Current Density Approaches to Modelling Landscape Connectivity

NSERC-Alliance

Connectivity Workshop – Okotoks - Oct. 30th. 2025

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Alberta Ministry of Environment & Protected Areas

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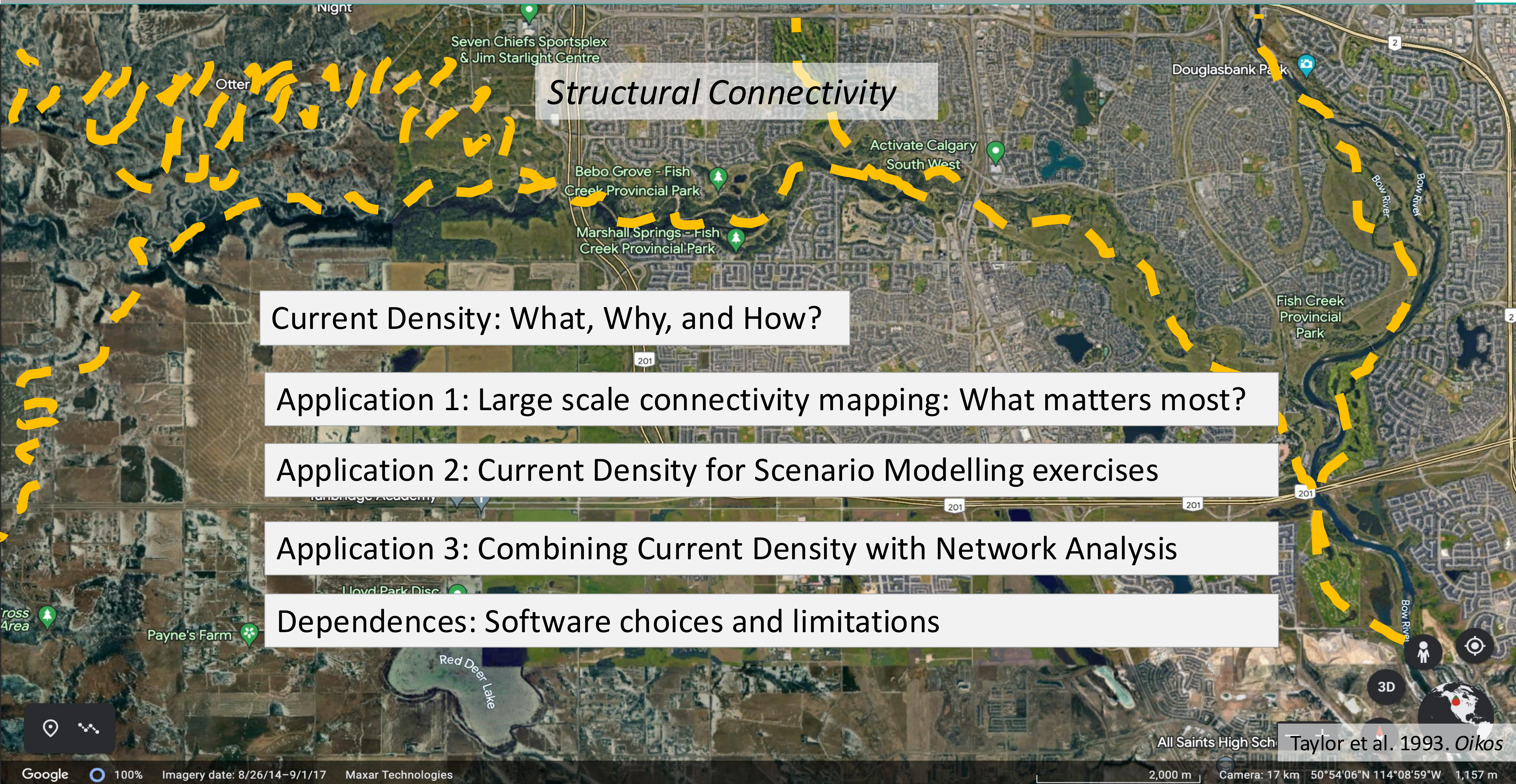

Structural Connectivity

Current Density: What, Why, and How?

Application 1: Large scale connectivity mapping: What matters most?

Application 2: Current Density for Scenario Modelling exercises

Application 3: Combining Current Density with Network Analysis

Dependences: Software choices and limitations

Taylor et al. 1993. *Oikos*

Where it all began!

2006

Evolution, 60(8), 2006, pp. 1551–1561

ISOLATION BY RESISTANCE

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Abstract.—Despite growing interest in the effects of landscape heterogeneity on genetic structuring, few tools are available to incorporate data on landscape composition into population genetic studies. Analyses of isolation by distance have typically either assumed spatial homogeneity for convenience or applied theoretically unjustified distance metrics to compensate for heterogeneity. Here I propose the isolation-by-resistance (IBR) model as an alternative for predicting equilibrium genetic structuring in complex landscapes. The model predicts a positive relationship between genetic differentiation and the resistance distance, a distance metric that exploits precise relationships between random walk times and effective resistances in electronic networks. As a predictor of genetic differentiation, the resistance distance is both more theoretically justified and more robust to spatial heterogeneity than Euclidean or least cost path-based distance measures. Moreover, the metric can be applied with a wide range of data inputs, including coarse-scale range maps, simple maps of habitat and nonhabitat within a species' range, or complex spatial datasets with habitats and barriers of differing qualities. The IBR model thus provides a flexible and efficient tool to account for habitat heterogeneity in studies of isolation by distance, improve understanding of how landscape characteristics affect genetic structuring, and predict genetic and evolutionary consequences of landscape change.

Key words.—Gene flow, graph theory, isolation by distance, isolation by resistance, landscape connectivity, landscape genetics, resistance distance.

2008

CONCEPTS & SYNTHESIS

EMPHASIZING NEW IDEAS TO STIMULATE RESEARCH IN ECOLOGY

Ecology, 89(10), 2008, pp. 2712–2724

USING CIRCUIT THEORY TO MODEL CONNECTIVITY IN ECOLOGY, EVOLUTION, AND CONSERVATION

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Abstract. Connectivity among populations and habitats is important for a wide range of ecological processes. Understanding, preserving, and restoring connectivity in complex landscapes requires connectivity models and metrics that are reliable, efficient, and process based. We introduce a new class of ecological connectivity models based in electrical circuit

2019

Conservation Biology

Review

Circuit-theory applications to connectivity science and conservation

Brett G. Dickson,[1,2*] Christine M. Albano,[1] Ranjan Anantharaman,[3] Paul Beier,[4] Joe Fargione,[5] Tabitha A. Graves,[6] Miranda E. Gray,[1] Kimberly R. Hall,[5] Josh J. Lawler,[7] Paul B. Leonard,[8] Caitlin E. Littlefield,[7] Meredith L. McClure,[1] John Novembre,[9] Carrie A. Schloss,[10] Nathan H. Schumaker,[11] Viral B. Shah,[3] and David M. Theobald[1]

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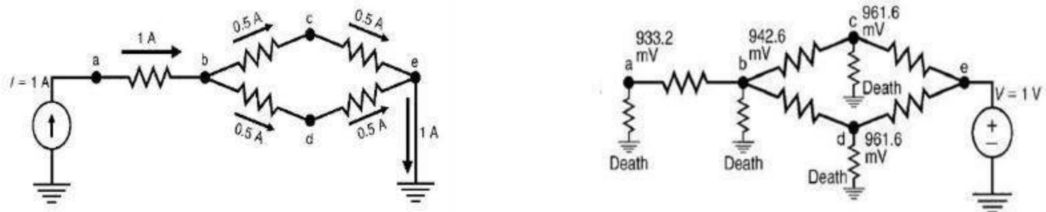
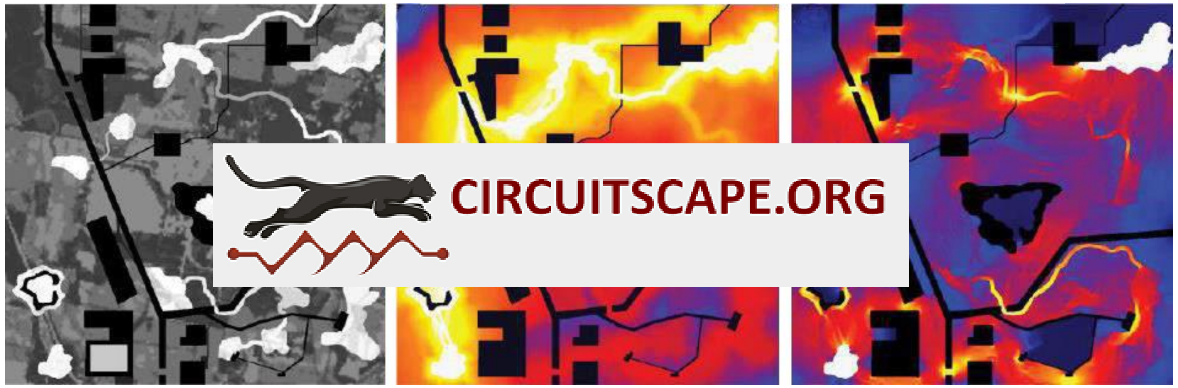
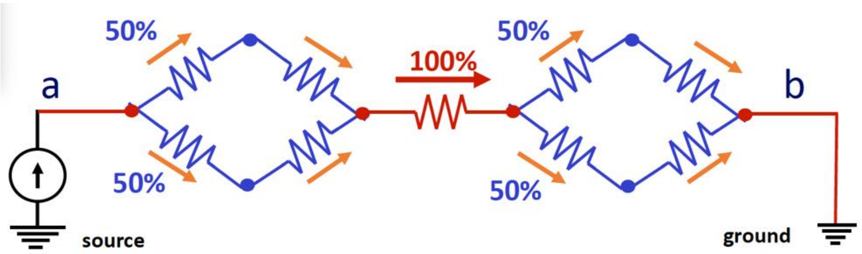




