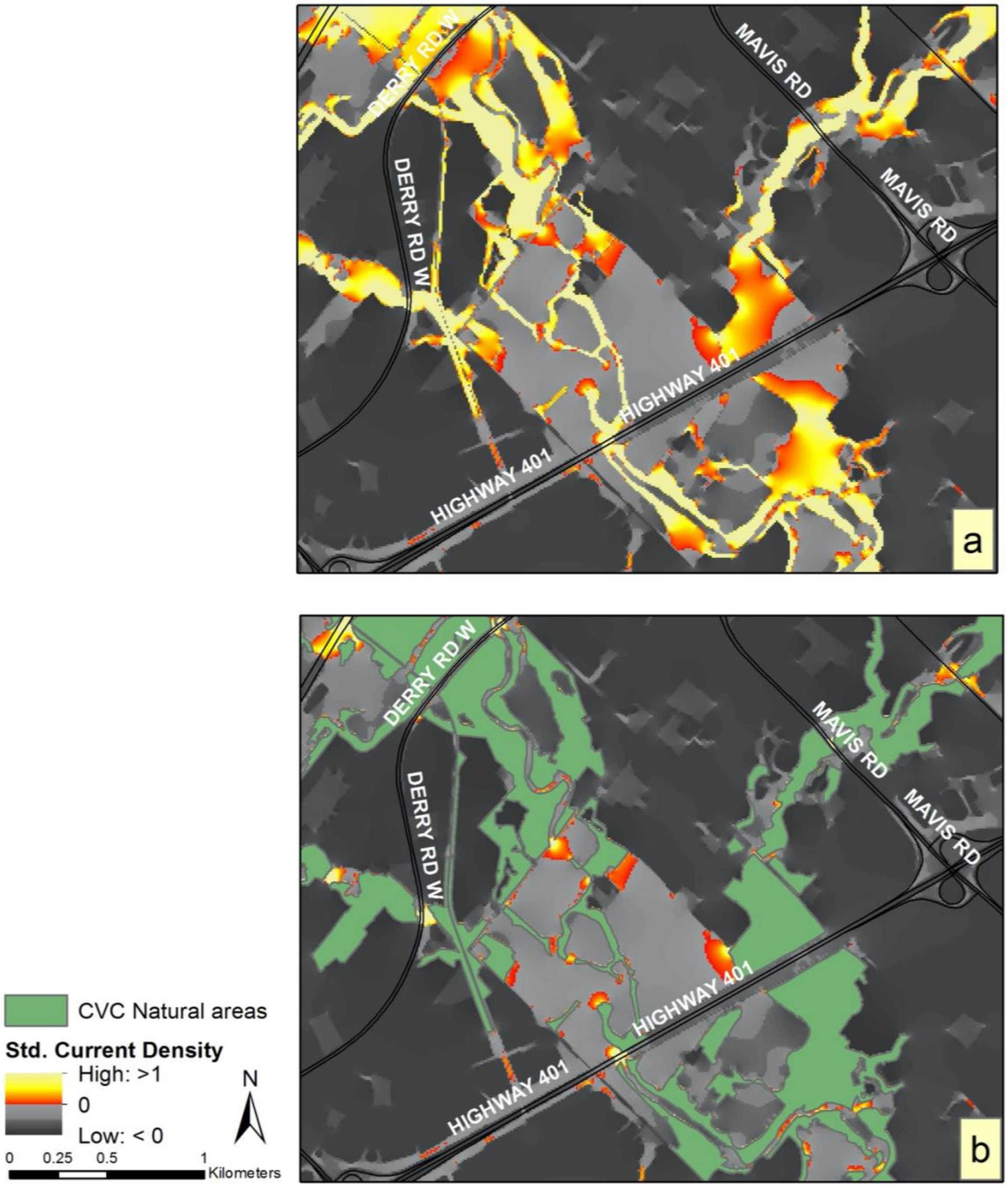


Figure 12: A close-up current density map of: a) the area around the Conservation's 401 and the Credit River Administration Office in the Village of Meadowvale, Mississauga illustrating important pinch-points points (e.g. culverts and underpasses intersecting with Highway 401 and with Old Derry Road) and high current flow patterns of fine natural elements in the landscape; and b) the same area with natural areas (green) overlaid on the current density map, with halo effects where flow funneled through natural areas diffuses into adjacent areas of intermediate resistance.

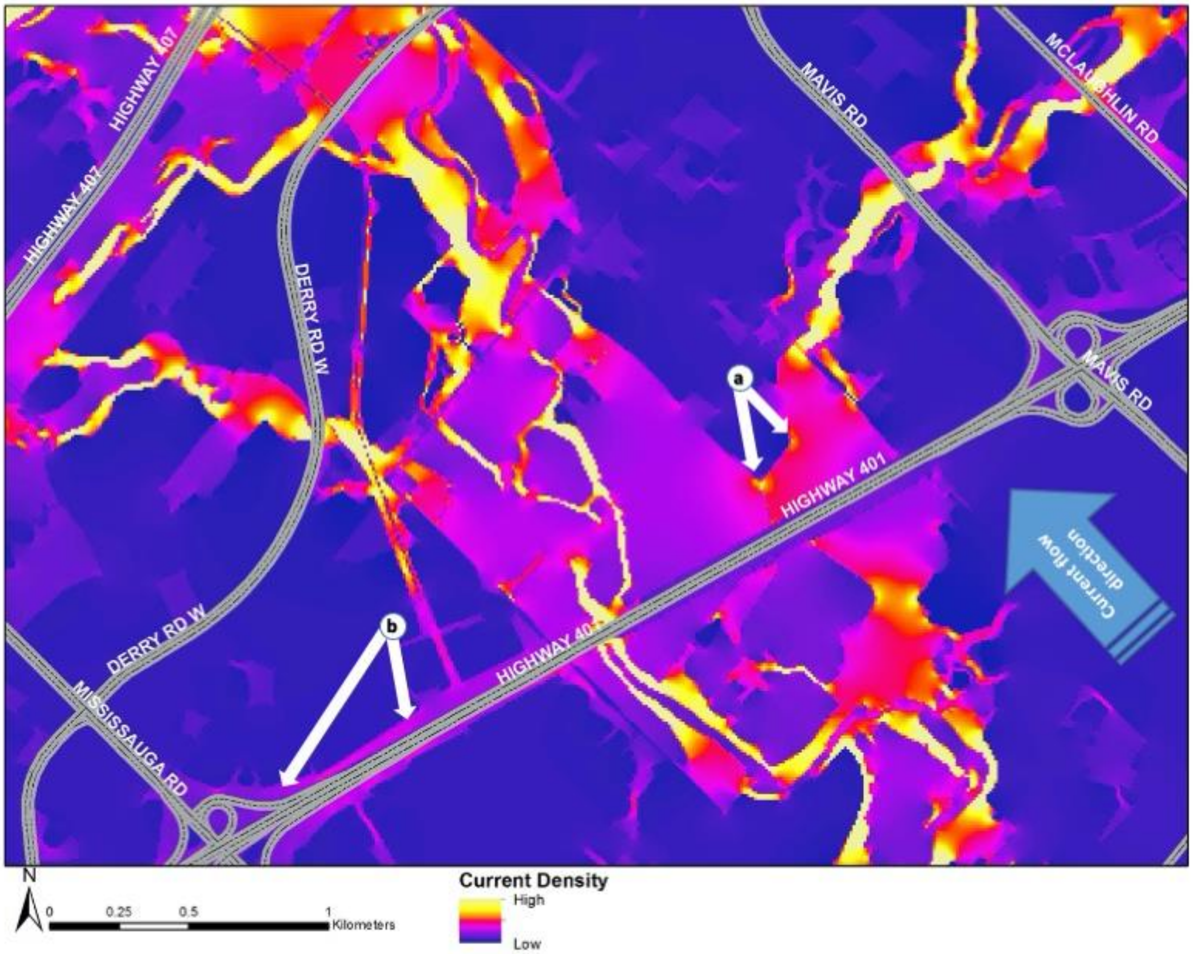


Figure 13: Close-up current density map around the CVC area showing: a) Halo effect around blocks of impermeable features (e.g. St. Julia Catholic Elementary School and residential neighborhood). The current flow is diverted around the buildings with high current density right adjacent to the impermeable structure; b) Another halo effect due to stronger diversion of the current when the structure lies orthogonal (e.g. Highway 401) to the current flow direction. Main current flow direction is demonstrated with the blue arrow.

5.3. Most Sensitive Dispersal Distance

For the network analysis with Conefor, we assessed the sensitivity of the stepping-stone function (*dPCconnector fraction*) across a range of dispersal thresholds. For the analysis with Euclidean edge-to-edge distances between natural areas, the share of the *dPCconnector* fraction did not show a clear maximum but a plateau for median dispersal distances between 300 – 1750 m (Fig. 14). This suggests that, based on the physical distance between natural areas, stepping-stone patches in the network of natural areas in the Credit River watershed are especially important for species with low or medium dispersal ability, i.e., the first two groups identified by CVC, with median dispersal thresholds of 300 m and 1750 m.

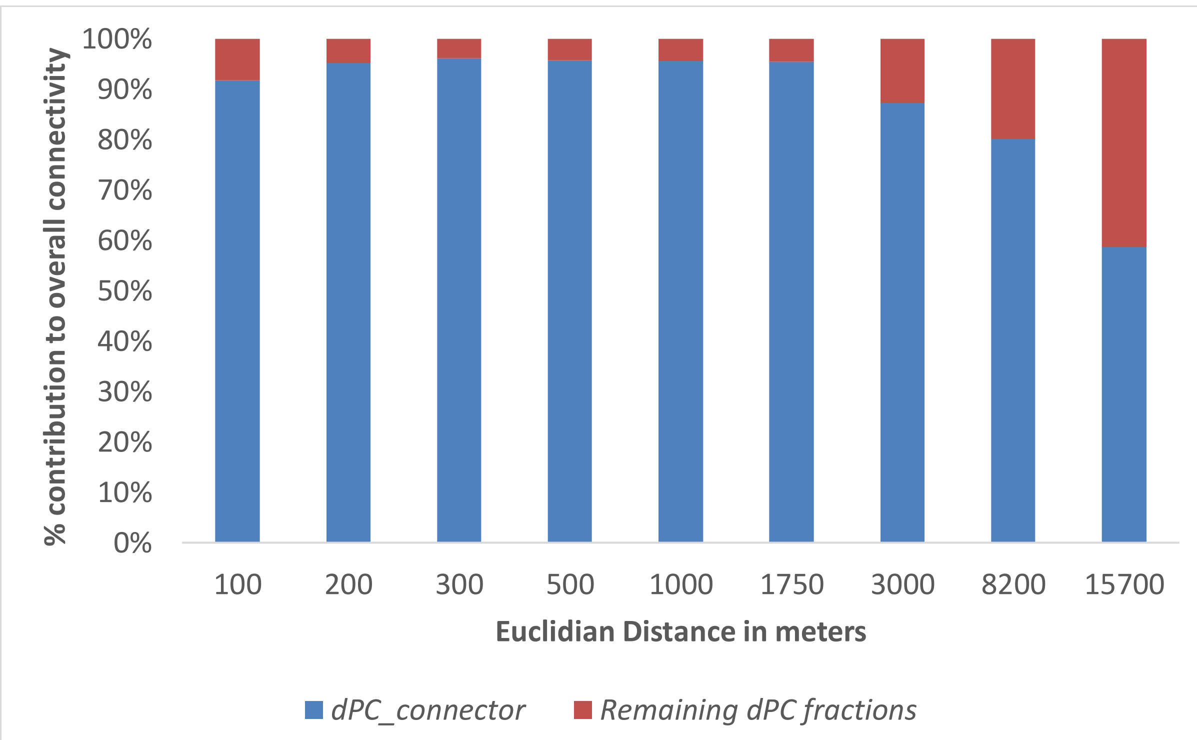


Figure 14: Relative contribution of *dPCconnector* to the total importance of natural habitat patches in the connectivity network of the Credit River Watershed, as a function of the median dispersal distance.

With least-cost distances, the share of the *dPCconnector* fraction was found to increase with the threshold, asymptotically reaching a plateau around 820,000 (Fig. 15). This value corresponds to the threshold for the third group (820000 = 8200 m * 100, where 100 is the median resistance value corresponding to non-natural but permeable areas).

The results show an increase at short threshold values, as expected, but no decrease at high threshold values, which suggests that a conversion factor larger than 100 would be needed to reflect the range of responses seen for Euclidean distances. Such a high conversion factor of Euclidean distance thresholds to cost distances, however, is biologically hard to justify, as it would imply that species can move large distances through areas classified as 'impermeable'. Based on these results, we recommend that interpretation of the network connectivity analysis be based on the analysis with Euclidean distances.

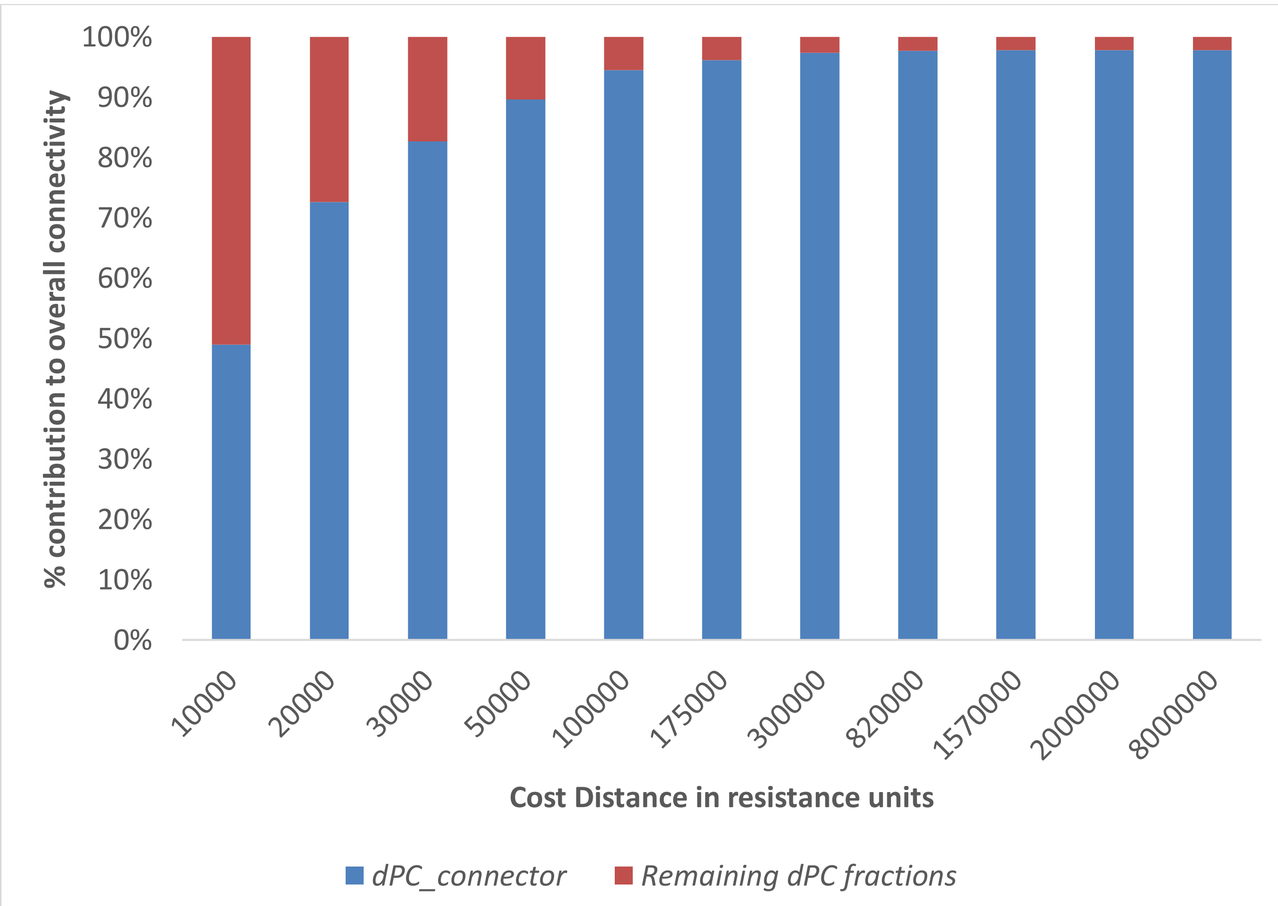


Figure 15: Relative contribution of *dPCconnector* to the total importance of natural habitat patches in the connectivity network of the Credit River Watershed, as a function of the cost distance.

5.4. Network Connectivity Analysis Results

All maps are presented in Appendix C, appended to this report. Given the results from the sensitivity analysis, we focus the discussion of the network connectivity analysis on the results for Euclidean distances with a median dispersal threshold of 1750 m.

The overall probability of connectivity in the network of natural areas in the Credit River watershed can be decomposed into additive values dPC_i that express how much of the overall PC would be lost if patch *i* were lost from the network (Appendix C-6). This contribution of each patch is again composed of three additive fractions. Patches with high *dPCintra* values contain an important portion of the total natural area in the watershed (Appendix C-8). Note that this is a direct function of patch size and does not consider patch type, quality, core area, etc. Patches with high *dPCflux* values are more important than based on their area alone, as they are part of a local cluster through direct connections with nearby patches (Appendix C-9). Note that the probability of these direct connections is based on distance alone (for maps with Euclidean distance) and does not take into account whether patches are separated by permeable or impermeable non-natural features. Finally, patches with high *dPCconnector* values have an important stepping-stone function in the network. Note that this value is based on the shortest paths between pairs of other patches that are routed through the stepping stone, it does not directly say whether or not there are alternative, longer routes available.