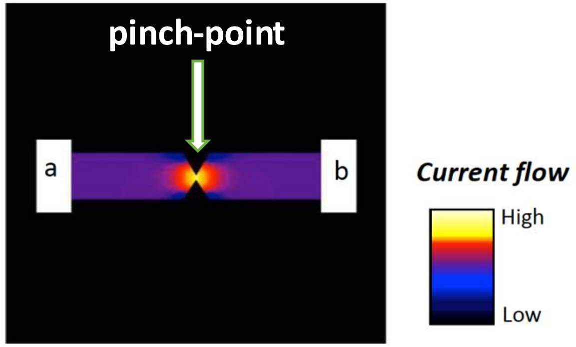
What is Current Density?



Circuit theory ⇄ movement: random walkers take many pathways

Electrical analogy ⇄ resistance surface with multiple current pathways

Current density → increases in pinch-points



Why Circuit Theory? Dickson et al. 2019

Connectivity is not just about corridors!

- Need to think about it more diffusely, particularly in working or dynamic landscapes: **The matrix matters**
- Connectivity is a dynamic process**: All possible pathways are important**
- Redundancy is important - especially under **changing land cover or climate**

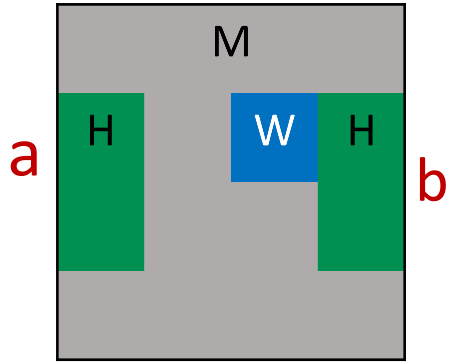
Circuit theory helps to:

- ➢ Quantify **ecological and gene flow** and redundancy over complex landscapes
- ➢ Prioritize **pinch-points** where connectivity might be lost sooner
- ➢ Identify **restoration opportunities** and explore change **scenarios**
- ➢ Provide theoretical justification for **protecting and reconnecting** landscapes.

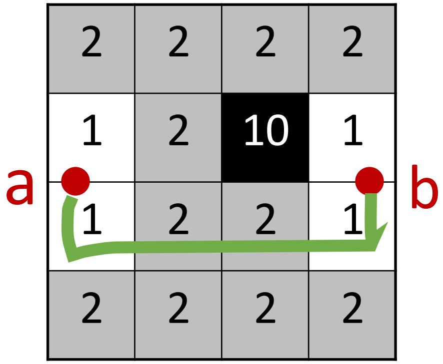
How Current Density Maps Are Made?

Based on Graph and Circuit theory

Landscape

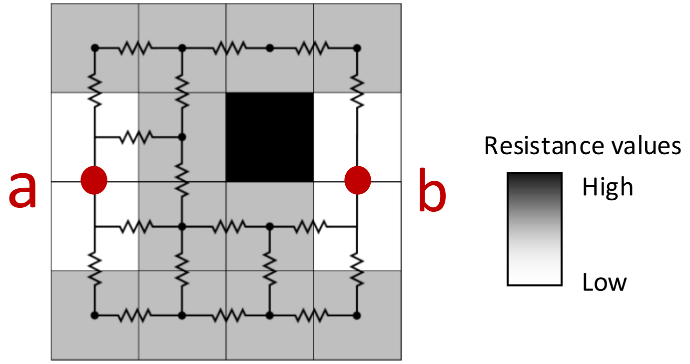


Least-cost path (LCP)

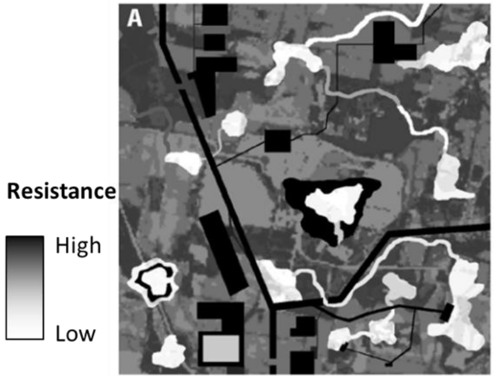


Landscape Resistance

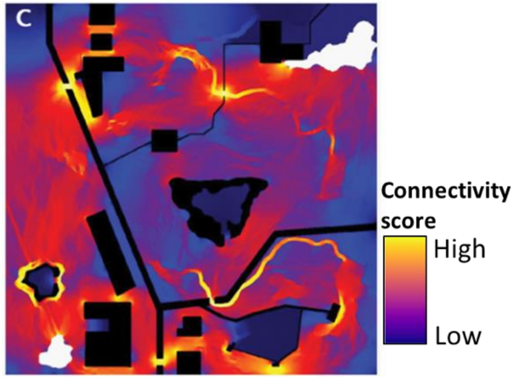
All possible paths (current density)



Landscape Resistance



Resistance

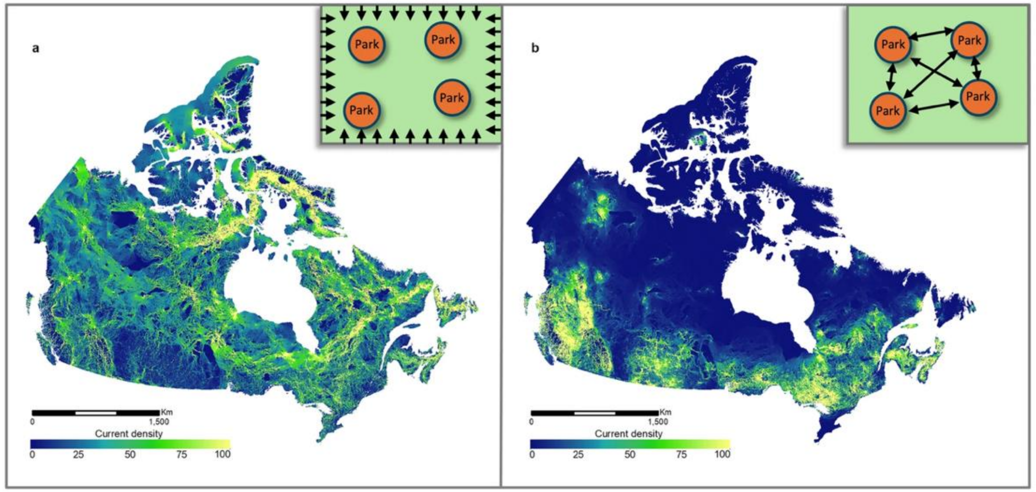


Current Density

McRae et al. 2008. Ecology

Current Direction

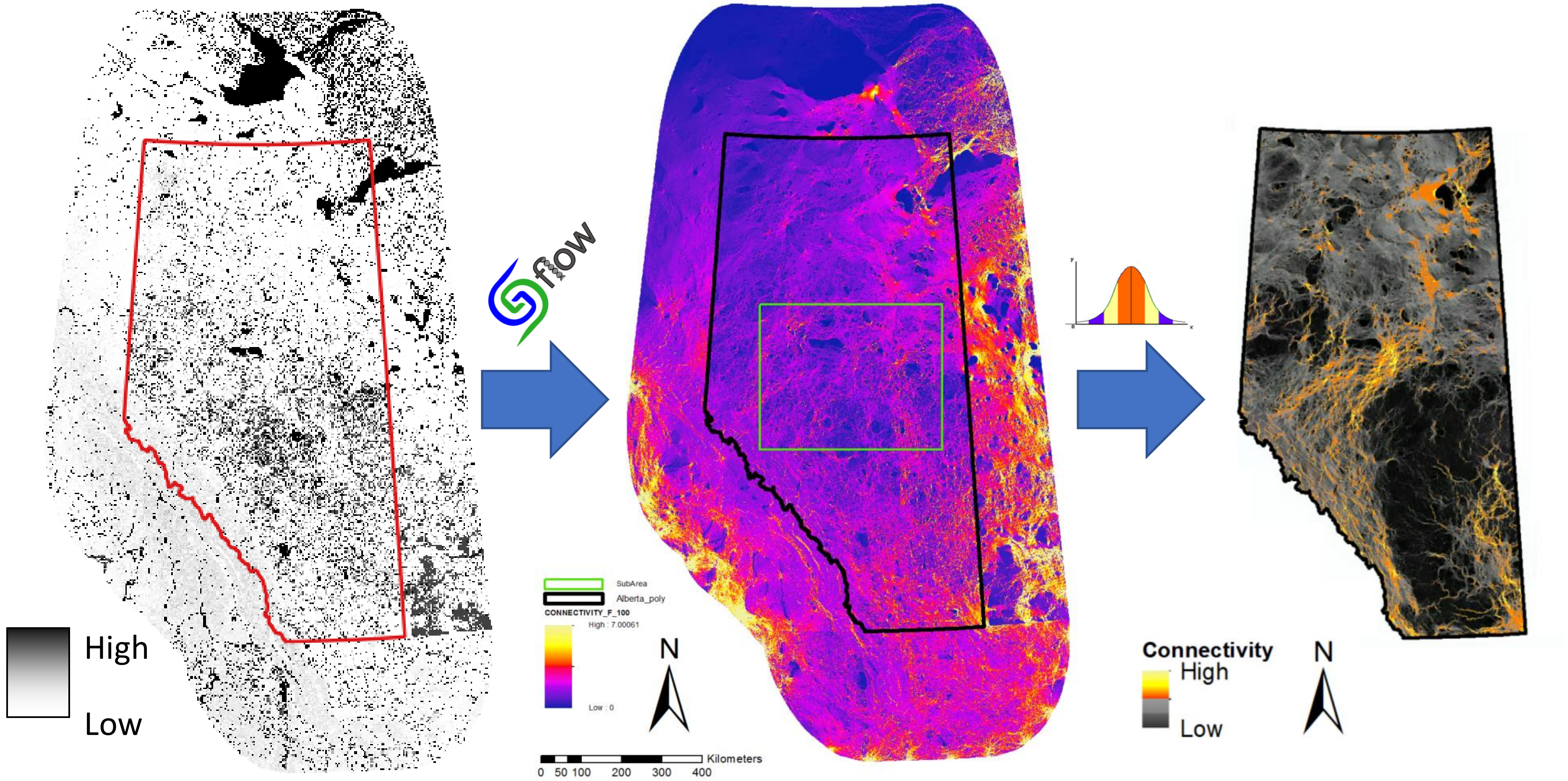
Omnidirictional **P2P**



Brennan et al. 2025. LSE

Large scale – Species Agnostic Connectivity mapping

Current Density Maps Workflow?



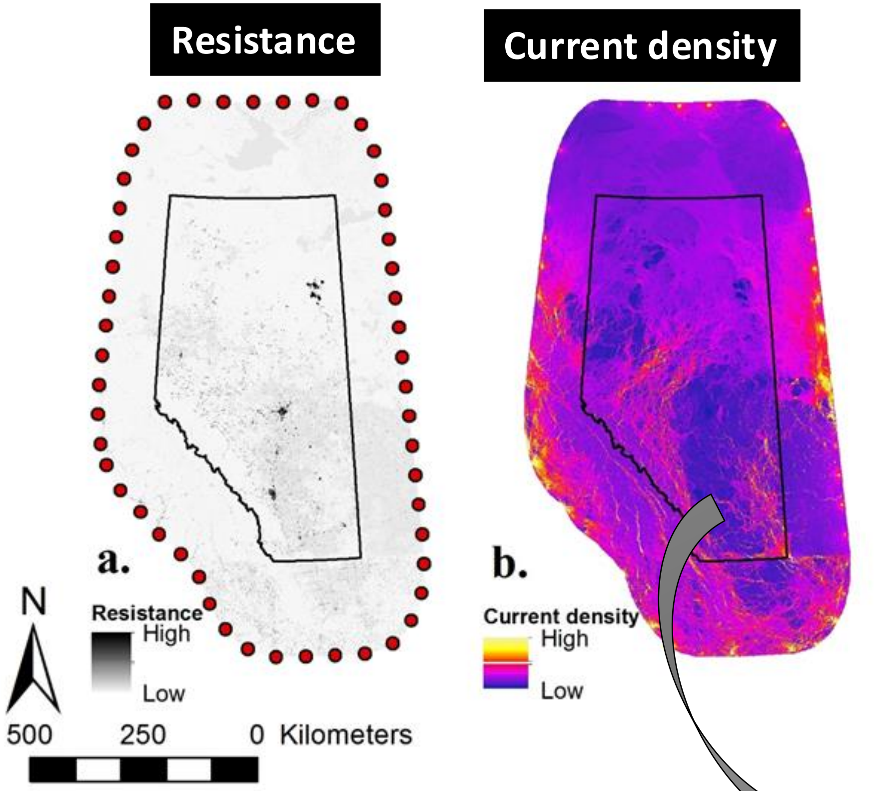
Resistance | **Current density** | **Standardized CD**

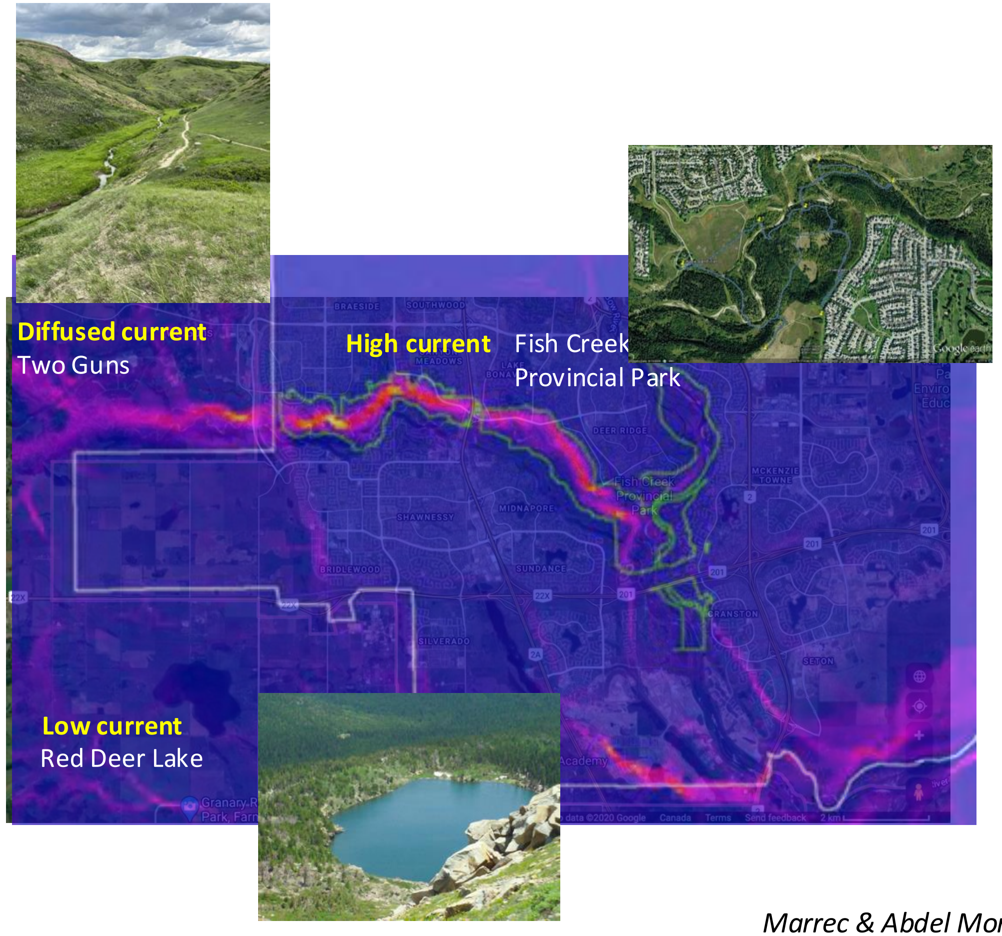
Marrec & Abdel Moniem et al. 2020

Overview | Current Density | **Application 1** | Application 2 | Application 3 | Dependencies

Large scale – Species Agnostic Connectivity mapping

How to interpret Current Density Maps?