The relative magnitude of these three components tends to vary with the mean dispersal distance of organisms (Saura & Rubio, 2010):

1- At short and intermediate median dispersal distances, the *dPCconnector* (the probability that a patch is a stepping-stone for dispersal between two patches) contributes the most to overall habitat connectivity. The sensitivity analysis suggests that this is the case for species with median dispersal distances of 300 - 1750 m. Stepping-stone patches may thus be most important for these species groups. Local resource availability can be enhanced by maintaining links within local clusters of natural areas. Hence, such species which will likely benefit the most from an integrated strategy that focuses on promoting connectivity routes across the landscape, maintaining multiple connections within local clusters, and enhancing habitat amount and quality at the patch level, especially for the stepping-stone patches.

2- For very large median dispersal distances, *dPCflux* (the probability that two randomly placed points occur within patches that are connected) is the fraction that makes the largest contribution to overall habitat connectivity (*dPC*). Due to the dispersal abilities of these species, most of the natural habitat patches will be connected anyways. Therefore, maintaining a large-scale connectivity pathways would likely allow these species to move across the landscape. The sensitivity analysis suggests that this is the case for species with median dispersal distances larger than 1750 m.

Thus, there is not a single fraction of the dPC metric that would be most important, given the diverse habitat patches in the area. Rather, our results support that integration of conservation mechanisms at both local (natural habitat amount and size, connections within local clusters) and landscape levels (connectivity corridors) is needed to maintain the biodiversity and connectivity in this natural heritage system. This is reflected in the values of the *dPC* metrics, as listed in Appendix D for the top 100 natural areas in the Credit River Watershed.

6. Recommendations

This project enabled us to provide some important recommendations that should be taken into account for conservation practices and development planning. The following are the key points:

- **Scenarios involving the conversion of natural areas** (from resistance value 10 to 100): the conservation value of a natural area will depend on many factors and will likely be assesses based on species inventories and an assessment of habitat quality, in addition to an assessment of its role in the network of natural areas. The contribution of each patch to network connectivity is summarized by its overall *dPC* value, whereas the three component scores (*dPCintra*, *dPCflux* and *dPCconnector*) help characterize its main role in the network (as a large patch, part of a cluster, or stepping stone, respectively).
- **Scenarios involving the conversion of permeable to impermeable non-natural areas** (from resistance value 100 to 1000): the current density map can be used to check whether an existing, permeable non-natural area lies on a 'biodiversity highway' and thus needs special consideration. It can also be used to identify alternative routes that could be enhanced as a mitigation measure, and intersections between existing or planned barriers with 'biodiversity highways' where mitigation measures such as underpasses would be most important. As a general recommendation, structures would ideally be placed in parallel with the main direction of flow, rather than orthogonal to it, with corridors along the main direction of flow that link to natural areas along connectivity routes.

While updating the resistance map is straight-forward, the current density map should not be recalculated locally but for the entire watershed, so that it can appropriately capture current flow across the watershed.

- **Combination of current density and network connectivity approaches for local assessment**: ideally, network connectivity analysis with Conefor using least-cost distances would integrate aspects relating to natural and non-natural areas as discussed above. However, the sensitivity analysis illustrated major concerns related to the definition and interpretation of a dispersal threshold for cost distances. Therefore, we recommend an overlay of the natural area over the connectivity map in order to assess the local interplay between the network of natural areas and the intervening, non-natural landscape features (Fig. 11b). It is important to consider a large-enough local landscape so that the connectivity routes passing through the local landscape are adequately represented to provide spatial context.

  Specifically, such an overlay can be used to identify bottlenecks that require special attention, as well as the main connectivity routes, including alternative routes. General principles for managing areas along connectivity routes would include (1) mitigating, and avoiding the creation of new pinch points; (2) maintaining or enhancing flow along major connectivity routes (biodiversity highways); (3) promoting redundancy in the system by maintaining alternative routes; and (4) minimizing the diversion of diffused flow by new development.

It is very important to state that these results should never be the only criterion to assess conservation value. Rather, they should be seen as additional valuable tools that complement existing conservation planning tools (e.g. habitat quality and species occurrence data).

7. Limitations

7.1. Computational Resources

Current density modelling with Circuitscape using high resolution rasters for the extent of this project, and the network analysis in Conefor for 2181 patches are very resource-demanding computational processes. The following table represents some examples of computation times. Note that we carried out these steps on PC Desktop machines, where possible, to assess feasibility with CVC’s resources. However, we were forced to run the network analysis on a high-performance computing (HPC) cluster.

Table 1: Computation time per process and software showing the high computation demand of different analysis.

Process	Software	Platform specs.	Time (Days)
Wall-to-wall map	Circuitscape	PC Desktop (6 cores, 32GB RAM)	3
LCP computation	Linkage Mapper (ArcGIS)	PC Desktop (6 cores, 32GB RAM)	7-10
Network analysis	Conefor	UTM HPC cluster (CALCULON) 12 cores, 120 GB RAM	4-7
Network analysis	Conefor	PC Desktop	ONLY local applications

7.2. Conefor Limitations

Link-level analysis, which would quantify also the *dPCconnector* function of each linkage between patches, is not yet available in the command line version of Conefor (Martensen et al., 2017). In order to complete the watershed-level analysis, we ran the command line version of Conefor through UTM's HPC facility 'Calculon'. Given the computational demands for this large-scale analysis, completing the estimations with the standalone software on a regular desktop computer is not viable.

7.3. Probability of Connectivity Indices

The total probability of connectivity of the network (PC) is a probability and thus scaled between 0 – 1. The dPC values are calculated as the ratio of PC without the patch divided by PC with the patch, resulting in a proportion. These dPC values are additive across patches and across fractions (*dPCintra*, *dPCflux* and *dPCconnector*) and thus represent percentages of the total PC of the network, given the inter-patch distances and the median dispersal distance threshold. This means that *dPC* values can be compared within one map but not between maps. It also helps explain why the maximum patch *dPC* values decreased with increasing dispersal threshold (Appendices C-4 through C-6): larger dispersal distances lead to higher overall PC as more patches are connected directly or via stepping stones (higher dPCflux and dPCconnector fractions). This increases redundancy in the network so that if one patch is removed, other patches still remain connected.

As discussed above, we recommend using Euclidean edge-to-edge distances over least-cost distances. These straight-line distances do not reflect the effect of any barriers (impermeable features) between patches. The underlying assumption is that the non-natural area is uniformly permeable and that the negative binomial dispersal function defined by the median dispersal threshold adequately models the organism's probability of dispersal between patches. These assumptions have not been validated here.

7.4. Current Density Modeling

This project uses a species-agnostic model, which does not account for any specific ecological or biological requirements of terrestrial wildlife. Rather, structural connectivity modelling is based on the degree of non-naturalness of landscape elements following the classification scheme by Bowman and Cordes (2015). Although this approach can be criticized for lacking a species-specific consideration, it has been validated with amphibian road crossing data and with genetic data for four mammal species (Koen et al., 2014; Marrotte et al., 2017). We recommend further validation for additional taxonomic groups and in an urbanized setting more representative of the Credit River watershed.

8. Spatial Data and Project Products

8.1. Report, Appendices and Maps

Three products are available through CVC:

1. The final report and appendices (this document).

2. The project user manual to reproduce results and maps for the project.

3. Final resistance, current density and standardized current density maps in PDF format, and as ArcGIS layers at CVC.

8.2. GIS data

GIS data created for this project, including natural areas polygons, CVC boundary, buffer boundary, resistance thematic and raster layers, and current flow raster, are available at CVC.

8.3. Scripts:

Computer code created to run Conefor network analysis on the HPC are available through UTM Dataverse data repository at: https://dataverse.scholarsportal.info/dataset.xhtml?persistentId=doi:10.5683/SP2/CMGXZR

9. Appendices

9.1. Appendix A: Land cover types and resistance classification.

Land cover types in CVC's 2018 ELC and Land use	*Resistance Value*	*Justification for resistance category*
		Aquatic communities
Open aquatic	1000	Consistent with Bowman & Cordes (2015).
*Open aquatic river**	100	Bowman and Cordes (2015) considered all open aquatic habitat to be impermeable to wildlife. CVC's ELC and Land use shapefile delineates all waterbodies as open aquatic habitat, but it also delineates much of the Credit River as open aquatic (generally sections of the river which are >20 m). The project team agreed that rivers should not be considered impermeable to wildlife, as many terrestrial species are able to cross rivers.
Floating-leaved shallow aquatic	1000	Consistent with Bowman & Cordes (2015).
Mixed shallow aquatic	1000	Consistent with Bowman & Cordes (2015).
Submerged shallow aquatic	1000	Consistent with Bowman & Cordes (2015).
		Wetland communities
Shrub bog	10	Consistent with Bowman & Cordes (2015).
Treed bog	10	Consistent with Bowman & Cordes (2015).
Open fen	10	Consistent with Bowman & Cordes (2015).
Shrub fen	10	Consistent with Bowman & Cordes (2015).
Treed fen	10	Consistent with Bowman & Cordes (2015).
Marsh	10	Consistent with Bowman & Cordes (2015).
Coniferous swamp	10	Consistent with Bowman & Cordes (2015).
Deciduous swamp	10	Consistent with Bowman & Cordes (2015).
Mixed swamp	10	Consistent with Bowman & Cordes (2015).
Thicket swamp	10	Consistent with Bowman & Cordes (2015).
		Upland forest communities
Coniferous forest	10	Consistent with Bowman & Cordes (2015).
Deciduous forest	10	Consistent with Bowman & Cordes (2015).
Mixed forest	10	Consistent with Bowman & Cordes (2015).
		Cultural forest communities
Cultural woodland	10	Consistent with Bowman & Cordes (2015).
Plantation	10	Consistent with Bowman & Cordes (2015).
		Successional communities
Cultural hedgerow	100	Cultural hedgerows are susceptible to removal anytime by landowners.
Cultural meadow	100	Cultural meadows are susceptible to active management anytime by landowners.
Cultural savannah	10	Cultural savannahs are assumed to be at lower risk of active management by landowners due to the landowner's tolerance for tree cover.
Cultural thicket	10	Cultural thickets are assumed to be at lower risk of active management by landowners due to the landowner's tolerance for succession.
		Other natural communities
Shrub beach / bar	10	Consistent with Bowman & Cordes (2015).
Open beach / bar	10	Consistent with Bowman & Cordes (2015).
Treed beach / bar	10	Consistent with Bowman & Cordes (2015).

Open rock barren	10	Consistent with Bowman & Cordes (2015).
Open bluff	100	Bluffs are assumed to be generally climbable by terrestrial wildlife.
Shrub bluff	100	Bluffs are assumed to be generally climbable by terrestrial wildlife.
Treed bluff	100	Bluffs are assumed to be climbable by terrestrial wildlife.
Open clay barren	10	Consistent with Bowman & Cordes (2015).
Shrub clay barren	10	Consistent with Bowman & Cordes (2015).
Treed clay barren	10	Consistent with Bowman & Cordes (2015).
Open sand barren	10	Consistent with Bowman & Cordes (2015).
Shrub sand barren	10	Consistent with Bowman & Cordes (2015).
Treed sand barren	10	Consistent with Bowman & Cordes (2015).
Shrub sand dune	10	Consistent with Bowman & Cordes (2015).
Treed cliff	1000	Consistent with Bowman & Cordes (2015).
Carbonate treed talus	100	Talus slopes are assumed to be generally climbable by terrestrial wildlife.
Carbonate shrub talus	100	Talus slopes are assumed to be generally climbable by terrestrial wildlife.
Tallgrass Prairie	10	Consistent with Bowman & Cordes (2015).
		Open Space land uses
Commercial / industrial/ institutional/ private open space	100	Consistent with Bowman & Cordes (2015).
Recreational open space	100	Consistent with Bowman & Cordes (2015).
Manicured open space	100	Consistent with Bowman & Cordes (2015).
		Agricultural land uses
Intensive agriculture	100	Consistent with Bowman & Cordes (2015).
Non-intensive agriculture	100	Consistent with Bowman & Cordes (2015).
Wet meadow	100	Consistent with Bowman & Cordes (2015).
Inactive aggregate	100	Consistent with Bowman & Cordes (2015).
		Urban land uses
Active aggregate	1000	Consistent with Bowman & Cordes (2015).
Commercial / industrial	1000	Consistent with Bowman & Cordes (2015).
Educational / institutional	1000	Consistent with Bowman & Cordes (2015).
Construction	1000	Consistent with Bowman & Cordes (2015).
Landfill	1000	Consistent with Bowman & Cordes (2015).
Major trail	100	Not natural but passable by all terrestrial wildlife.
Rural development	1000	Contains building footprints, not passable by wildlife.
General urban	1000	Consistent with Bowman & Cordes (2015).
Residential	1000	Consistent with Bowman & Cordes (2015).
		Transportation land uses
Highway	1000	Consistent with Bowman & Cordes (2015).
Regional road	1000	Consistent with Bowman & Cordes (2015).
Railroad	100	Studies have shown that rail networks serve as movement corridors for many species, particularly mammals.
Airport	1000	Not passable by wildlife.
Collector	1000	Not passable by wildlife.
*Gravel roads**	100	Lower risk of collision with terrestrial species.
*Wildlife passage**	100	Although wildlife passages permit movement of species under roads, the presence of a man-made structure (i.e. bridges and culverts), human presence and traffic noise may discourage movement.

* Land cover types that were added to CVC's ELC and Land Use shapefile to better reflect the resistance of the landscape.

9.2. Appendix B: Data Sources

Table B1. The GIS shapefiles created by CVC and provided to UTM for analysis.

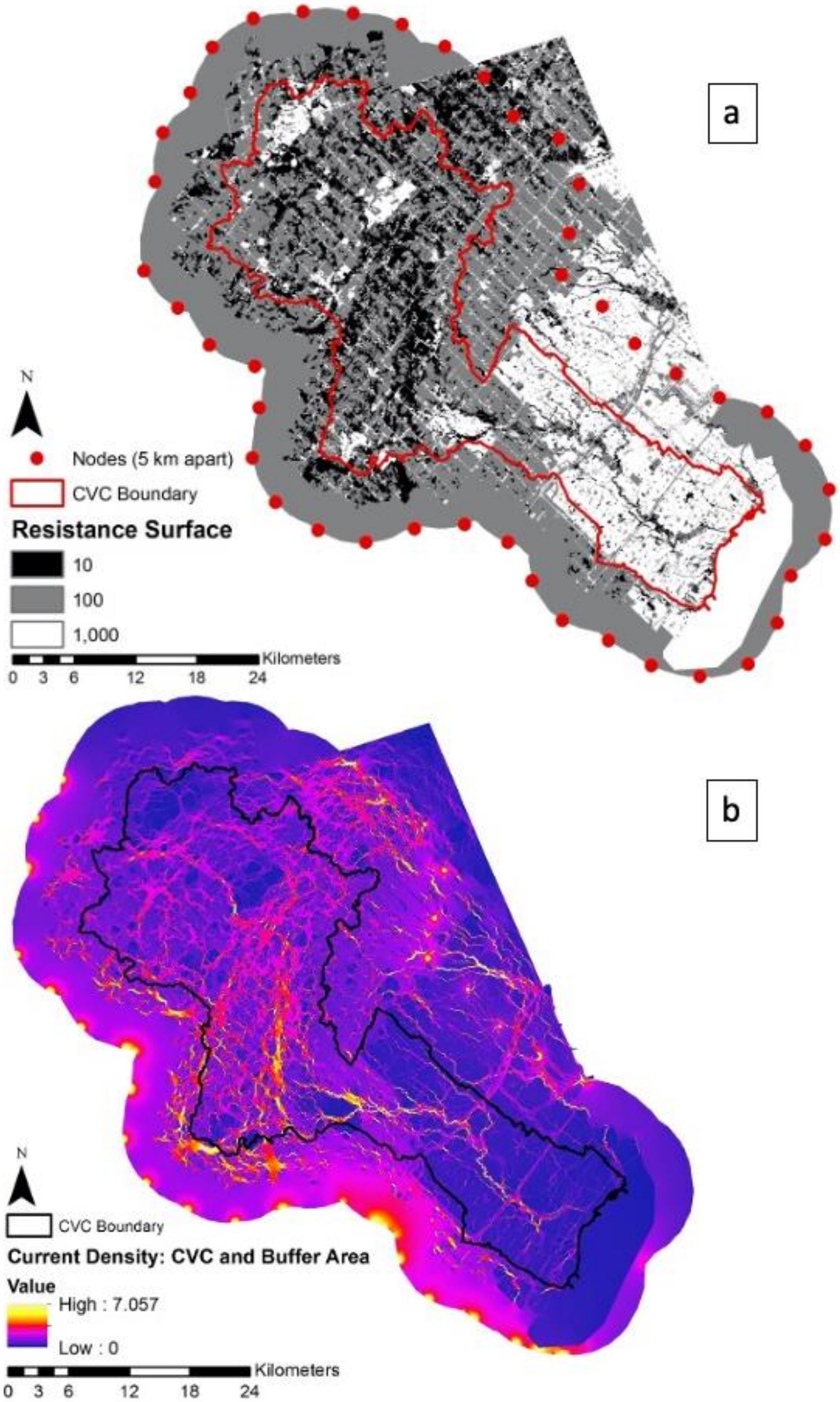
Created GIS Data	Shapefile name	Year	Scale
Resistance shapefile	CVC_Connectivity_Resistance_undissolved_20190417.shp	2019	1:10,000
Natural areas shapefile	CVC_Connectivity_NaturalAreas_final_20190417.shp	2019	1:10,000