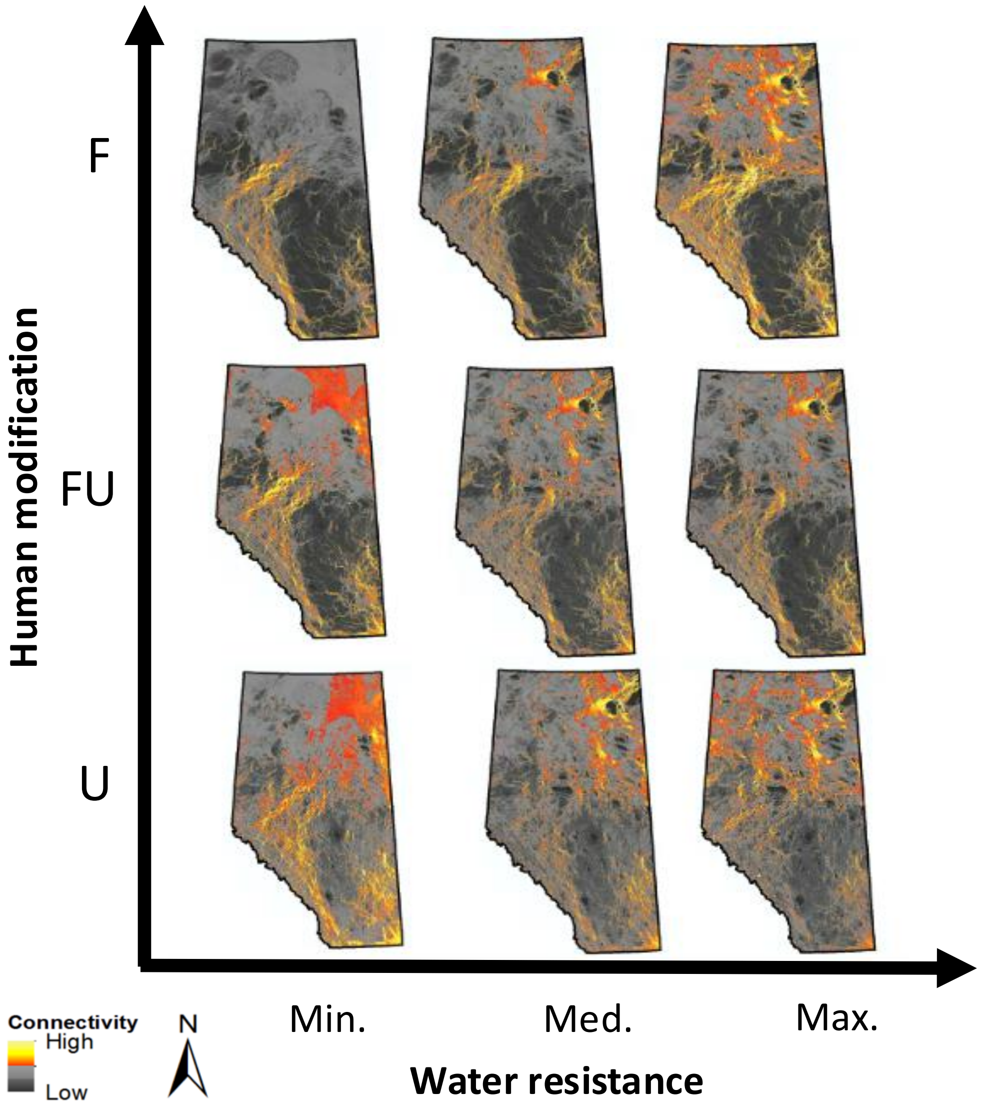


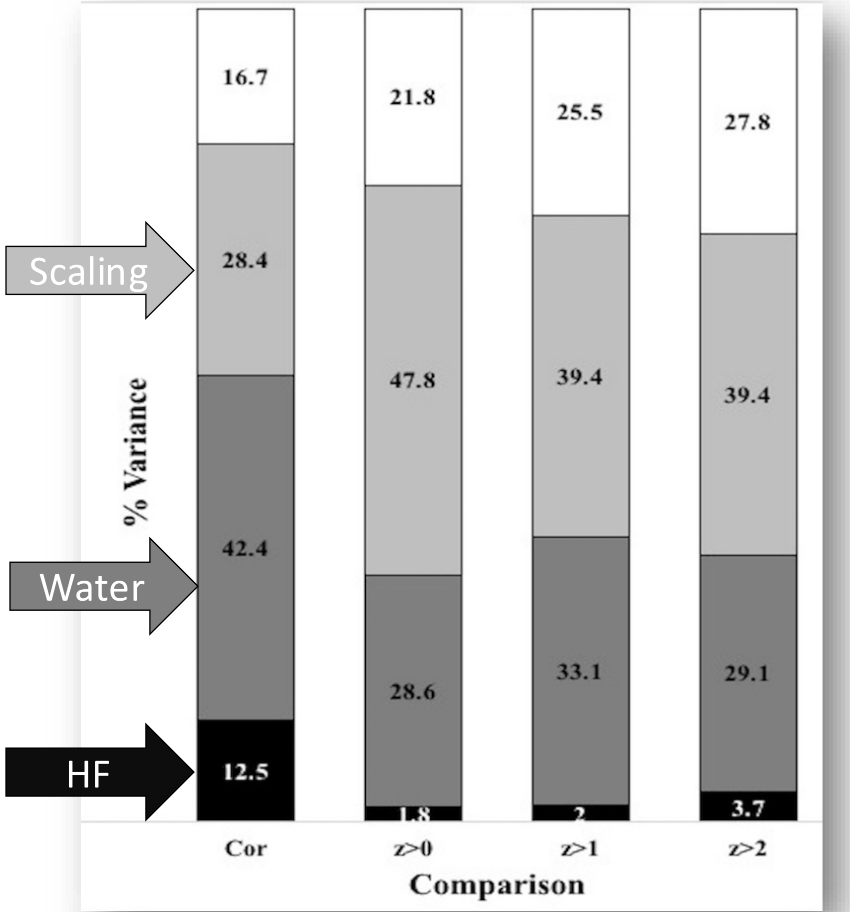


Marrec & Abdel Moniem et al. 2020

Large scale – Species Agnostic Connectivity mapping

What matters most? Sensitivity analysis





Marrec & Abdel Moniem et al. 2020

Current Density for Scenario Modelling: Grassland Study

PLOS One

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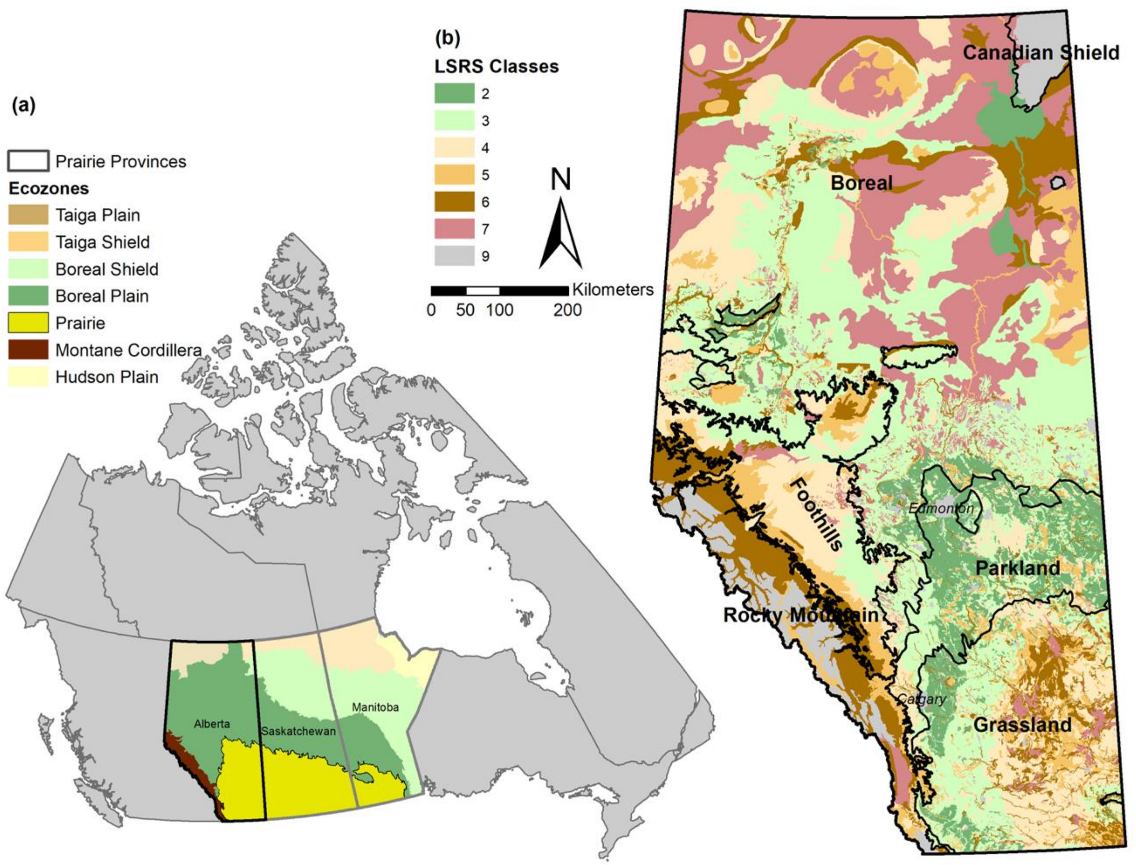
RESEARCH ARTICLE

Divergent trends in structural landscape connectivity from historic and potential future grassland conversion in Alberta, Canada

Hossam E. Abdel Moniem, Majid Iravani, Tim McAllister, Kim Ominski, Helene H. Wagner