Table B2. Existing GIS files used by CVC to create the shapefiles in Table B1

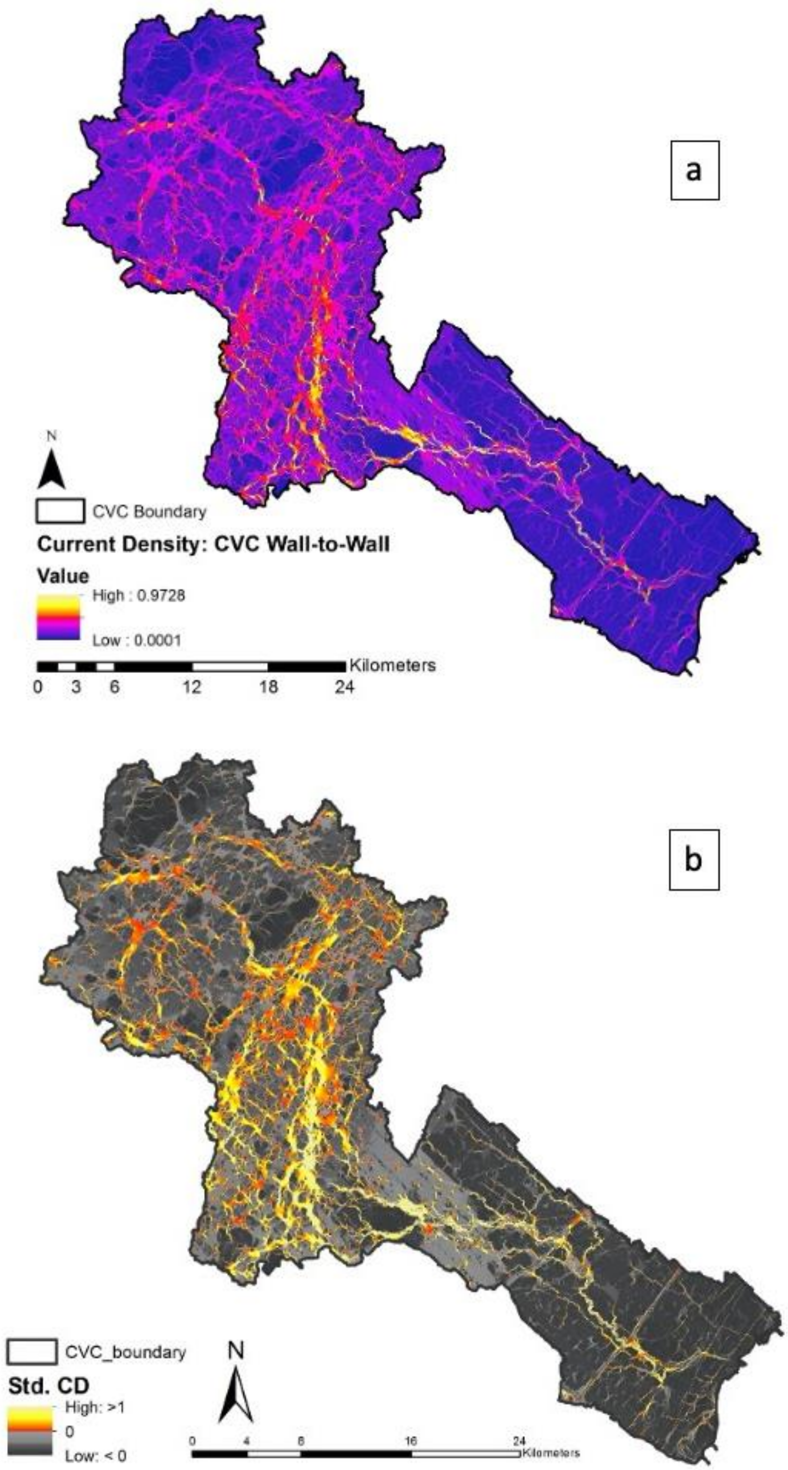
Existing GIS Data	Shapefile or Geodatabase name	Year	Scale
ELC and land use shapefile	dta_Corporate_Milestone_ELC_Land_Use_20200309.gdb/ELCLandUse_20180530	2017	1:10,000
Credit River Watershed boundary shapefile	Boundary_CVC.shp	2008	1:10,000
Cliffs shapefile	dta_Corporate_Milestone_ELC_Land_Use_20200309.gdb/Cliffs_Banks_20150421	2015	1:10,000
Road and Valley Crossings	Road_and_Valley_Crossings.shp	2018	1:10,000

9.3. Appendix C: Maps

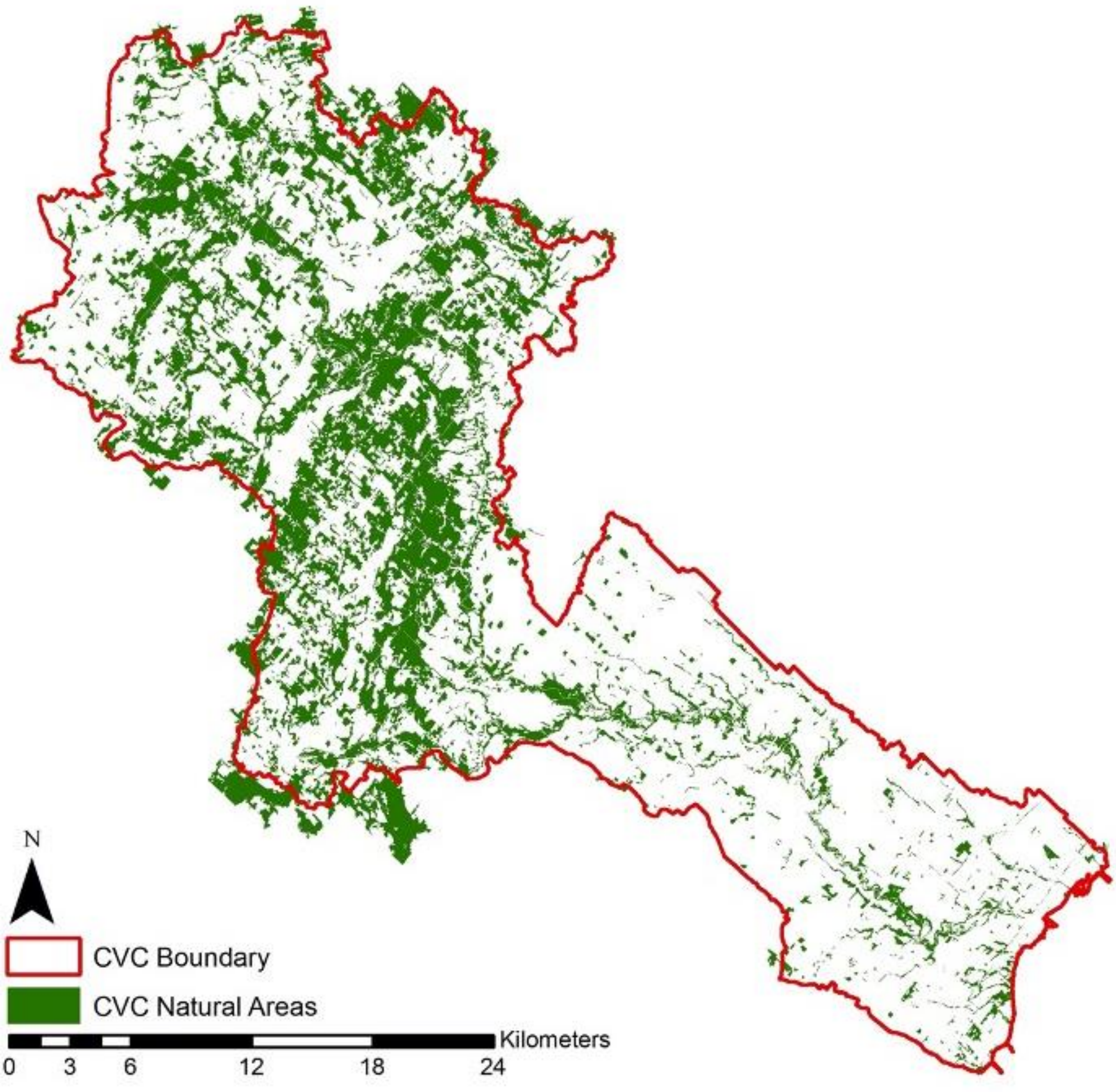
C-1: a) Resistance surface for the Credit River Watershed. The boundary of CVC jurisdiction (red line) is surrounded by a 25% buffer zone where current sources (nodes) are placed. b) Current density map modelled in Circuitscape.



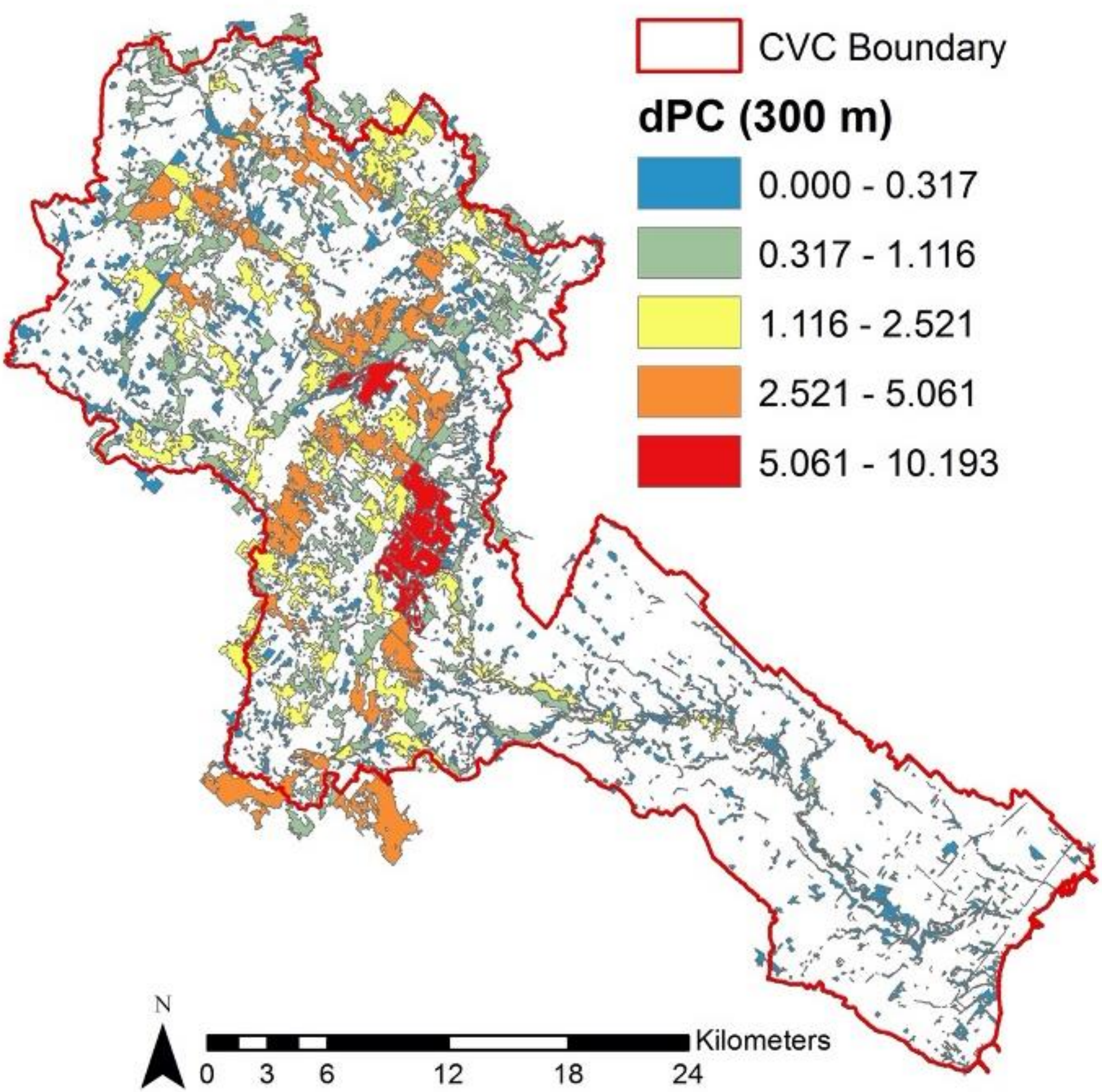
C-2: a) Current density map clipped to CVC boundary polygon after removing the buffer area to eliminate artifacts due to high current flow near the current sources. b) Standardized current density map contrasting biodiversity highways and pinch-points to diffused and low flow areas in the background.



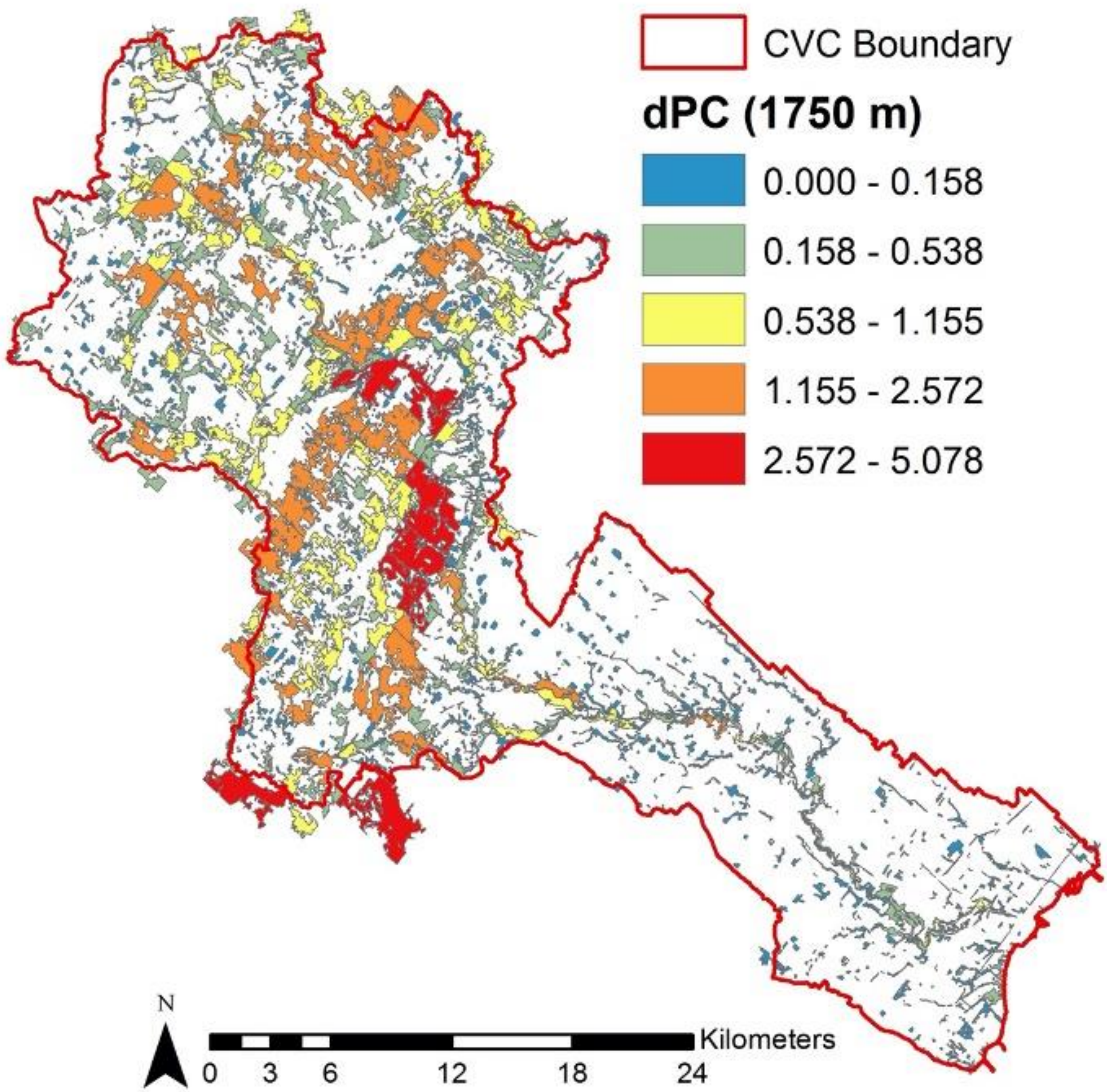
C-3: Natural areas within and intersecting with the boundary of the Credit Valley Conservation jurisdiction in the Credit River Watershed. A total of 2181 natural areas were included in the network analysis.



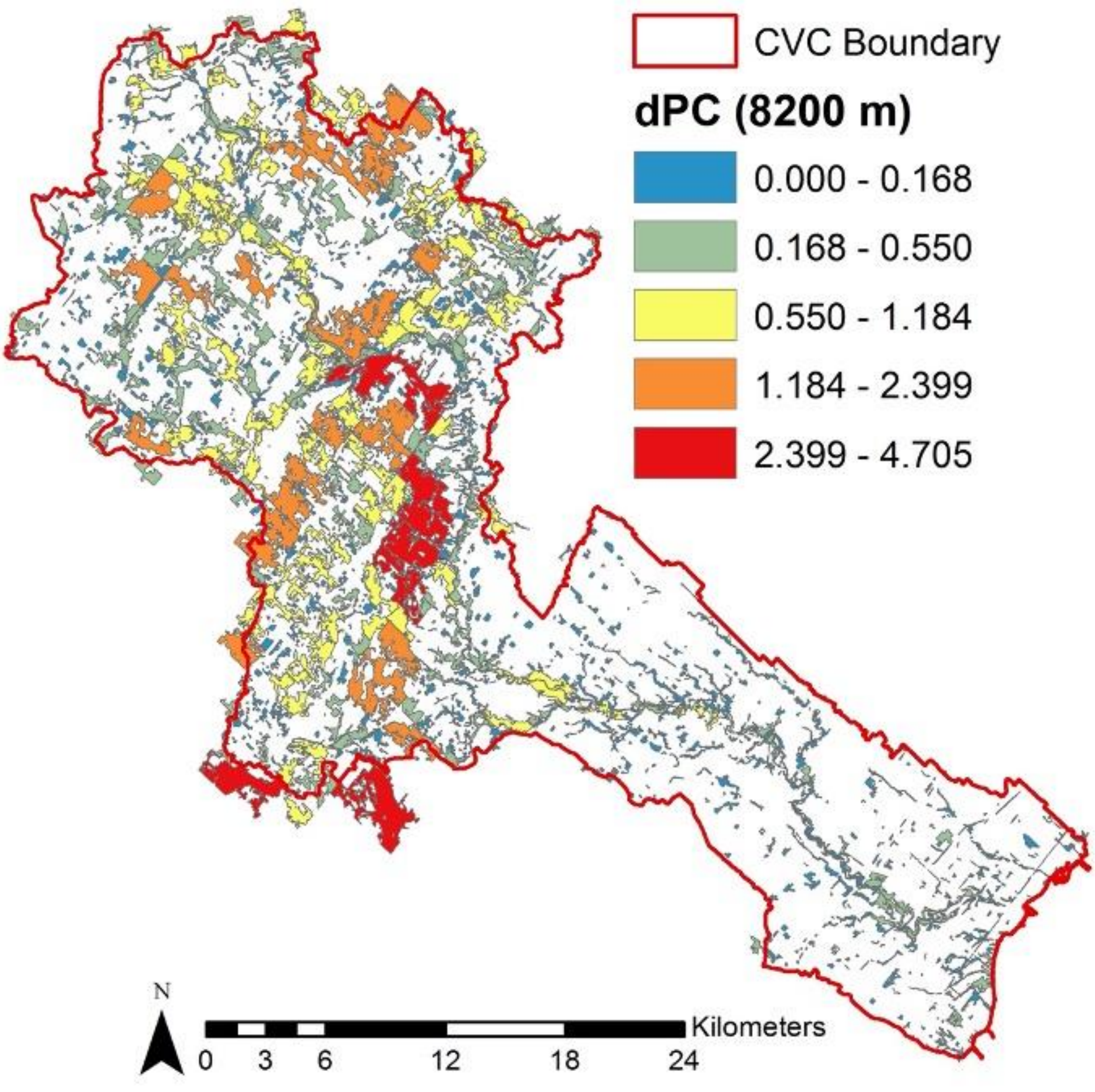
C-4: Network analysis results using a median dispersal distance of 300 m. Analysis is based on Euclidian distances among all 2181 natural areas (patches) in the Credit River Watershed. Patches are colored according to their total *dPC* value, i.e., the change in the probability of connectivity of the entire network if the patch is removed. Higher values thus indicate a larger contribution to network connectivity.



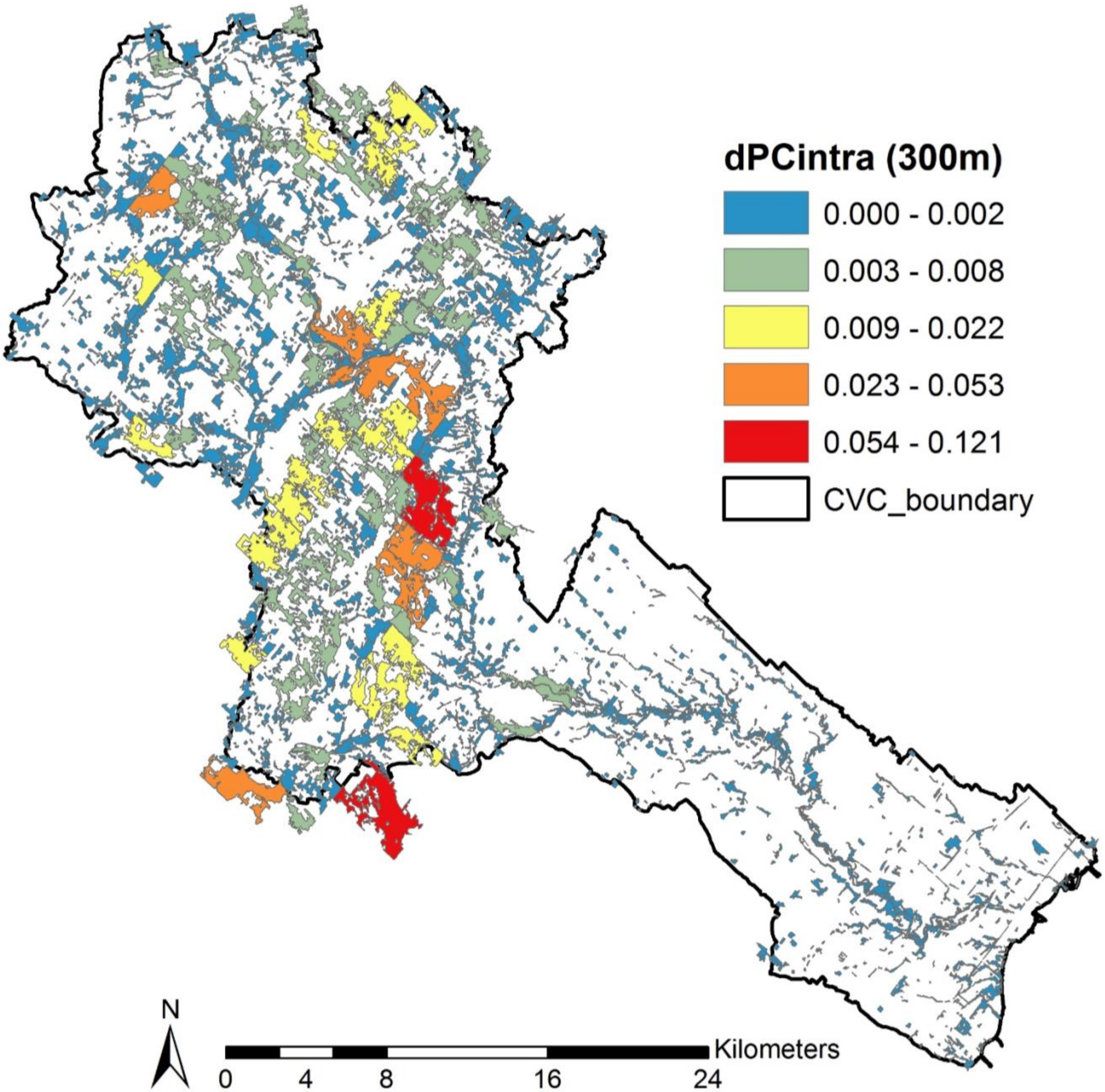
C-5: Network analysis results using a median dispersal distance of 1750 m. Analysis is based on Euclidian distances among all 2181 natural areas (patches) in the Credit River Watershed. Patches are colored according to their total *dPC* value, i.e., the change in the probability of connectivity of the entire network if the patch is removed. Higher values thus indicate a larger contribution to network connectivity..



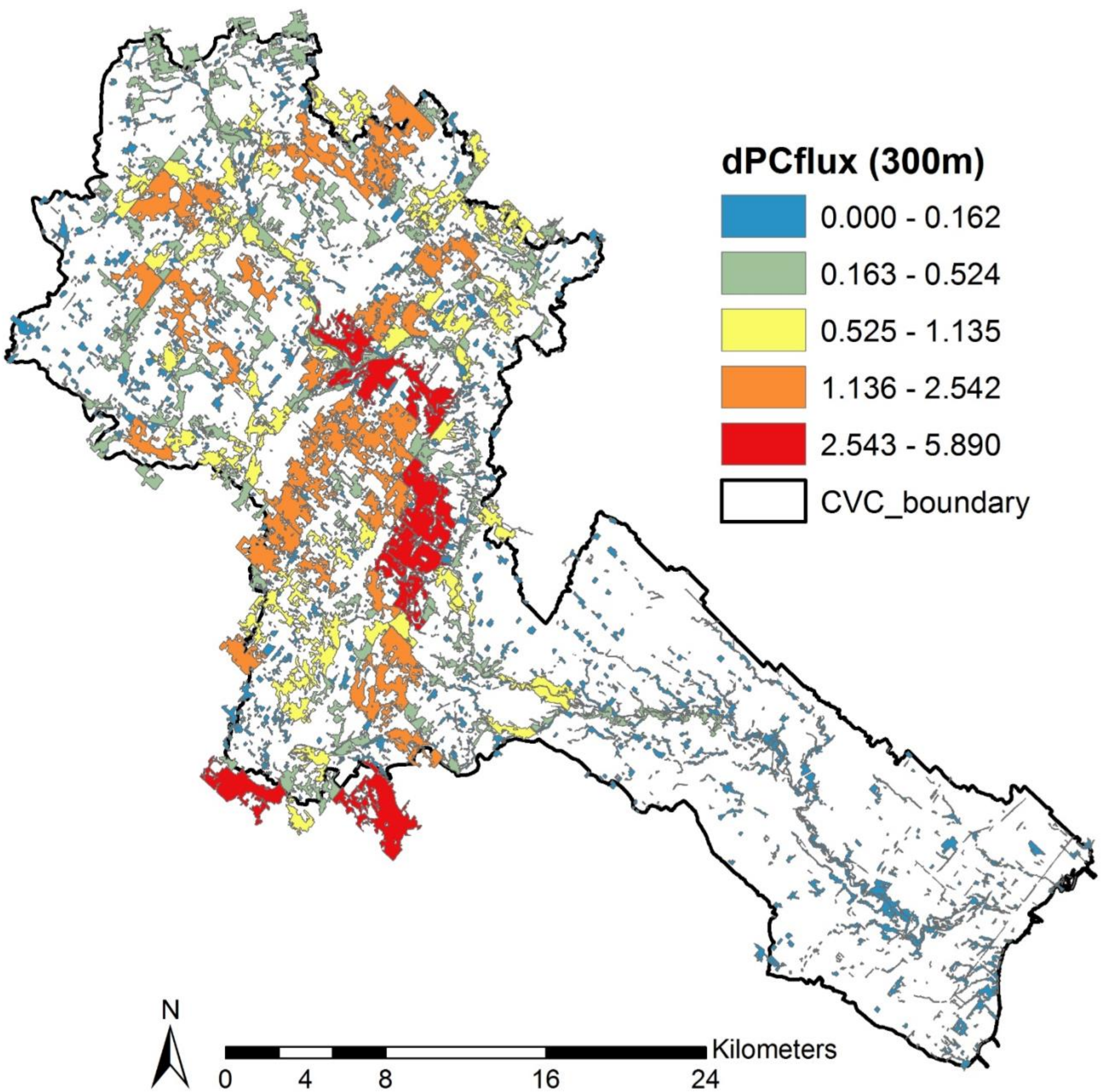
C-6: Network analysis results using a median dispersal distance of 8200 m. Analysis is based on Euclidian distances among all 2181 natural areas (patches) in the Credit River Watershed. Patches are colored according to their total *dPC* value, i.e., the change in the probability of connectivity of the entire network if the patch is removed. Higher values thus indicate a larger contribution to network connectivity.



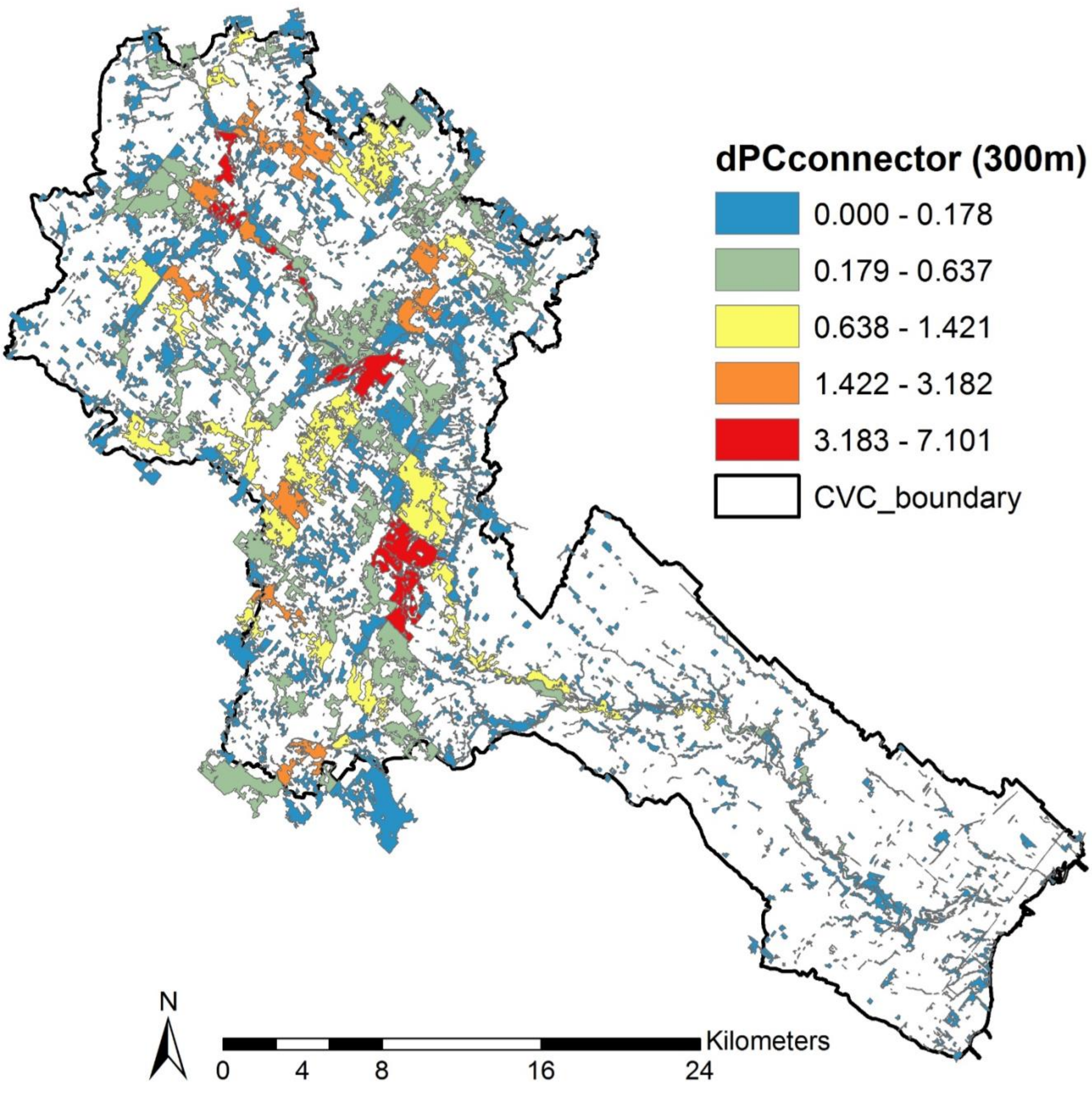
C-7: Network analysis results using a median dispersal distance of 300 m. Analysis is based on Euclidian distances among all 2181 natural areas (patches) in the Credit River Watershed. Patches are colored according to their total *dPCintra* value. This fraction quantifies the contribution of the patch to network connectivity due to patch area only (reflecting the probability that two random points are located in the same patch). Higher values thus indicate a larger contribution to network connectivity.