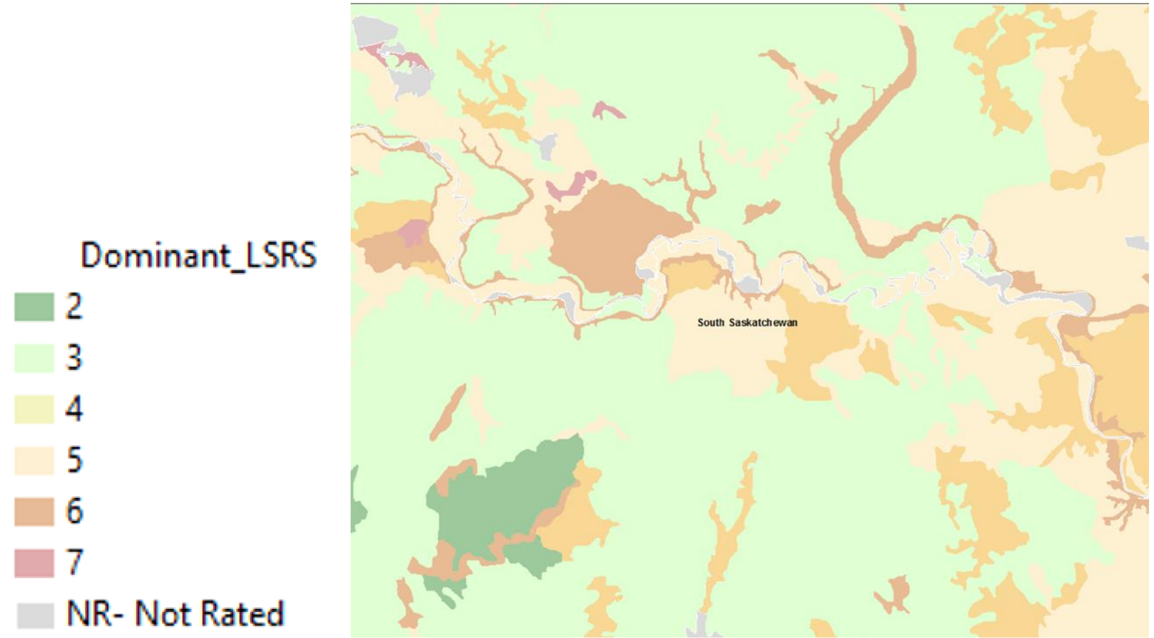
Published: August 1, 2025 • https://doi.org/10.1371/journal.pone.0325729

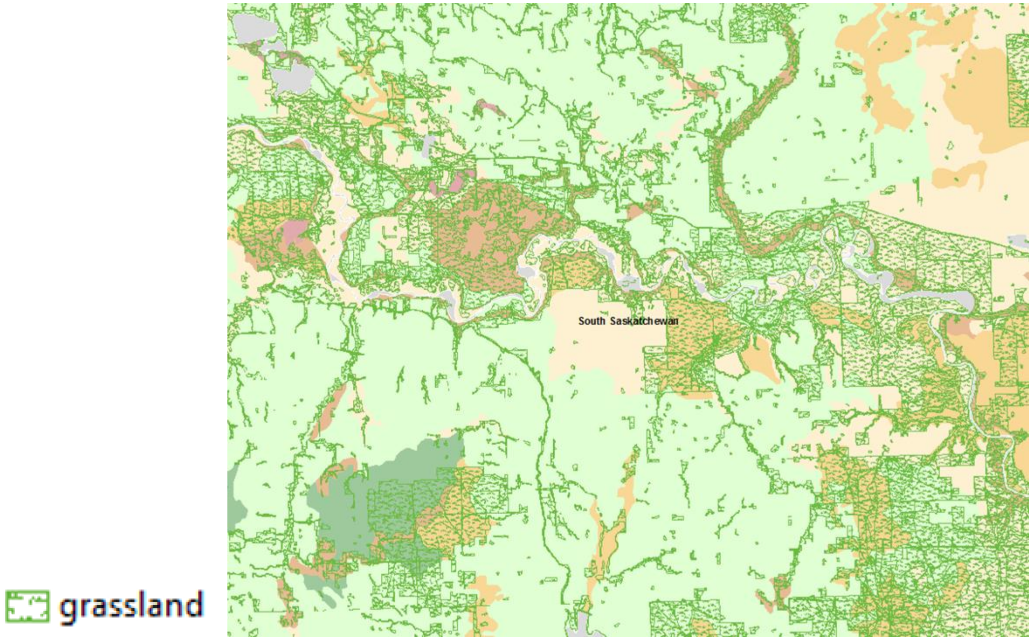


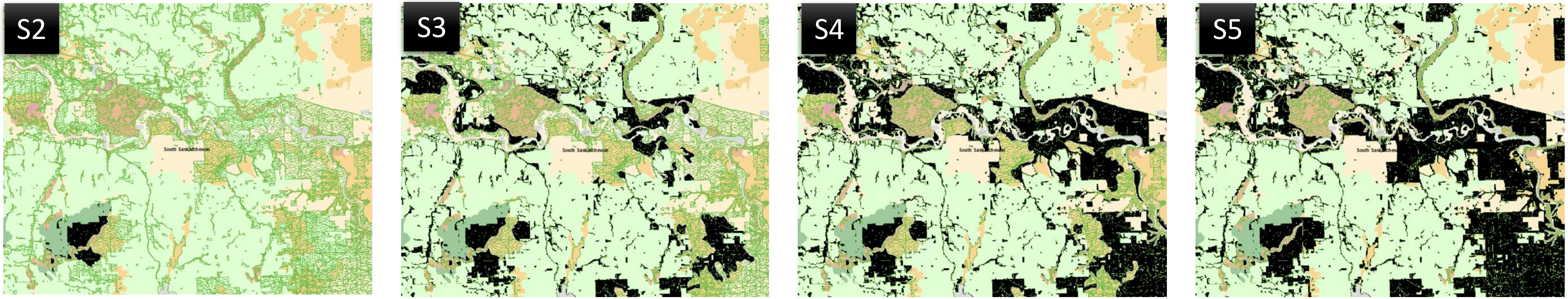
Objective

To assess the impact of converting native grassland to cropland and other land-uses on connectivity in the prairie region of Alberta.

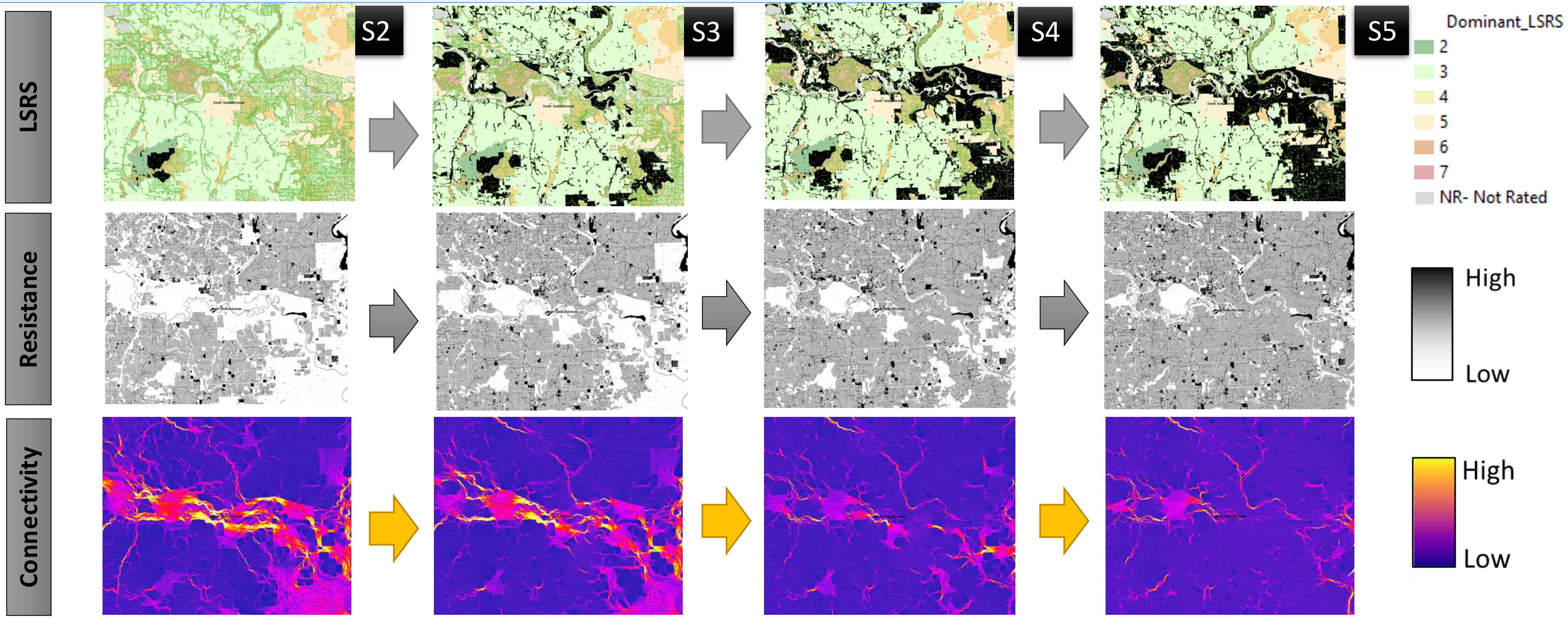
Current Density for Scenario Modelling: Grassland Study





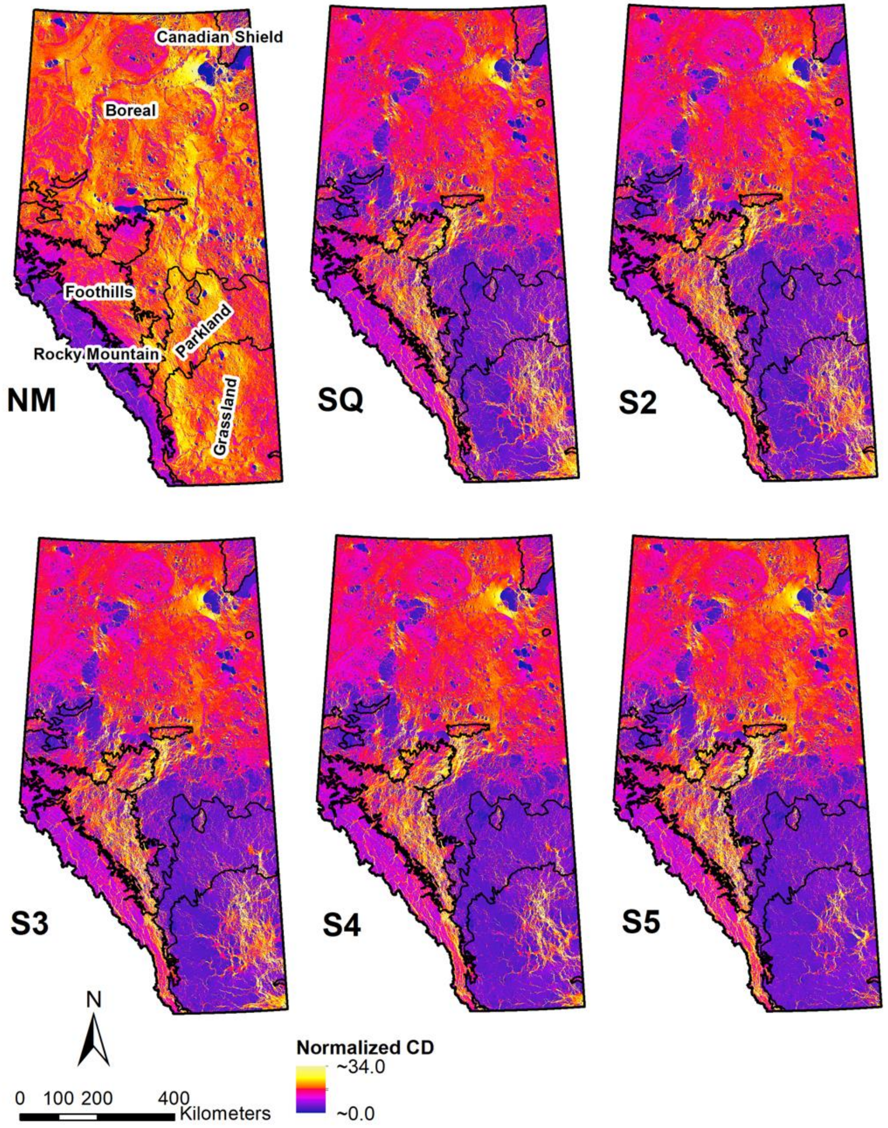


Current Density for Scenario Modelling: Grassland Study

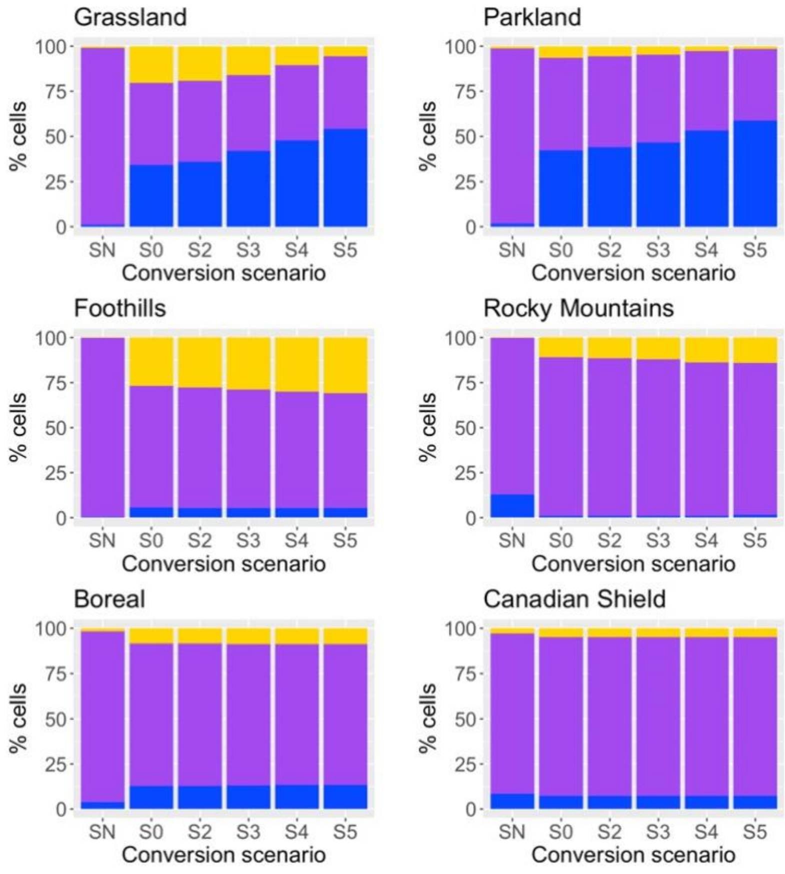


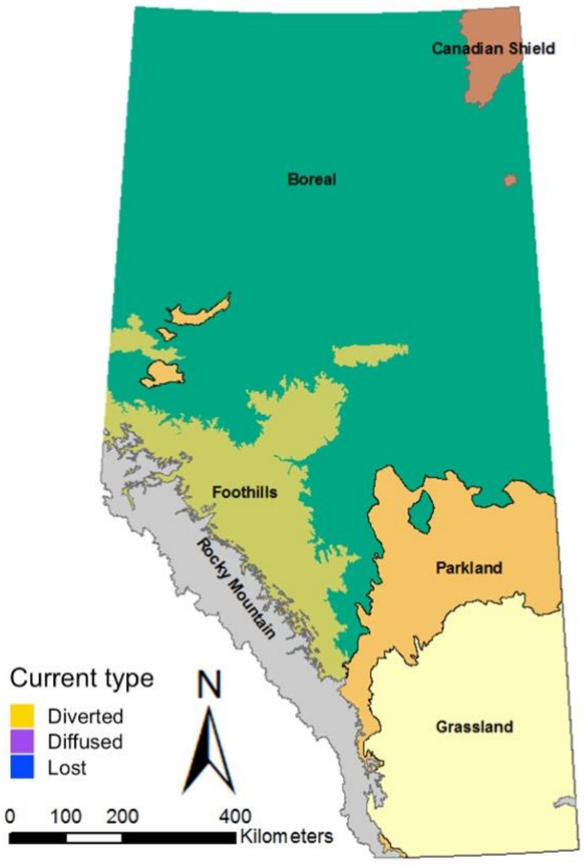
Mean current density **decreased** with the severity of conversion