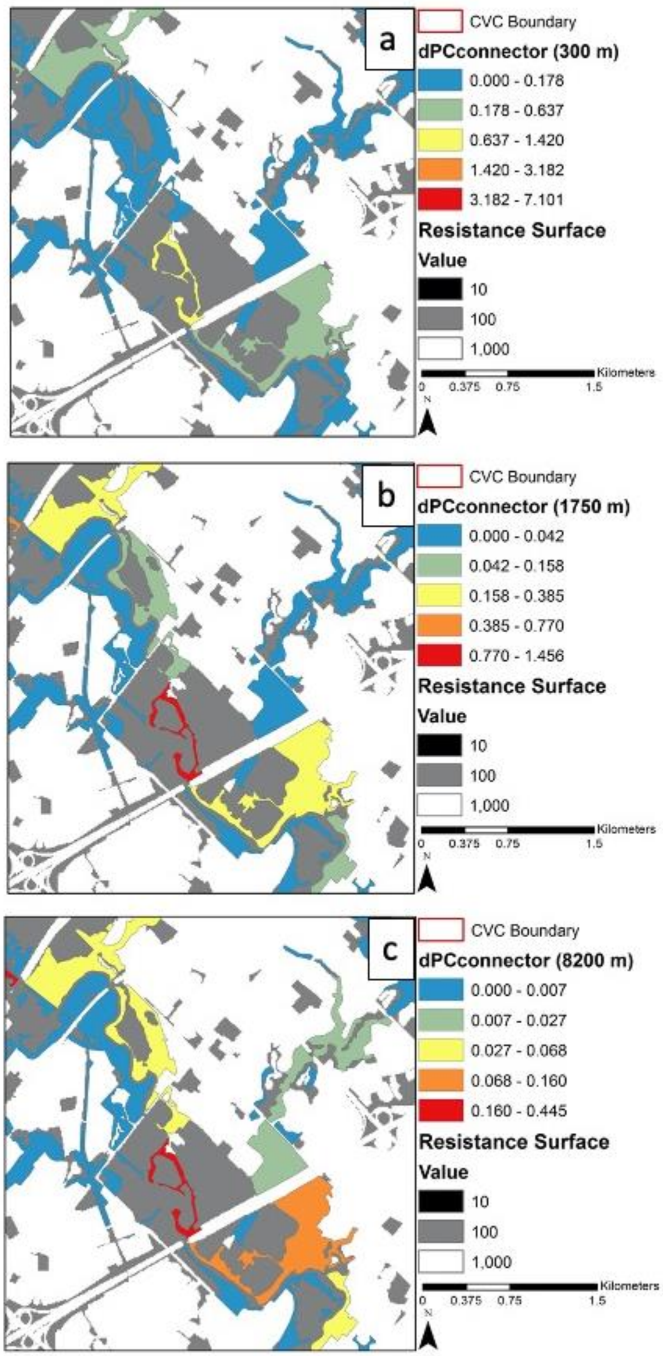
C-8: Network analysis results using a median dispersal distance of 300 m. Analysis is based on Euclidian distances among all 2181 natural areas (patches) in the Credit River Watershed. Patches are colored according to their total *dPCflux* value. This fraction quantifies the contribution of the patch to network connectivity due to being part of a local cluster only (reflecting the probability that two random points are located in two patches with a direct link). Higher values thus indicate a larger contribution to network connectivity.



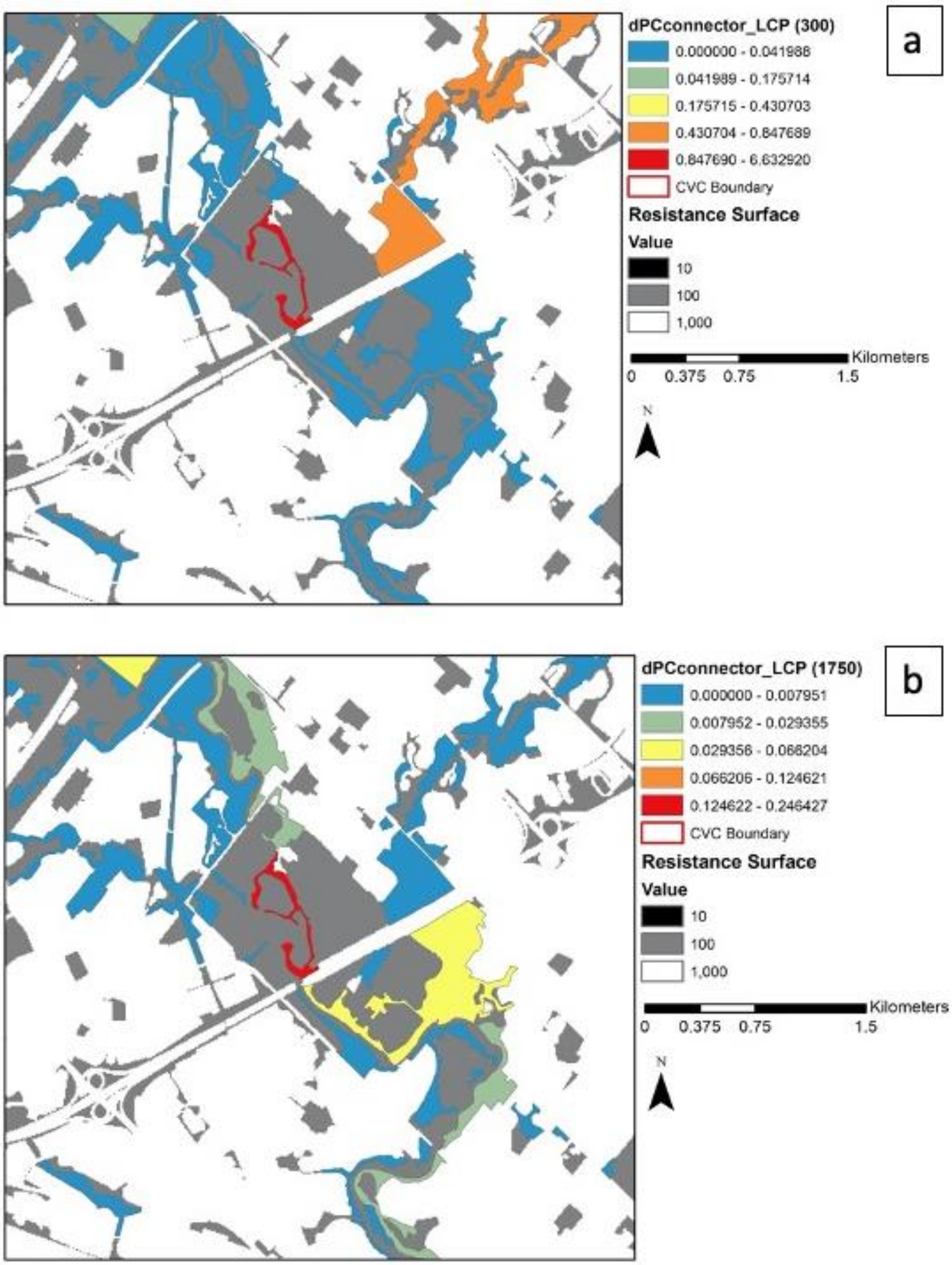
C-9: Network analysis results using a median dispersal distance of 300 m. Analysis is based on Euclidian distances among all 2181 natural areas (patches) in the Credit River Watershed. Patches are colored according to their total *dPCconnector* value. This fraction quantifies the contribution of the patch to network connectivity due to its stepping-stone function (reflecting the probability that two random points are located in patches where the shortest path between those patches goes through the stepping-stone patch). Higher values thus indicate a larger contribution to network connectivity.



C-10: Illustration of how patch importance as steppingstones, measured by the *dPCconnector* fraction, in the Credit River Watershed changes based on the median dispersal distance used in the analysis. a) Patches indicate low to medium importance with a median dispersal distance of 300m. b) Patches indicate higher importance with a median dispersal distance of 1750m. c) As median dispersal distance increase to 8200m, same patches showed higher importance as steppingstones in the network. Values of *dPCconnector* are specific to each median dispersal distance map.



C-11: Illustration of how patches importance as steppingstones, measured by the *dPCconnector* fraction, in the Credit River Watershed changes based on the cost distance and LCP analysis. a) patches importance with cost distance 30000 b) patches importance with cost distance 175000. Values of *dPCconnector* are specific to each median dispersal distance map. Cost distances are in resistance units.



9.4. Appendix D: Top 100 Natural Area Patches Important for Conservation Prioritization Based on Connectivity Network Analysis for The Credit River Watershed.

D-1: Top 100 natural area patches important for conservation prioritization ranked from most important to least important based on its value as a steppingstone patch (*dPCconnector*) to maintain connectivity in the entire network of the Credit River Watershed. Analysis is based on least cost path threshold of 30000 cost distance (analogous to 300m dispersal distance).

Patch	Centroid_X	Centroid_Y	dPC_300_LCP	dPCintra	dPCflux	dPCconnector
423	602467.5913	4830034.175	6.678	0	0.045	6.633
435	603311.7099	4830298.794	0.964	0	0.117	0.848
480	603444.4296	4830964.209	0.826	0	0.043	0.782
544	603929.3262	4831357.895	0.775	0	0.101	0.673
1971	586509.3528	4859747.691	1.108	0.001	0.435	0.672
1461	581599.6096	4849911.026	3.403	0.019	2.727	0.657
569	594910.9838	4831883.774	0.749	0	0.134	0.615
1269	570425.0245	4846640.607	1.953	0.005	1.373	0.575
840	587404.888	4835414.998	0.949	0	0.435	0.513
633	604281.2015	4832176.429	0.666	0	0.156	0.51
1841	567136.8762	4857190.582	0.607	0	0.099	0.508
638	603752.2799	4833008.411	0.503	0	0.002	0.5
681	603368.9291	4833334.19	0.5	0	0.07	0.431
1737	570206.1337	4854677.092	1.962	0.006	1.557	0.399
2178	575284.113	4866641.465	0.825	0.001	0.44	0.384
1053	583277.3787	4839446.321	2.894	0.016	2.498	0.379
719	602690.2962	4833986.719	0.431	0	0.056	0.375
736	602178.5379	4834403.463	0.37	0	0.002	0.368
237	615123.3157	4824999.693	0.37	0	0.007	0.363
2124	570041.2539	4864044.223	0.965	0.001	0.621	0.343
446	597045.7601	4830428.249	0.356	0	0.026	0.33
771	601842.8049	4834646.553	0.368	0	0.062	0.306
783	596236.0784	4834396.841	0.439	0	0.163	0.276
447	597798.1755	4830642.619	0.327	0	0.053	0.274
777	601176.9615	4834757.147	0.299	0	0.025	0.274
1590	589898.6325	4853238.835	0.308	0	0.051	0.257
573	599772.7007	4831977.465	0.305	0	0.053	0.251
815	600739.9531	4835221.196	0.266	0	0.027	0.239
1445	584481.6936	4848758.894	2.997	0.02	2.739	0.239
149	607426.862	4822380.8	0.399	0	0.168	0.231

Patch	Centroid_X	Centroid_Y	dPC_300_LCP	dPCintra	dPCflux	dPCconnector
1086	583743.1195	4841212.737	2.921	0.019	2.671	0.231
1647	584688.8749	4853567.608	1.034	0.002	0.808	0.224
1003	586251.2758	4838675.69	0.679	0.001	0.455	0.223
263	615681.6473	4825594.681	0.229	0	0.006	0.223
269	616018.7682	4826031.119	0.223	0	0.002	0.222
1452	568519.7058	4850542.195	0.393	0	0.18	0.214
1343	567834.6577	4848604.028	0.554	0	0.341	0.213
1371	586734.8536	4849428.987	0.277	0	0.074	0.203
152	606610.2048	4822643.988	0.232	0	0.042	0.19
824	595158.6014	4835258.969	0.269	0	0.084	0.185
789	590371.3904	4834410.724	1.184	0.003	1	0.182
841	594186.0645	4835803.905	0.185	0	0.009	0.176
1600	583748.0248	4852765.026	1.149	0.002	0.973	0.174
845	593707.445	4835938.51	0.176	0	0.01	0.165
1358	566943.784	4849392.825	0.181	0	0.016	0.165
966	586995.4118	4838800.792	0.197	0	0.034	0.163
287	616304.7572	4826278.759	0.166	0	0.004	0.161
858	600331.2774	4835760.187	0.239	0	0.079	0.16
1187	575782.6121	4845112.206	0.777	0.001	0.619	0.157
1168	584468.2826	4843421.875	4.971	0.06	4.762	0.148
1369	574007.6758	4849417.957	0.237	0	0.088	0.148
886	599819.7627	4836334.927	0.16	0	0.012	0.148
1765	569293.7808	4855917.226	0.309	0	0.174	0.135
1612	572115.2753	4852677.389	1.264	0.003	1.126	0.135
1378	566805.5705	4849683.98	0.165	0	0.031	0.133
1359	587294.6514	4849318.605	0.203	0	0.072	0.131
869	592860.8991	4836239.655	0.157	0	0.039	0.117
942	583235.645	4837375.443	0.812	0.001	0.695	0.116
1906	574408.0165	4857928.746	0.866	0.001	0.75	0.115
1801	584674.5122	4855701.468	1.381	0.004	1.267	0.11
641	599481.1616	4832806.548	0.177	0	0.067	0.109
2053	570410.1196	4862581.459	0.11	0	0.003	0.107
1263	586794.9376	4847268.295	0.204	0	0.098	0.106
983	577103.6882	4838269.83	1.06	0.002	0.952	0.105
496	598071.3264	4831110.937	0.195	0	0.092	0.103
2060	570567.9806	4862659.641	0.107	0	0.006	0.101
986	586906.8591	4839331.965	0.117	0	0.016	0.101
481	597267.2735	4831204.147	0.102	0	0.003	0.099
222	615304.4508	4824867.782	0.107	0	0.008	0.099
884	599524.1883	4836523.02	0.148	0	0.049	0.099
1652	577085.1865	4854348.488	0.126	0	0.029	0.096
163	613374.0763	4823180.682	0.107	0	0.012	0.096

Patch	Centroid_X	Centroid_Y	dPC_300_LCP	dPCintra	dPCflux	dPCconnector
277	616829.2863	4826038.991	0.161	0	0.065	0.095
1864	566284.5216	4857283.415	0.282	0	0.188	0.094
505	578819.0226	4830785.51	1.007	0.002	0.911	0.094
1131	577654.0306	4843407.43	1.89	0.008	1.789	0.093
1342	576181.144	4848650.683	0.211	0	0.12	0.091
1242	572105.0394	4846783.063	0.82	0.001	0.729	0.09
763	592352.1525	4834220.437	0.234	0	0.144	0.09
1680	579340.4118	4854790.817	0.111	0	0.022	0.088
1873	575681.8252	4857009.157	0.647	0.001	0.559	0.087
883	592547.3978	4836595.312	0.114	0	0.027	0.087
804	581524.0187	4833689.416	1.672	0.007	1.579	0.087
1465	567733.2484	4851057.897	0.108	0	0.022	0.086
171	613770.6953	4823428.671	0.126	0	0.041	0.085
208	614708.1528	4824342.474	0.089	0	0.007	0.082
1380	572078.7357	4848892.308	0.401	0	0.321	0.081
1238	587372.7238	4847210.646	0.106	0	0.026	0.081
901	599116.9651	4836959.079	0.099	0	0.018	0.08
145	605732.2637	4822417.735	0.181	0	0.103	0.078
2166	578020.7522	4865964.947	0.606	0.001	0.528	0.077
853	586388.6256	4835847.531	0.098	0	0.024	0.074
1173	578441.2319	4844670.277	1.604	0.006	1.526	0.073
658	598317.8787	4832783.542	0.552	0.001	0.482	0.07
1536	579352.8878	4851484.64	0.358	0	0.288	0.069
2159	571225.062	4865313.318	0.728	0.001	0.658	0.069
1891	565845.0706	4858233.933	0.079	0	0.013	0.066
1222	583933.1412	4846516.575	0.466	0	0.4	0.066
818	592426.8246	4835142.166	0.09	0	0.025	0.065
906	586562.5302	4836705.06	0.261	0	0.197	0.064

D-2: Top 100 natural area patches important for conservation prioritization ranked from most important to least important based on its value as a steppingstone patch (*dPCconnector*) to maintain connectivity in the entire network of the Credit River Watershed. Analysis is based on least cost path threshold of 175000 cost distance (analogous to 1750m dispersal distance).