Current Density for Scenario Modelling: Grassland Study

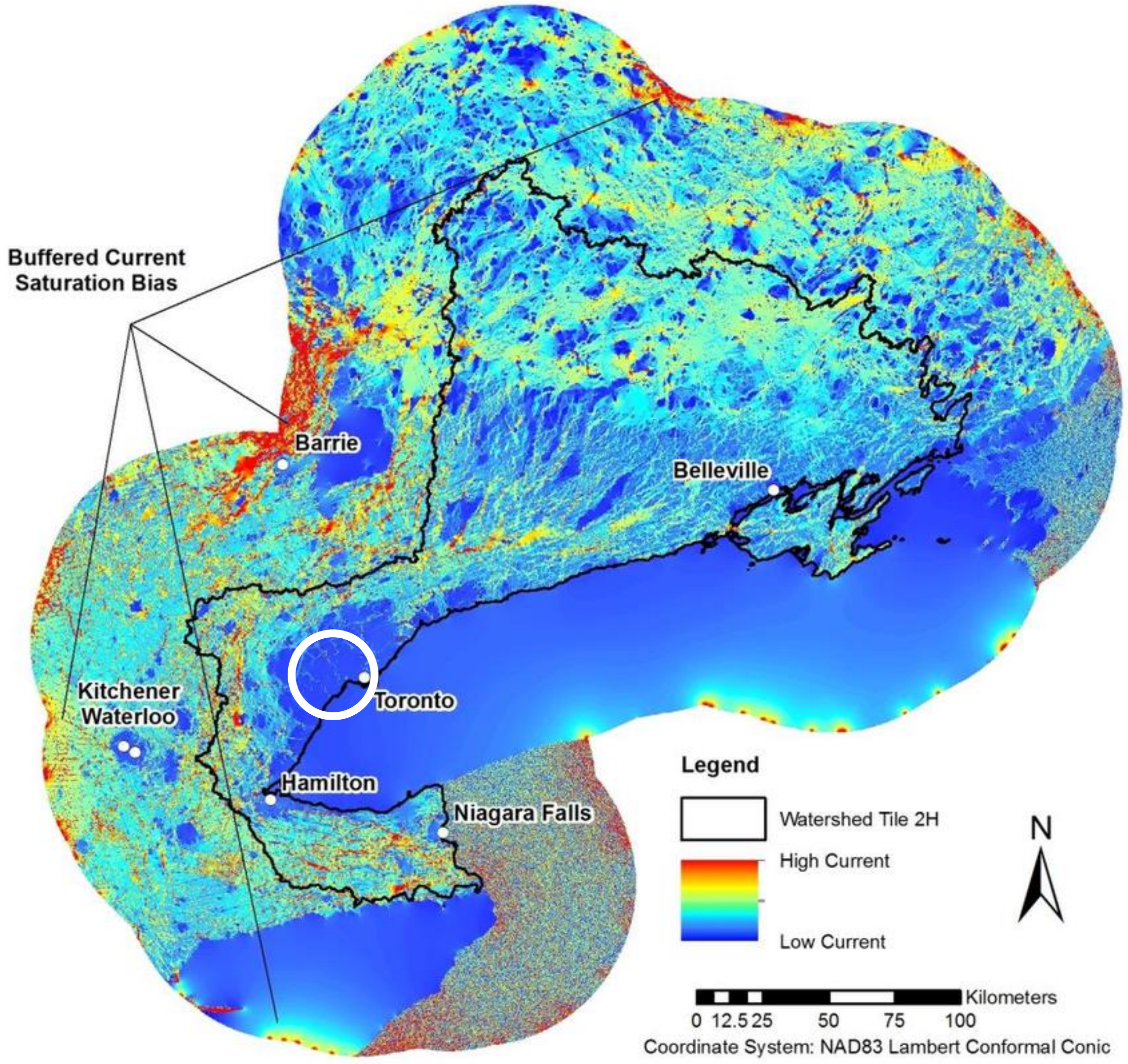


- Assess the divergent patterns of connectivity due to grassland conversion
- Quantify connectivity loss/gain at different scales





Combining Current Density with Network Analysis: CVC Case Study



Bowman & Cordes. 2015

Why does this map not work for CVC?

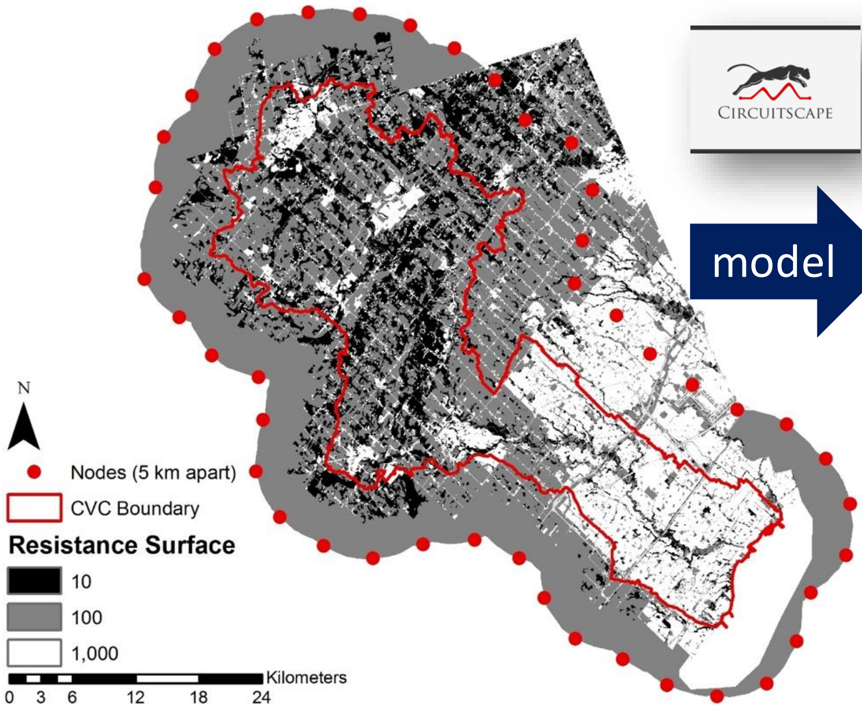
- **Spatial resolution too coarse**: 100 m
- **Spatial extent too large**: Map shows provincial-scale connectivity, not watershed-scale
- **Color ramp**: does not highlight variation among low-range values (within blue).
- **Important habitat patches**: not represented.

Objective

- ➢ Map ecological connectivity at an appropriate scale for CVC
- ➢ Prioritize important habitat to maintain the NHS connectivity

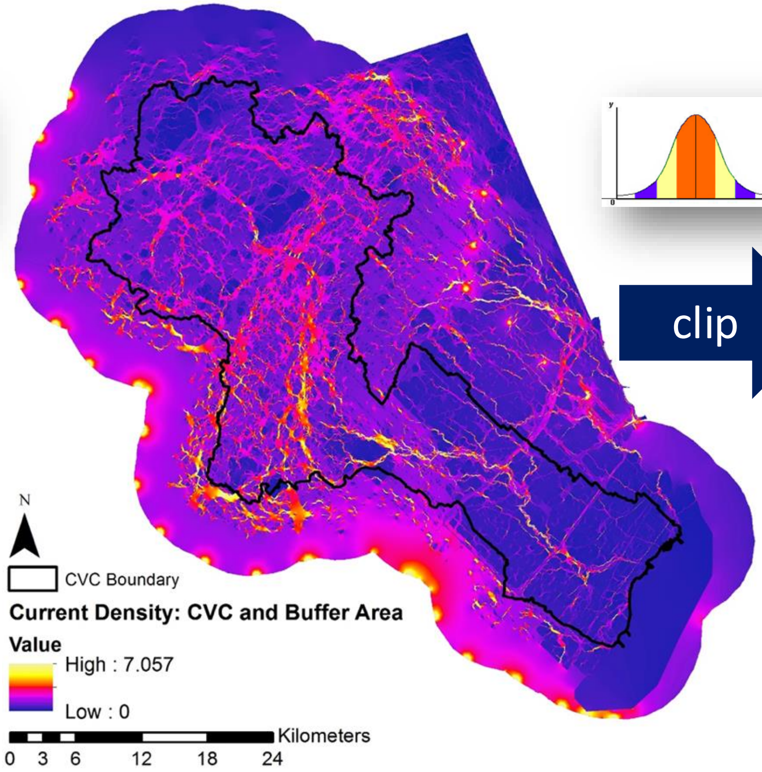
Combining Current Density with Network Analysis: CVC Case Study