Patch	*Centroid_X*	*Centroid_Y*	*dPC_1750_LCP*	*dPCintra*	*dPCflux*	*dPCconnector*
840	587404.888	4835414.998	0.573	0	0.416	0.156
1053	583277.3787	4839446.321	2.509	0.014	2.371	0.123
1445	584481.6936	4848758.894	2.693	0.017	2.595	0.081
1647	584688.8749	4853567.608	0.837	0.001	0.768	0.067
1461	581599.6096	4849911.026	2.664	0.017	2.583	0.064
1086	583743.1195	4841212.737	2.614	0.017	2.535	0.062
1600	583748.0248	4852765.026	0.984	0.002	0.922	0.06
641	599481.1616	4832806.548	0.123	0	0.065	0.058
1168	584468.2826	4843421.875	4.629	0.054	4.518	0.058
423	602467.5913	4830034.175	0.087	0	0.044	0.043
1906	574408.0165	4857928.746	0.753	0.001	0.712	0.04
1801	584674.5122	4855701.468	1.246	0.004	1.205	0.038
658	598317.8787	4832783.542	0.5	0.001	0.463	0.037
942	583235.645	4837375.443	0.696	0.001	0.659	0.036
130	604545.9896	4822125.882	0.044	0	0.01	0.034
789	590371.3904	4834410.724	0.993	0.002	0.957	0.033
853	586388.6256	4835847.531	0.055	0	0.023	0.032
183	610590.856	4823045.374	0.382	0	0.354	0.028
906	586562.5302	4836705.06	0.216	0	0.188	0.028
1187	575782.6121	4845112.206	0.616	0.001	0.589	0.026
568	600657.4907	4831943.696	0.099	0	0.073	0.026
505	578819.0226	4830785.51	0.906	0.002	0.879	0.025
1536	579352.8878	4851484.64	0.296	0	0.273	0.024
1222	583933.1412	4846516.575	0.403	0	0.379	0.023
137	612628.7778	4821469.82	0.058	0	0.034	0.023
1131	577654.0306	4843407.43	1.733	0.007	1.702	0.023
657	597050.2218	4833144.518	0.036	0	0.014	0.023
1173	578441.2319	4844670.277	1.476	0.005	1.449	0.021
673	593513.9	4832924.69	0.465	0.001	0.443	0.021
1299	579648.06	4847122.763	1.315	0.004	1.29	0.021
1771	577543.4635	4855383.203	0.397	0	0.376	0.021
1937	573398.6899	4858990.189	1.001	0.002	0.978	0.02
1242	572105.0394	4846783.063	0.72	0.001	0.699	0.019
1196	584427.8572	4846030.403	0.406	0	0.387	0.019
804	581524.0187	4833689.416	1.534	0.006	1.509	0.019
237	615123.3157	4824999.693	0.026	0	0.007	0.018

Patch	Centroid_X	Centroid_Y	dPC_1750_LCP	dPCintra	dPCflux	dPCconnector
171	613770.6953	4823428.671	0.058	0	0.041	0.018
1873	575681.8252	4857009.157	0.548	0.001	0.53	0.018
2131	572764.8715	4864862.75	0.121	0	0.104	0.017
854	582540.7859	4834612.93	1.407	0.005	1.385	0.017
913	583147.5102	4836039.678	1.88	0.009	1.854	0.017
208	614708.1528	4824342.474	0.024	0	0.008	0.016
2168	572618.0273	4865849.734	0.576	0.001	0.559	0.016
1646	578748.2672	4853777.63	0.1	0	0.084	0.016
591	583743.2894	4831485.302	1.383	0.005	1.363	0.015
319	608470.1528	4827279.1	0.025	0	0.01	0.015
1983	574543.2217	4860055.658	0.612	0.001	0.597	0.014
1217	574881.8125	4846100.587	0.589	0.001	0.574	0.014
148	613327.6173	4822644.86	0.024	0	0.01	0.014
1229	578941.4972	4846048.502	1.003	0.002	0.987	0.014
1125	581831.4814	4843135.951	1.03	0.003	1.014	0.014
1705	572562.006	4854260.732	1.186	0.004	1.169	0.013
956	575746.7908	4837459.753	0.632	0.001	0.618	0.013
1952	582989.2243	4859227.454	0.428	0	0.415	0.013
425	577559.964	4829831.376	0.491	0.001	0.478	0.012
1931	584246.1589	4858088.05	1.035	0.003	1.02	0.012
573	599772.7007	4831977.465	0.063	0	0.052	0.012
785	587510.2772	4834933.51	0.049	0	0.037	0.012
2029	574592.7241	4861649.345	0.406	0	0.393	0.012
661	592457.666	4833101.598	0.038	0	0.027	0.011
2088	575942.7737	4862443.51	0.774	0.001	0.761	0.011
1093	577191.0435	4842062.902	1.486	0.006	1.469	0.011
83	611905.32	4820332.245	0.068	0	0.057	0.011
983	577103.6882	4838269.83	0.923	0.002	0.91	0.011
1861	583751.1768	4857116.81	0.412	0	0.401	0.011
1269	570425.0245	4846640.607	1.338	0.005	1.323	0.01
2010	582069.7595	4860377.708	1.477	0.006	1.461	0.01
1961	570900.9713	4858823.758	2.182	0.012	2.16	0.01
679	592149.3865	4833476.547	0.019	0	0.009	0.01
2013	577856.753	4860664.398	1.19	0.004	1.177	0.01
291	605178.6398	4826023.576	0.154	0	0.145	0.009
895	575240.2394	4836045.792	1.363	0.005	1.35	0.009
30	611537.4325	4818014.276	0.035	0	0.027	0.009
644	588628.2419	4832325.412	0.704	0.001	0.694	0.009
685	594119.1807	4833132.653	0.115	0	0.107	0.008
28	611098.5697	4817435.958	0.213	0	0.205	0.008
1612	572115.2753	4852677.389	1.089	0.003	1.078	0.008
382	603823.1728	4828903.53	0.071	0	0.063	0.008

Patch	Centroid_X	Centroid_Y	dPC_1750_LCP	dPCintra	dPCflux	dPCconnector
2069	582546.2296	4861760.186	1.512	0.006	1.498	0.008
1934	572429.6008	4858205.885	0.996	0.002	0.986	0.008
1024	577812.3284	4839389.3	0.75	0.001	0.741	0.008
934	585893.7241	4837124.562	0.303	0	0.295	0.008
348	603248.0159	4828016.092	0.064	0	0.057	0.008
249	605313.9758	4825309.827	0.076	0	0.068	0.008
1091	586212.7906	4842738.346	0.108	0	0.1	0.008
1335	580506.1171	4848085.172	1.084	0.003	1.074	0.007
1380	572078.7357	4848892.308	0.315	0	0.308	0.007
1073	586308.6385	4842121.704	0.026	0	0.019	0.007
1928	575547.2405	4859137.667	0.039	0	0.032	0.007
1056	585991.0839	4840766.986	0.285	0	0.278	0.007
1848	571937.5074	4856426.669	0.328	0	0.321	0.007
2076	578883.6451	4861557.391	1.46	0.005	1.448	0.006
1548	582811.5673	4851865.272	0.755	0.001	0.747	0.006
1064	586096.3198	4841867.058	0.013	0	0.007	0.006
1690	588011.2166	4854323.047	0.539	0.001	0.532	0.006
181	607731.0744	4823122.265	0.433	0	0.427	0.006
37	612250.9541	4818337.024	0.161	0	0.155	0.006
1023	585495.1813	4839511.067	0.788	0.002	0.781	0.006
1140	580897.0726	4844382.017	0.338	0	0.332	0.006
18	610728.661	4816656.876	0.068	0	0.062	0.006

D-3: Top 100 natural area patches important for conservation prioritization ranked from most important to least important based on its value as a steppingstone patch (*dPCconnector*) to maintain connectivity in the entire network of the Credit River Watershed. Analysis is based on dispersal threshold of 300m (Edge-to-edge Euclidian distance between patches).

Patch	*Centroid_X*	*Centroid_Y*	*Area_ha*	*dPC_300*	*dPCintra*	*dPCflux*	*dPCconnector*
1053	583277.3787	4839446.321	343.6260524	10.177	0.030	3.045	7.101
1461	581599.6096	4849911.026	374.4754926	10.193	0.036	3.449	6.708
1086	583743.1195	4841212.737	367.6449359	7.570	0.035	3.301	4.234
1906	574408.0165	4857928.746	102.4777899	5.061	0.003	0.877	4.182
1771	577543.4635	4855383.203	53.95010173	4.540	0.001	0.479	4.060
942	583235.645	4837375.443	94.70395758	4.805	0.002	0.839	3.964
1881	575234.0222	4857647.588	22.86283914	4.002	0.000	0.198	3.804
1983	574543.2217	4860055.658	85.88866853	4.225	0.002	0.709	3.514
1646	578748.2672	4853777.63	12.04365066	3.614	0.000	0.112	3.503
2029	574592.7241	4861649.345	56.63467578	3.813	0.001	0.441	3.371
1937	573398.6899	4858990.189	140.9630562	4.376	0.005	1.189	3.182
2013	577856.753	4860664.398	170.1852216	4.089	0.007	1.231	2.851
2076	578883.6451	4861557.391	209.9412348	3.777	0.011	1.479	2.287
425	577559.964	4829831.376	69.34412838	2.746	0.001	0.497	2.248
1873	575681.8252	4857009.157	76.09646392	2.847	0.001	0.668	2.178
1600	583748.0248	4852765.026	132.5582625	3.304	0.005	1.178	2.121
1647	584688.8749	4853567.608	110.5601279	2.992	0.003	0.935	2.053
2088	575942.7737	4862443.51	109.8715705	2.754	0.003	0.812	1.938
2038	575170.0754	4861916.318	33.95435491	2.152	0.000	0.261	1.892
1131	577654.0306	4843407.43	246.3131028	3.980	0.016	2.122	1.842
983	577103.6882	4838269.83	131.3554522	2.782	0.004	1.024	1.753
1801	584674.5122	4855701.468	173.7960809	3.104	0.008	1.414	1.682
505	578819.0226	4830785.51	127.6258878	2.628	0.004	0.943	1.680
1705	572562.006	4854260.732	169.0394842	2.898	0.007	1.338	1.552
1990	580941.8828	4859754.56	172.4148988	2.624	0.008	1.195	1.421
532	580362.7696	4831335.376	41.61522908	1.736	0.000	0.318	1.418
906	586562.5302	4836705.06	27.04614023	1.457	0.000	0.221	1.236
1023	585495.1813	4839511.067	112.3661879	2.164	0.003	0.994	1.166
1299	579648.06	4847122.763	185.9427623	2.888	0.009	1.713	1.166
956	575746.7908	4837459.753	89.05793423	1.837	0.002	0.671	1.163
423	602467.5913	4830034.175	6.328986433	1.179	0.000	0.018	1.160
1093	577191.0435	4842062.902	212.3111466	2.935	0.012	1.790	1.134
1187	575782.6121	4845112.206	84.69071498	1.844	0.002	0.719	1.124
2069	582546.2296	4861760.186	217.7701522	2.521	0.012	1.414	1.095
1168	584468.2826	4843421.875	661.8639221	7.032	0.113	5.890	1.030
1229	578941.4972	4846048.502	142.1162169	2.318	0.005	1.285	1.028

Patch	*Centroid_X*	*Centroid_Y*	*Area_ha*	*dPC_300*	*dPCintra*	*dPCflux*	*dPCconnector*
804	581524.0187	4833689.416	218.5860671	2.812	0.012	1.775	1.024
889	579201.1179	4836057.848	120.0914937	1.890	0.004	0.881	1.005
934	585893.7241	4837124.562	42.41380954	1.360	0.000	0.368	0.992
1612	572115.2753	4852677.389	156.1235209	2.163	0.006	1.194	0.963
2010	582069.7595	4860377.708	211.9934044	2.348	0.012	1.412	0.925
1217	574881.8125	4846100.587	82.81332241	1.515	0.002	0.607	0.907
1173	578441.2319	4844670.277	209.1250747	2.733	0.011	1.839	0.883
673	593513.9	4832924.69	63.91576925	1.271	0.001	0.413	0.856
658	598317.8787	4832783.542	66.79515501	1.223	0.001	0.375	0.847
1335	580506.1171	4848085.172	154.6374031	2.294	0.006	1.442	0.845
789	590371.3904	4834410.724	138.2580251	1.799	0.005	0.965	0.829
1269	570425.0245	4846640.607	192.3117355	2.094	0.010	1.274	0.810
1817	586288.1174	4856088.475	158.6939353	2.030	0.006	1.239	0.785
840	587404.888	4835414.998	59.94647633	1.205	0.001	0.443	0.761
2149	574102.0458	4864688.609	81.30397349	1.273	0.002	0.520	0.751
1737	570206.1337	4854677.092	216.7322985	2.405	0.012	1.645	0.748
1287	576003.4356	4847233.998	90.98523305	1.501	0.002	0.773	0.726
2178	575284.113	4866641.465	62.14605784	0.940	0.001	0.255	0.683
1246	573902.962	4847129.104	56.04428485	1.075	0.001	0.406	0.669
1971	586509.3528	4859747.691	60.35350929	1.042	0.001	0.404	0.637
785	587510.2772	4834933.51	5.311936846	0.674	0.000	0.039	0.635
1242	572105.0394	4846783.063	101.1375921	1.326	0.003	0.700	0.624
2131	572764.8715	4864862.75	15.03946428	0.703	0.000	0.086	0.617
573	599772.7007	4831977.465	7.443654806	0.643	0.000	0.030	0.613
568	600657.4907	4831943.696	10.49999578	0.648	0.000	0.038	0.610
1472	581703.5404	4850854.6	36.42710521	0.929	0.000	0.339	0.590
1934	572429.6008	4858205.885	142.1400703	1.770	0.005	1.180	0.584
2108	573326.908	4864136.125	8.464131394	0.630	0.000	0.054	0.575
1974	574797.014	4860586.971	3.186783123	0.589	0.000	0.025	0.564
1256	582291.9623	4846473.78	259.7327969	2.959	0.017	2.388	0.554
1405	575686.2269	4849464.358	71.71767683	1.117	0.001	0.566	0.549
1380	572078.7357	4848892.308	44.40881428	0.864	0.001	0.314	0.549
1342	576181.144	4848650.683	16.51654616	0.677	0.000	0.136	0.541
1275	572905.2014	4847634.025	28.11819252	0.719	0.000	0.199	0.520
598	599875.858	4832314.42	3.649400857	0.525	0.000	0.016	0.509
1521	569354.7008	4851134.428	71.67099879	1.000	0.001	0.506	0.493
1618	578926.2802	4852227.235	103.9635479	1.435	0.003	0.961	0.471
854	582540.7859	4834612.93	200.26345	2.153	0.010	1.680	0.463
2157	574647.6111	4865939.827	1.069868082	0.445	0.000	0.005	0.441
2158	576009.8437	4865702.179	12.17692582	0.484	0.000	0.046	0.438
1290	571250.8743	4847782.879	60.31116005	0.850	0.001	0.415	0.434
1125	581831.4814	4843135.951	145.867585	1.749	0.005	1.313	0.431

Patch	Centroid_X	Centroid_Y	Area_ha	dPC_300	dPCintra	dPCflux	dPCconnector
691	579994.4731	4833135.101	49.45883922	0.815	0.001	0.397	0.417
1438	580059.5148	4850492.975	34.59777578	0.737	0.000	0.323	0.413
571	579949.1073	4831740.399	24.82337468	0.603	0.000	0.191	0.411
1625	588842.2333	4853514.924	79.38564577	0.997	0.002	0.586	0.409
1150	575250.3852	4845322.365	1.821149334	0.413	0.000	0.014	0.399
913	583147.5102	4836039.678	268.1698627	2.730	0.019	2.324	0.387
1024	577812.3284	4839389.3	106.8663276	1.257	0.003	0.868	0.386
1961	570900.9713	4858823.758	313.4510247	2.947	0.025	2.542	0.380
641	599481.1616	4832806.548	9.305464157	0.422	0.000	0.049	0.373
417	579649.9695	4829431.085	51.32111875	0.706	0.001	0.348	0.357
2111	583482.2268	4862976.662	289.4507646	2.181	0.022	1.804	0.356
1800	577855.3997	4855732.855	110.9739475	1.327	0.003	0.971	0.353
1652	577085.1865	4854348.488	4.028252653	0.383	0.000	0.030	0.353
1434	572481.4292	4850225.769	51.76203757	0.728	0.001	0.375	0.352
2172	576729.3045	4866222.987	50.76236345	0.537	0.001	0.185	0.351
1931	584246.1589	4858088.05	147.4110505	1.343	0.006	1.005	0.332
2159	571225.062	4865313.318	93.57474934	0.783	0.002	0.452	0.329
463	575233.6006	4829349.568	453.288463	3.460	0.053	3.082	0.326
1671	577829.003	4854494.799	16.16798763	0.466	0.000	0.141	0.325
1690	588011.2166	4854323.047	76.81771182	0.884	0.002	0.576	0.306
1445	584481.6936	4848758.894	376.1910526	3.750	0.036	3.417	0.296
1615	580308.833	4851919.472	340.6251765	3.408	0.030	3.084	0.294

D-4: Top 100 natural area patches important for conservation prioritization ranked from most important to least important based on its value as a steppingstone patch (*dPCconnector*) to maintain connectivity in the entire network of the Credit River Watershed. Analysis is based on dispersal threshold of 1750m (Edge-to-edge Euclidian distance between patches).

Patch	*Centroid_X*	*Centroid_Y*	*Area_ha*	*dPC_1750*	*dPCintra*	*dPCflux*	*dPCconnector*
1461	581599.6096	4849911.026	374.4754926	4.235	0.020	2.759	1.456
1053	583277.3787	4839446.321	343.6260524	3.980	0.017	2.516	1.447
423	602467.5913	4830034.175	6.328986433	1.401	0.000	0.039	1.362
1906	574408.0165	4857928.746	102.4777899	1.658	0.002	0.751	0.906
1771	577543.4635	4855383.203	53.95010173	1.273	0.000	0.399	0.873
1086	583743.1195	4841212.737	367.6449359	3.575	0.019	2.697	0.859
1983	574543.2217	4860055.658	85.88866853	1.482	0.001	0.626	0.856
2029	574592.7241	4861649.345	56.63467578	1.238	0.000	0.408	0.829
1881	575234.0222	4857647.588	22.86283914	0.994	0.000	0.168	0.825
658	598317.8787	4832783.542	66.79515501	1.229	0.001	0.458	0.771
942	583235.645	4837375.443	94.70395758	1.445	0.001	0.698	0.746
1646	578748.2672	4853777.63	12.04365066	0.824	0.000	0.090	0.734
1937	573398.6899	4858990.189	140.9630562	1.737	0.003	1.029	0.706
568	600657.4907	4831943.696	10.49999578	0.723	0.000	0.067	0.656
2013	577856.753	4860664.398	170.1852216	1.843	0.004	1.206	0.633
573	599772.7007	4831977.465	7.443654806	0.680	0.000	0.048	0.632
425	577559.964	4829831.376	69.34412838	1.054	0.001	0.492	0.561
2076	578883.6451	4861557.391	209.9412348	1.992	0.006	1.479	0.506
598	599875.858	4832314.42	3.649400857	0.522	0.000	0.024	0.498
673	593513.9	4832924.69	63.91576925	0.936	0.001	0.449	0.486
1873	575681.8252	4857009.157	76.09646392	1.021	0.001	0.561	0.460
2088	575942.7737	4862443.51	109.8715705	1.216	0.002	0.783	0.431
2038	575170.0754	4861916.318	33.95435491	0.675	0.000	0.244	0.430
983	577103.6882	4838269.83	131.3554522	1.374	0.002	0.946	0.426
906	586562.5302	4836705.06	27.04614023	0.613	0.000	0.198	0.415
1600	583748.0248	4852765.026	132.5582625	1.394	0.003	0.977	0.414
1647	584688.8749	4853567.608	110.5601279	1.224	0.002	0.808	0.413
1023	585495.1813	4839511.067	112.3661879	1.216	0.002	0.829	0.385
505	578819.0226	4830785.51	127.6258878	1.269	0.002	0.910	0.357
934	585893.7241	4837124.562	42.41380954	0.669	0.000	0.312	0.356
1131	577654.0306	4843407.43	246.3131028	2.155	0.009	1.799	0.347
1801	584674.5122	4855701.468	173.7960809	1.609	0.004	1.260	0.345
789	590371.3904	4834410.724	138.2580251	1.327	0.003	0.981	0.343
641	599481.1616	4832806.548	9.305464157	0.398	0.000	0.063	0.335
1269	570425.0245	4846640.607	192.3117355	1.677	0.005	1.344	0.328
183	610590.856	4823045.374	51.53347558	0.606	0.000	0.279	0.327

Patch	*Centroid_X*	*Centroid_Y*	*Area_ha*	*dPC_1750*	*dPCintra*	*dPCflux*	*dPCconnector*
1705	572562.006	4854260.732	169.0394842	1.530	0.004	1.219	0.307
291	605178.6398	4826023.576	21.00858366	0.428	0.000	0.122	0.306
2149	574102.0458	4864688.609	81.30397349	0.872	0.001	0.566	0.305
1990	580941.8828	4859754.56	172.4148988	1.520	0.004	1.212	0.304
840	587404.888	4835414.998	59.94647633	0.732	0.001	0.430	0.301
2178	575284.113	4866641.465	62.14605784	0.698	0.001	0.401	0.297
532	580362.7696	4831335.376	41.61522908	0.590	0.000	0.299	0.290
956	575746.7908	4837459.753	89.05793423	0.921	0.001	0.638	0.282
2069	582546.2296	4861760.186	217.7701522	1.777	0.007	1.511	0.259
409	603485.8796	4829614.097	36.94156668	0.480	0.000	0.223	0.257
785	587510.2772	4834933.51	5.311936846	0.292	0.000	0.038	0.254
538	600231.3592	4831761.485	1.595812773	0.241	0.000	0.010	0.231
1187	575782.6121	4845112.206	84.69071498	0.848	0.001	0.620	0.227
889	579201.1179	4836057.848	120.0914937	1.082	0.002	0.855	0.225
137	612628.7778	4821469.82	5.115089816	0.244	0.000	0.023	0.222
1168	584468.2826	4843421.875	661.8639221	5.078	0.063	4.806	0.210
1217	574881.8125	4846100.587	82.81332241	0.795	0.001	0.591	0.203
1093	577191.0435	4842062.902	212.3111466	1.754	0.006	1.546	0.202
1299	579648.06	4847122.763	185.9427623	1.582	0.005	1.377	0.199
601	601701.375	4832026.762	27.88938492	0.374	0.000	0.175	0.199
2010	582069.7595	4860377.708	211.9934044	1.683	0.006	1.478	0.198
2131	572764.8715	4864862.75	15.03946428	0.301	0.000	0.103	0.198
1612	572115.2753	4852677.389	156.1235209	1.319	0.004	1.119	0.197
804	581524.0187	4833689.416	218.5860671	1.782	0.007	1.581	0.194
1737	570206.1337	4854677.092	216.7322985	1.742	0.007	1.549	0.187
1229	578941.4972	4846048.502	142.1162169	1.231	0.003	1.050	0.178
249	605313.9758	4825309.827	9.933964269	0.234	0.000	0.057	0.176
2108	573326.908	4864136.125	8.464131394	0.235	0.000	0.059	0.175
348	603248.0159	4828016.092	8.211321757	0.223	0.000	0.048	0.174
2158	576009.8437	4865702.179	12.17692582	0.250	0.000	0.077	0.172
1817	586288.1174	4856088.475	158.6939353	1.304	0.004	1.142	0.158
2172	576729.3045	4866222.987	50.76236345	0.479	0.000	0.320	0.158
2157	574647.6111	4865939.827	1.069868082	0.164	0.000	0.007	0.157
1246	573902.962	4847129.104	56.04428485	0.555	0.000	0.399	0.155
1173	578441.2319	4844670.277	209.1250747	1.696	0.006	1.535	0.155
1335	580506.1171	4848085.172	154.6374031	1.306	0.003	1.149	0.153
1521	569354.7008	4851134.428	71.67099879	0.659	0.001	0.508	0.150
1242	572105.0394	4846783.063	101.1375921	0.857	0.001	0.714	0.141
1287	576003.4356	4847233.998	90.98523305	0.808	0.001	0.666	0.141
654	591159.9626	4832880.186	21.46218198	0.289	0.000	0.152	0.138
1971	586509.3528	4859747.691	60.35350929	0.559	0.001	0.424	0.134
1974	574797.014	4860586.971	3.186783123	0.147	0.000	0.023	0.124

Patch	Centroid_X	Centroid_Y	Area_ha	dPC_1750	dPCintra	dPCflux	dPCconnector
2159	571225.062	4865313.318	93.57474934	0.745	0.001	0.620	0.123
746	590468.8062	4833987.515	97.75347699	0.815	0.001	0.693	0.122
1275	572905.2014	4847634.025	28.11819252	0.321	0.000	0.200	0.121
1380	572078.7357	4848892.308	44.40881428	0.429	0.000	0.315	0.114
1256	582291.9623	4846473.78	259.7327969	2.039	0.010	1.919	0.110
170	612575.102	4823309.128	10.52082783	0.166	0.000	0.056	0.110
148	613327.6173	4822644.86	1.500198383	0.116	0.000	0.007	0.110
1405	575686.2269	4849464.358	71.71767683	0.629	0.001	0.519	0.109
1472	581703.5404	4850854.6	36.42710521	0.378	0.000	0.272	0.106
2111	583482.2268	4862976.662	289.4507646	2.107	0.012	1.990	0.105
382	603823.1728	4828903.53	9.158638569	0.159	0.000	0.055	0.104
1934	572429.6008	4858205.885	142.1400703	1.141	0.003	1.034	0.104
463	575233.6006	4829349.568	453.288463	3.287	0.030	3.154	0.104
1342	576181.144	4848650.683	16.51654616	0.223	0.000	0.120	0.102
1883	568577.5279	4857869.093	14.1438524	0.201	0.000	0.102	0.098
534	602197.7362	4831318.578	17.14732249	0.204	0.000	0.106	0.098
454	602448.6346	4830665.221	3.723793774	0.121	0.000	0.023	0.098
1618	578926.2802	4852227.235	103.9635479	0.871	0.002	0.773	0.097
1625	588842.2333	4853514.924	79.38564577	0.662	0.001	0.567	0.094
1290	571250.8743	4847782.879	60.31116005	0.519	0.001	0.426	0.092
1927	569259.8296	4858508.771	70.76979013	0.603	0.001	0.513	0.090
1438	580059.5148	4850492.975	34.59777578	0.345	0.000	0.258	0.086

D-5: Top 100 natural area patches important for conservation prioritization ranked from most important to least important based on its value as a steppingstone patch (*dPCconnector*) to maintain connectivity in the entire network of the Credit River Watershed. Analysis is based on dispersal threshold of 8200m (Edge-to-edge Euclidian distance between patches).

Patch	*Centroid_X*	*Centroid_Y*	*Area_ha*	*dPC_8200*	*dPCintra*	*dPCflux*	*dPCconnector*
423	602467.5913	4830034.175	6.328986433	0.488	0.000	0.043	0.446
1461	581599.6096	4849911.026	374.4754926	2.951	0.018	2.608	0.325
1053	583277.3787	4839446.321	343.6260524	2.717	0.015	2.393	0.310
658	598317.8787	4832783.542	66.79515501	0.691	0.001	0.462	0.228
1906	574408.0165	4857928.746	102.4777899	0.919	0.001	0.718	0.200
568	600657.4907	4831943.696	10.49999578	0.271	0.000	0.072	0.199
1771	577543.4635	4855383.203	53.95010173	0.572	0.000	0.379	0.193
1983	574543.2217	4860055.658	85.88866853	0.794	0.001	0.601	0.192
573	599772.7007	4831977.465	7.443654806	0.242	0.000	0.051	0.191
1086	583743.1195	4841212.737	367.6449359	2.764	0.017	2.559	0.188
2029	574592.7241	4861649.345	56.63467578	0.583	0.000	0.396	0.186
1881	575234.0222	4857647.588	22.86283914	0.343	0.000	0.161	0.182
1646	578748.2672	4853777.63	12.04365066	0.246	0.000	0.085	0.161
942	583235.645	4837375.443	94.70395758	0.823	0.001	0.665	0.157
1937	573398.6899	4858990.189	140.9630562	1.144	0.002	0.986	0.155
598	599875.858	4832314.42	3.649400857	0.174	0.000	0.025	0.149
2013	577856.753	4860664.398	170.1852216	1.324	0.004	1.182	0.138
673	593513.9	4832924.69	63.91576925	0.580	0.001	0.445	0.134
425	577559.964	4829831.376	69.34412838	0.610	0.001	0.483	0.126
183	610590.856	4823045.374	51.53347558	0.455	0.000	0.339	0.115
2076	578883.6451	4861557.391	209.9412348	1.571	0.006	1.455	0.111
906	586562.5302	4836705.06	27.04614023	0.295	0.000	0.190	0.105
1873	575681.8252	4857009.157	76.09646392	0.636	0.001	0.534	0.101
641	599481.1616	4832806.548	9.305464157	0.163	0.000	0.064	0.099
1023	585495.1813	4839511.067	112.3661879	0.887	0.002	0.789	0.097
983	577103.6882	4838269.83	131.3554522	1.014	0.002	0.917	0.096
291	605178.6398	4826023.576	21.00858366	0.236	0.000	0.141	0.096
2038	575170.0754	4861916.318	33.95435491	0.333	0.000	0.237	0.095
2088	575942.7737	4862443.51	109.8715705	0.862	0.002	0.765	0.095
934	585893.7241	4837124.562	42.41380954	0.390	0.000	0.298	0.091
789	590371.3904	4834410.724	138.2580251	1.054	0.002	0.962	0.090
1647	584688.8749	4853567.608	110.5601279	0.866	0.002	0.774	0.090
1600	583748.0248	4852765.026	132.5582625	1.021	0.002	0.930	0.089
1269	570425.0245	4846640.607	192.3117355	1.419	0.005	1.331	0.083
137	612628.7778	4821469.82	5.115089816	0.113	0.000	0.032	0.080
840	587404.888	4835414.998	59.94647633	0.498	0.000	0.419	0.079

Patch	Centroid_X	Centroid_Y	Area_ha	dPC_8200	dPCintra	dPCflux	dPCconnector
505	578819.0226	4830785.51	127.6258878	0.969	0.002	0.889	0.078
409	603485.8796	4829614.097	36.94156668	0.327	0.000	0.249	0.078
1801	584674.5122	4855701.468	173.7960809	1.292	0.004	1.213	0.075
1131	577654.0306	4843407.43	246.3131028	1.801	0.008	1.719	0.074
2149	574102.0458	4864688.609	81.30397349	0.639	0.001	0.564	0.074
2178	575284.113	4866641.465	62.14605784	0.499	0.000	0.424	0.074
538	600231.3592	4831761.485	1.595812773	0.079	0.000	0.011	0.068
785	587510.2772	4834933.51	5.311936846	0.104	0.000	0.037	0.066
1990	580941.8828	4859754.56	172.4148988	1.265	0.004	1.195	0.066
1705	572562.006	4854260.732	169.0394842	1.248	0.004	1.178	0.065
956	575746.7908	4837459.753	89.05793423	0.686	0.001	0.621	0.063
532	580362.7696	4831335.376	41.61522908	0.354	0.000	0.291	0.063
601	601701.375	4832026.762	27.88938492	0.249	0.000	0.190	0.059
2069	582546.2296	4861760.186	217.7701522	1.567	0.006	1.504	0.058
249	605313.9758	4825309.827	9.933964269	0.122	0.000	0.066	0.055
348	603248.0159	4828016.092	8.211321757	0.109	0.000	0.055	0.054
1187	575782.6121	4845112.206	84.69071498	0.645	0.001	0.594	0.050
889	579201.1179	4836057.848	120.0914937	0.888	0.002	0.836	0.049
1168	584468.2826	4843421.875	661.8639221	4.662	0.055	4.560	0.047
2131	572764.8715	4864862.75	15.03946428	0.151	0.000	0.104	0.047
1217	574881.8125	4846100.587	82.81332241	0.624	0.001	0.578	0.046
1737	570206.1337	4854677.092	216.7322985	1.556	0.006	1.506	0.043
2010	582069.7595	4860377.708	211.9934044	1.514	0.006	1.465	0.043
1612	572115.2753	4852677.389	156.1235209	1.133	0.003	1.087	0.042
1093	577191.0435	4842062.902	212.3111466	1.530	0.006	1.482	0.042
2158	576009.8437	4865702.179	12.17692582	0.125	0.000	0.083	0.042
1299	579648.06	4847122.763	185.9427623	1.350	0.004	1.303	0.042
804	581524.0187	4833689.416	218.5860671	1.570	0.006	1.523	0.041
2108	573326.908	4864136.125	8.464131394	0.100	0.000	0.059	0.041
2172	576729.3045	4866222.987	50.76236345	0.385	0.000	0.345	0.039
170	612575.102	4823309.128	10.52082783	0.107	0.000	0.069	0.038
148	613327.6173	4822644.86	1.500198383	0.047	0.000	0.010	0.038
1229	578941.4972	4846048.502	142.1162169	1.037	0.003	0.997	0.038
654	591159.9626	4832880.186	21.46218198	0.187	0.000	0.150	0.037
2157	574647.6111	4865939.827	1.069868082	0.045	0.000	0.007	0.037
1246	573902.962	4847129.104	56.04428485	0.427	0.000	0.391	0.036
1521	569354.7008	4851134.428	71.67099879	0.535	0.001	0.499	0.035
1817	586288.1174	4856088.475	158.6939353	1.144	0.003	1.106	0.034
382	603823.1728	4828903.53	9.158638569	0.095	0.000	0.062	0.033
1173	578441.2319	4844670.277	209.1250747	1.500	0.005	1.462	0.033
1242	572105.0394	4846783.063	101.1375921	0.737	0.001	0.703	0.033
1335	580506.1171	4848085.172	154.6374031	1.121	0.003	1.086	0.032

Patch	Centroid_X	Centroid_Y	Area_ha	dPC_8200	dPCintra	dPCflux	dPCconnector
746	590468.8062	4833987.515	97.75347699	0.714	0.001	0.681	0.032
1971	586509.3528	4859747.691	60.35350929	0.451	0.000	0.420	0.031
1287	576003.4356	4847233.998	90.98523305	0.669	0.001	0.638	0.030
2159	571225.062	4865313.318	93.57474934	0.673	0.001	0.642	0.030
534	602197.7362	4831318.578	17.14732249	0.146	0.000	0.116	0.029
454	602448.6346	4830665.221	3.723793774	0.055	0.000	0.025	0.029
1115	587884.9286	4842631.127	133.3350473	0.963	0.002	0.931	0.029
1275	572905.2014	4847634.025	28.11819252	0.224	0.000	0.196	0.028
1974	574797.014	4860586.971	3.186783123	0.050	0.000	0.022	0.027
145	605732.2637	4822417.735	15.09770062	0.124	0.000	0.098	0.025
1883	568577.5279	4857869.093	14.1438524	0.124	0.000	0.099	0.025
463	575233.6006	4829349.568	453.288463	3.162	0.026	3.112	0.025
1256	582291.9623	4846473.78	259.7327969	1.849	0.008	1.816	0.025
1380	572078.7357	4848892.308	44.40881428	0.334	0.000	0.310	0.024
322	603862.1278	4826933.478	18.28184999	0.147	0.000	0.122	0.024
2111	583482.2268	4862976.662	289.4507646	2.025	0.011	1.991	0.024
171	613770.6953	4823428.671	5.950403789	0.062	0.000	0.038	0.024
1405	575686.2269	4849464.358	71.71767683	0.526	0.001	0.502	0.024
1472	581703.5404	4850854.6	36.42710521	0.280	0.000	0.257	0.023
237	615123.3157	4824999.693	1.11424672	0.029	0.000	0.007	0.022
1342	576181.144	4848650.683	16.51654616	0.138	0.000	0.116	0.022
1934	572429.6008	4858205.885	142.1400703	1.018	0.003	0.994	0.022

D-6: Top 100 natural area patches important for conservation prioritization ranked from most important to least important based on its value as a steppingstone patch (*dPCconnector*) to maintain connectivity in the entire network of the Credit River Watershed. Analysis is based on dispersal threshold of 15700 (Edge-to-edge Euclidian distance between patches).

Patch	*Centroid_X*	*Centroid_Y*	*Area_ha*	*dPC15700*	*dPCintra*	*dPCflux*	*dPCconnector*
423	602467.5913	4830034.175	6.328986433	0.290	0.000	0.043	0.246
1461	581599.6096	4849911.026	374.4754926	2.775	0.017	2.587	0.171
1053	583277.3787	4839446.321	343.6260524	2.551	0.015	2.375	0.162
658	598317.8787	4832783.542	66.79515501	0.588	0.001	0.462	0.125
568	600657.4907	4831943.696	10.49999578	0.181	0.000	0.072	0.109
1906	574408.0165	4857928.746	102.4777899	0.820	0.001	0.714	0.105
573	599772.7007	4831977.465	7.443654806	0.156	0.000	0.051	0.104
1771	577543.4635	4855383.203	53.95010173	0.478	0.000	0.377	0.101
1983	574543.2217	4860055.658	85.88866853	0.700	0.001	0.598	0.101
1086	583743.1195	4841212.737	367.6449359	2.655	0.017	2.539	0.099
2029	574592.7241	4861649.345	56.63467578	0.492	0.000	0.394	0.098
1881	575234.0222	4857647.588	22.86283914	0.255	0.000	0.160	0.096
1646	578748.2672	4853777.63	12.04365066	0.169	0.000	0.084	0.084
942	583235.645	4837375.443	94.70395758	0.743	0.001	0.660	0.082
598	599875.858	4832314.42	3.649400857	0.107	0.000	0.025	0.082
1937	573398.6899	4858990.189	140.9630562	1.064	0.002	0.980	0.081
673	593513.9	4832924.69	63.91576925	0.517	0.001	0.444	0.073
2013	577856.753	4860664.398	170.1852216	1.254	0.004	1.178	0.072
425	577559.964	4829831.376	69.34412838	0.548	0.001	0.482	0.066
183	610590.856	4823045.374	51.53347558	0.412	0.000	0.348	0.064
2076	578883.6451	4861557.391	209.9412348	1.514	0.005	1.450	0.058
906	586562.5302	4836705.06	27.04614023	0.245	0.000	0.189	0.056
641	599481.1616	4832806.548	9.305464157	0.118	0.000	0.064	0.054
1873	575681.8252	4857009.157	76.09646392	0.584	0.001	0.531	0.053
291	605178.6398	4826023.576	21.00858366	0.196	0.000	0.143	0.053
1023	585495.1813	4839511.067	112.3661879	0.836	0.002	0.783	0.052
983	577103.6882	4838269.83	131.3554522	0.964	0.002	0.912	0.050
2038	575170.0754	4861916.318	33.95435491	0.286	0.000	0.236	0.050
2088	575942.7737	4862443.51	109.8715705	0.814	0.001	0.762	0.050
934	585893.7241	4837124.562	42.41380954	0.345	0.000	0.296	0.049
789	590371.3904	4834410.724	138.2580251	1.009	0.002	0.958	0.048
1647	584688.8749	4853567.608	110.5601279	0.818	0.002	0.769	0.047
1600	583748.0248	4852765.026	132.5582625	0.972	0.002	0.923	0.047
137	612628.7778	4821469.82	5.115089816	0.079	0.000	0.034	0.045
1269	570425.0245	4846640.607	192.3117355	1.377	0.005	1.328	0.044
409	603485.8796	4829614.097	36.94156668	0.295	0.000	0.252	0.043

Patch	Centroid_X	Centroid_Y	Area_ha	dPC15700	dPCintra	dPCflux	dPCconnector
840	587404.888	4835414.998	59.94647633	0.460	0.000	0.417	0.042
505	578819.0226	4830785.51	127.6258878	0.928	0.002	0.885	0.041
2178	575284.113	4866641.465	62.14605784	0.467	0.000	0.427	0.039
2149	574102.0458	4864688.609	81.30397349	0.603	0.001	0.563	0.039
1801	584674.5122	4855701.468	173.7960809	1.249	0.004	1.206	0.039
1131	577654.0306	4843407.43	246.3131028	1.753	0.007	1.707	0.039
538	600231.3592	4831761.485	1.595812773	0.048	0.000	0.011	0.037
785	587510.2772	4834933.51	5.311936846	0.073	0.000	0.037	0.036
1990	580941.8828	4859754.56	172.4148988	1.231	0.004	1.192	0.035
1705	572562.006	4854260.732	169.0394842	1.210	0.004	1.172	0.034
956	575746.7908	4837459.753	89.05793423	0.653	0.001	0.619	0.033
532	580362.7696	4831335.376	41.61522908	0.323	0.000	0.290	0.033
601	601701.375	4832026.762	27.88938492	0.224	0.000	0.191	0.032
249	605313.9758	4825309.827	9.933964269	0.098	0.000	0.068	0.030
2069	582546.2296	4861760.186	217.7701522	1.538	0.006	1.502	0.030
348	603248.0159	4828016.092	8.211321757	0.085	0.000	0.056	0.029
1187	575782.6121	4845112.206	84.69071498	0.617	0.001	0.590	0.026
889	579201.1179	4836057.848	120.0914937	0.861	0.002	0.833	0.026
1168	584468.2826	4843421.875	661.8639221	4.603	0.054	4.525	0.025
2131	572764.8715	4864862.75	15.03946428	0.129	0.000	0.104	0.025
1217	574881.8125	4846100.587	82.81332241	0.600	0.001	0.575	0.024
1737	570206.1337	4854677.092	216.7322985	1.528	0.006	1.500	0.023
2010	582069.7595	4860377.708	211.9934044	1.491	0.006	1.463	0.023
2158	576009.8437	4865702.179	12.17692582	0.106	0.000	0.084	0.022
1612	572115.2753	4852677.389	156.1235209	1.108	0.003	1.083	0.022
1093	577191.0435	4842062.902	212.3111466	1.500	0.006	1.472	0.022
1299	579648.06	4847122.763	185.9427623	1.319	0.004	1.293	0.022
2108	573326.908	4864136.125	8.464131394	0.080	0.000	0.059	0.021
804	581524.0187	4833689.416	218.5860671	1.542	0.006	1.514	0.021
170	612575.102	4823309.128	10.52082783	0.092	0.000	0.071	0.021
148	613327.6173	4822644.86	1.500198383	0.031	0.000	0.010	0.021
2172	576729.3045	4866222.987	50.76236345	0.369	0.000	0.348	0.021
654	591159.9626	4832880.186	21.46218198	0.169	0.000	0.149	0.020
2157	574647.6111	4865939.827	1.069868082	0.027	0.000	0.007	0.020
1229	578941.4972	4846048.502	142.1162169	1.011	0.002	0.989	0.020
1246	573902.962	4847129.104	56.04428485	0.409	0.000	0.390	0.019
1521	569354.7008	4851134.428	71.67099879	0.517	0.001	0.498	0.019
382	603823.1728	4828903.53	9.158638569	0.081	0.000	0.063	0.018
1817	586288.1174	4856088.475	158.6939353	1.122	0.003	1.101	0.018
746	590468.8062	4833987.515	97.75347699	0.697	0.001	0.678	0.017
1115	587884.9286	4842631.127	133.3350473	0.946	0.002	0.926	0.017
1242	572105.0394	4846783.063	101.1375921	0.720	0.001	0.701	0.017

Patch	Centroid_X	Centroid_Y	Area_ha	dPC15700	dPCintra	dPCflux	dPCconnector
1173	578441.2319	4844670.277	209.1250747	1.474	0.005	1.452	0.017
1335	580506.1171	4848085.172	154.6374031	1.097	0.003	1.077	0.017
1971	586509.3528	4859747.691	60.35350929	0.436	0.000	0.419	0.016
534	602197.7362	4831318.578	17.14732249	0.134	0.000	0.118	0.016
454	602448.6346	4830665.221	3.723793774	0.042	0.000	0.026	0.016
1287	576003.4356	4847233.998	90.98523305	0.650	0.001	0.634	0.016
2159	571225.062	4865313.318	93.57474934	0.661	0.001	0.644	0.016
145	605732.2637	4822417.735	15.09770062	0.116	0.000	0.101	0.015
1275	572905.2014	4847634.025	28.11819252	0.210	0.000	0.196	0.015
1974	574797.014	4860586.971	3.186783123	0.036	0.000	0.022	0.014
322	603862.1278	4826933.478	18.28184999	0.138	0.000	0.125	0.013
171	613770.6953	4823428.671	5.950403789	0.053	0.000	0.040	0.013
1883	568577.5279	4857869.093	14.1438524	0.112	0.000	0.099	0.013
463	575233.6006	4829349.568	453.288463	3.142	0.025	3.104	0.013
1256	582291.9623	4846473.78	259.7327969	1.823	0.008	1.802	0.013
1380	572078.7357	4848892.308	44.40881428	0.322	0.000	0.309	0.013
2111	583482.2268	4862976.662	289.4507646	2.012	0.010	1.989	0.013
152	606610.2048	4822643.988	6.011624518	0.053	0.000	0.041	0.013
237	615123.3157	4824999.693	1.11424672	0.020	0.000	0.007	0.013
1405	575686.2269	4849464.358	71.71767683	0.512	0.001	0.499	0.012
1472	581703.5404	4850854.6	36.42710521	0.267	0.000	0.255	0.012
181	607731.0744	4823122.265	62.13799459	0.432	0.000	0.420	0.012

10. Literature Cited

Anderson, M. G., Clark, M., & Sheldon, A. O. (2012). Resilient Sites for Terrestrial Conservation in the Northeast and Mid-Atlantic Region. *The Nature Conservancy, Eastern Conservation Science*, 169 pp.

Bowman, J., & Cordes, C. (2015). *Landscape Connectivity in the Great Lakes Basin Implication of Partinioning Population-Based Landscape Genetic Analysis into Sex Components View project*. https://doi.org/10.6084/m9.figshare.1471658.v1

Calabrese, J. M., & Fagan, W. F. (2004). A comparison-shopper's guide to connectivity metrics. In *Frontiers in Ecology and the Environment* (Vol. 2, Issue 10, pp. 529–536). Ecological Society of America. https://doi.org/10.1890/1540-9295(2004)002[0529:ACGTCM]2.0.CO;2

CVC. (2019). *Connectivity Modeling for the Credit River Watershed: Methodology for identifying functional groups of species based on dispersal requirements.*

Dale, M. R. T., & Fortin, M.-J. (2010). From Graphs to Spatial Graphs. *Annual Review of Ecology, Evolution, and Systematics*, *41*(1), 21–38. https://doi.org/doi:10.1146/annurev-ecolsys-102209-144718

Damschen, E., Haddad, N., Orrock, J., Tewksbury, J., & Levey, D. (2006). Corridors increase plant species richness at large scales. *Science*, *313*.

Dickson, B. G., Albano, C. M., McRae, B. H., Anderson, J. J., Theobald, D. M., Zachmann, L. J., Sisk, T. D., & Dombeck, M. P. (2017). Informing Strategic Efforts to Expand and Connect Protected Areas Using a Model of Ecological Flow, with Application to the Western United States. *Conservation Letters*, *10*(5), 564–571. https://doi.org/10.1111/conl.12322

Dilkina, B., Houtman, R., Gomes, C. P., Montgomery, C. A., McKelvey, K. S., Kendall, K., Graves, T. A., Bernstein, R., & Schwartz, M. K. (2017). Trade-offs and efficiencies in optimal budget-constrained multispecies corridor networks. *Conservation Biology*, *31*(1), 192–202. https://doi.org/10.1111/cobi.12814

Grimm, N. B., Faeth, S. H., Golubiewski, N. E., Redman, C. L., Wu, J., Bai, X., & Briggs, J. M. (2008). Global change and the ecology of cities. In *Science* (Vol. 319, Issue 5864, pp. 756–760). https://doi.org/10.1126/science.1150195

Gurrutxaga, M., Lozano, P. J., & del Gabriel, B. (2010). Assessing highway permeability for the restoration of landscape connectivity between protected areas in the Basque country, Northern Spain. *Landscape Research*, *35*(5), 529–550. https://doi.org/10.1080/01426397.2010.504915

Gurrutxaga, M., Rubio, L., & Saura, S. (2011). Key connectors in protected forest area networks and the impact of highways: A transnational case study from the Cantabrian Range to the Western Alps (SW Europe). *Landscape and Urban Planning*, *101*(4), 310–320. https://doi.org/10.1016/j.landurbplan.2011.02.036

Koen, E. L., Bowman, J., Sadowski, C., & Walpole, A. A. (2014). Landscape connectivity for wildlife: development and validation of multispecies linkage maps. *Methods in Ecology and Evolution*, *5*(7), 626–633. https://doi.org/10.1111/2041-210X.12197

Kramer-Schadt, S., Revilla, E., Wiegand, T., & Breitenmoser, U. (2004). Fragmented landscapes, road mortality and patch connectivity: Modelling influences on the dispersal of Eurasian lynx. *Journal of Applied Ecology*, *41*(4), 711–723. https://doi.org/10.1111/j.0021-8901.2004.00933.x

Lechner, A. M., Brown, G., & Raymond, C. M. (2015). Modeling the impact of future development and public conservation orientation on landscape connectivity for conservation planning. *Landscape Ecology*, *30*(4), 699–713. https://doi.org/10.1007/s10980-015-0153-0

Lee, H. T., Bakowsky, W. D., Riley, J., Bowles, J., Puddister, M., & Uhlig, P. (1998). *Ecological land classification of southern Ontario: First approximation and its application.*

Marrec, R., Abdel Moniem, H. E., Iravani, M., Hricko, B., Kariyeva, J., & Wagner, H. H. (2020). Conceptual framework and uncertainty analysis for large-scale, species-agnostic modelling of landscape connectivity across Alberta, Canada. *Scientific Reports*, *10*(1), 1–14. https://doi.org/10.1038/s41598-020-63545-z

Marrotte, R. R., Bowman, J., Brown, M. G. C., Cordes, C., Morris, K. Y., Prentice, M. B., & Wilson, P. J. (2017). Multi-species genetic connectivity in a terrestrial habitat network. *Movement Ecology*, *5*(1), 21. https://doi.org/10.1186/s40462-017-0112-2

Martensen, A. C., Saura, S., & Fortin, M. J. (2017). Spatio-temporal connectivity: assessing the amount of reachable habitat in dynamic landscapes. *Methods in Ecology and Evolution*, *8*(10), 1253–1264. https://doi.org/10.1111/2041-210X.12799

McRae, B. H. (2006). Isolation By Resistance. *Evolution*, *60*(8), 1551–1561. https://doi.org/10.1111/j.0014-3820.2006.tb00500.x

McRae, B. H., Dickson, B. G., Keitt, T. H., & Shah, V. B. (2008). Using circuit theory to model connectivity in ecology, evolution, and conservation. *Ecology*, *89*(10), 2712–2724. https://doi.org/10.1890/07-1861.1

Mitchell, M. G. E., Bennett, E. M., & Gonzalez, A. (2013). Linking Landscape Connectivity and Ecosystem Service Provision: Current Knowledge and Research Gaps. In *Ecosystems* (Vol. 16, Issue 5, pp. 894–908). Springer. https://doi.org/10.1007/s10021-013-9647-2

Mitchell, M. G. E., Suarez-Castro, A. F., Martinez-Harms, M., Maron, M., McAlpine, C., Gaston, K. J., Johansen, K., & Rhodes, J. R. (2015). Reframing landscape fragmentation's effects on ecosystem services. In *Trends in Ecology and Evolution* (Vol. 30, Issue 4, pp. 190–198). Elsevier Ltd.

https://doi.org/10.1016/j.tree.2015.01.011

MMAH. (2019). *A Place to Grow: Growth Plan for the Greater Golden Horseshoe*.

MMAH. (2020). *Provincial Policy Statement: Under the Planning Act*. https://files.ontario.ca/mmah-provincial-policy-statement-2020-accessible-final-en-2020-02-14.pdf

Pascula-Hortal, L., & Saura, S. (2007). Impact of spatial scale on the identification of critical habitat patches for the maintenance of landscape connectivity. *Landscape and Urban Planning*, *83*(2–3), 176–186. https://doi.org/10.1016/j.landurbplan.2007.04.003

Saura, S., & Rubio, L. (2010). A common currency for the different ways in which patches and links can contribute to habitat availability and connectivity in the landscape. *Ecography*, *33*(3), 523–537. https://doi.org/10.1111/j.1600-0587.2009.05760.x

Saura, S., & Torné, J. (2008). *Conefor Sensinode 2.2: A software package for quantifying the importance of habitat patches for landscape connectivity*. https://doi.org/10.1016/j.envsoft.2008.05.005

Taylor, P., Fahrig, L., Henein, K., & Merriam, G. (1993). Connectivity is a vital element of landscape structure. *Oikos*, *68*.

Theobald, D. M. (2013). A general model to quantify ecological integrity for landscape assessments and US application. *Landscape Ecology*, *28*(10), 1859–1874. https://doi.org/10.1007/s10980-013-9941-6

Theobald, D. M., Reed, S. E., Fields, K., & Soulé, M. (2012). Connecting natural landscapes using a landscape permeability model to prioritize conservation activities in the United States. *Conservation Letters*, *5*(2), 123–133. https://doi.org/10.1111/j.1755-263X.2011.00218.x

Tischendorf, L., & Fahrig, L. (2001). On the use of connectivity measures in spatial ecology. A reply. *OIKOS*, *95*(1), 152–155. https://doi.org/Doi 10.1034/J.1600-0706.2001.950117.X