Current Density Modelling: Ecological pathways



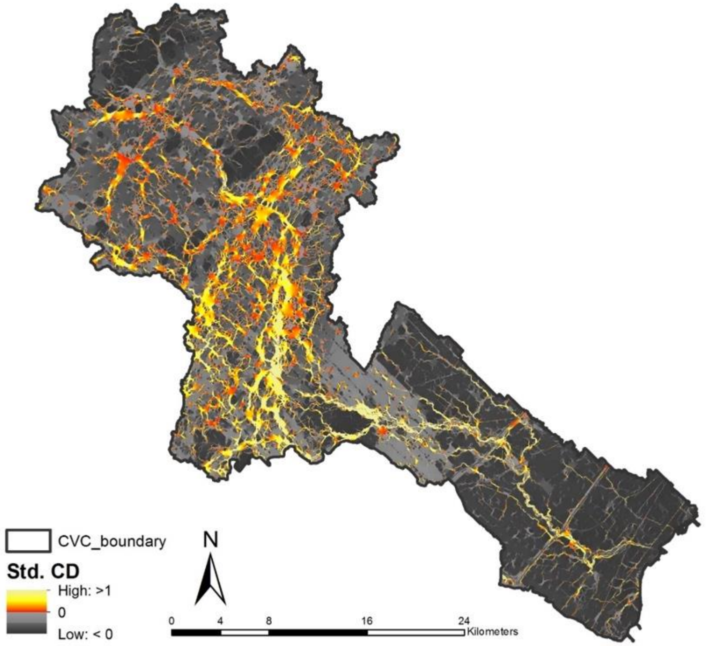
Resistance

model



Current Density

clip



Connectivity

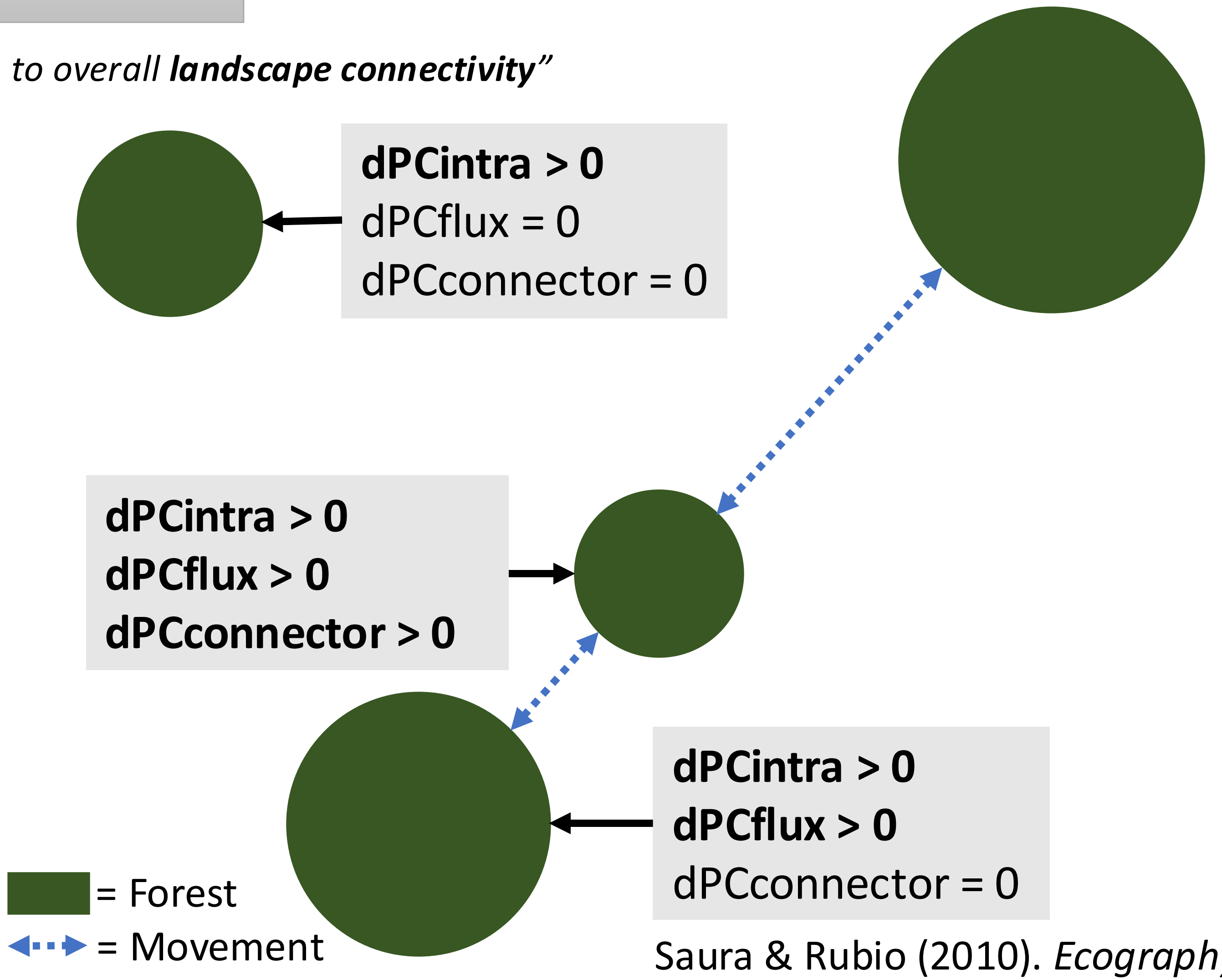
Combining Current Density with Network Analysis: CVC Case Study

Network Analysis: Important habitat patches and links

*“**Prioritize natural elements** and their **linkages** by their contribution to overall **landscape connectivity**”*

dPC = dPC**intra** + dPC**flux** + dPC**connector**

Fraction	Definition
dPCintra	**Available area** provided by each patch (intrapatch connectivity)
dPCflux	**Connections** of each patch with other patches
dPCconnector	Contribution to connectivity between other patches (**steppingstone**)

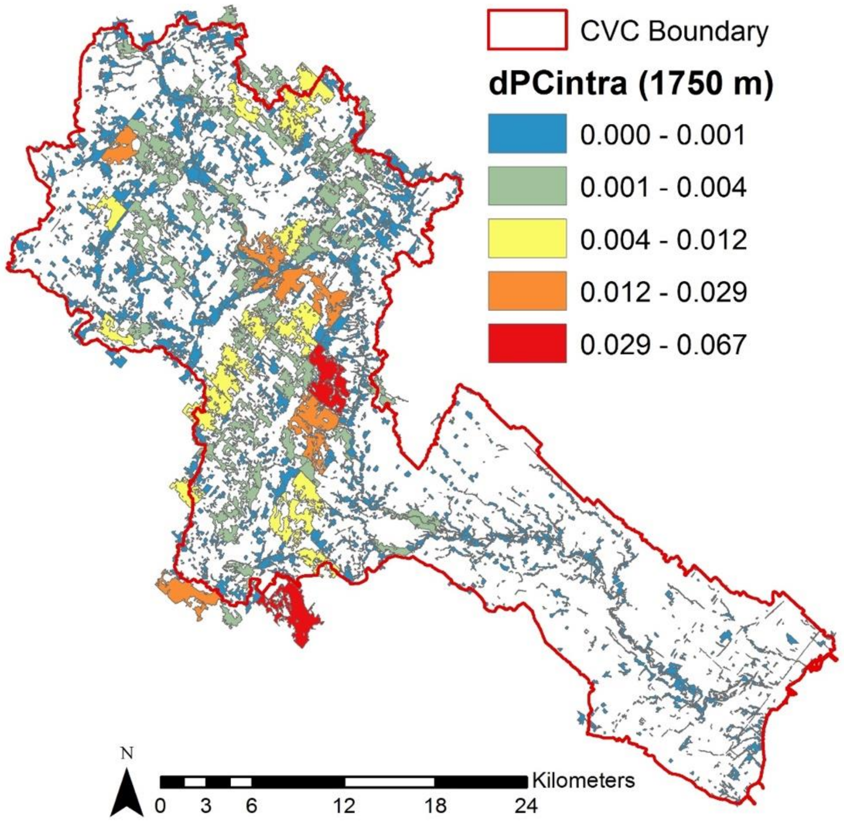


Saura & Rubio (2010). *Ecography.*

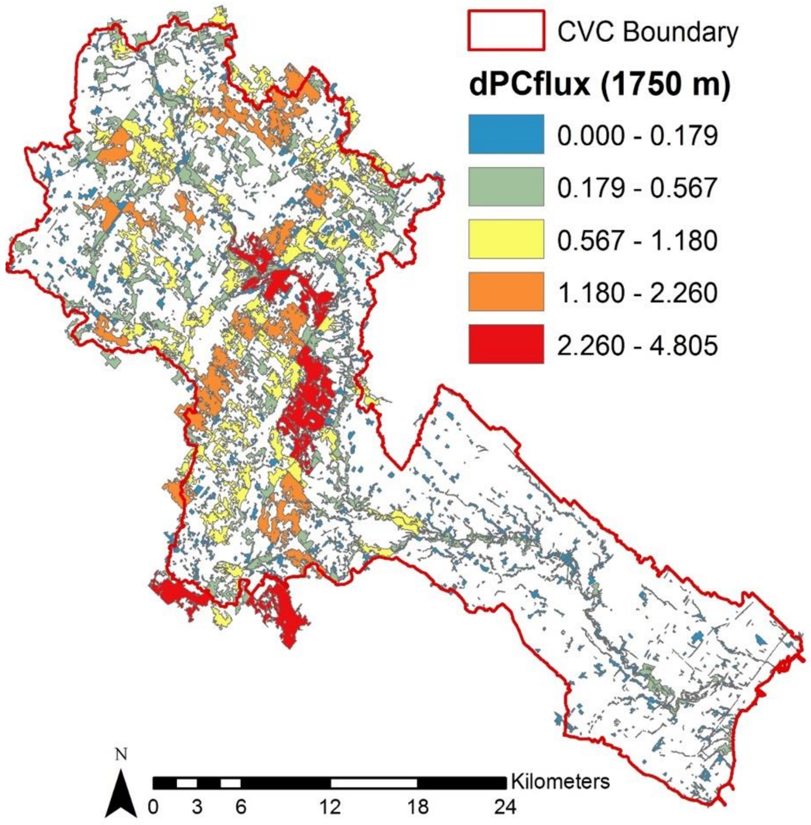
Combining Current Density with Network Analysis: CVC Case Study

Network Analysis: Important habitat patches and links

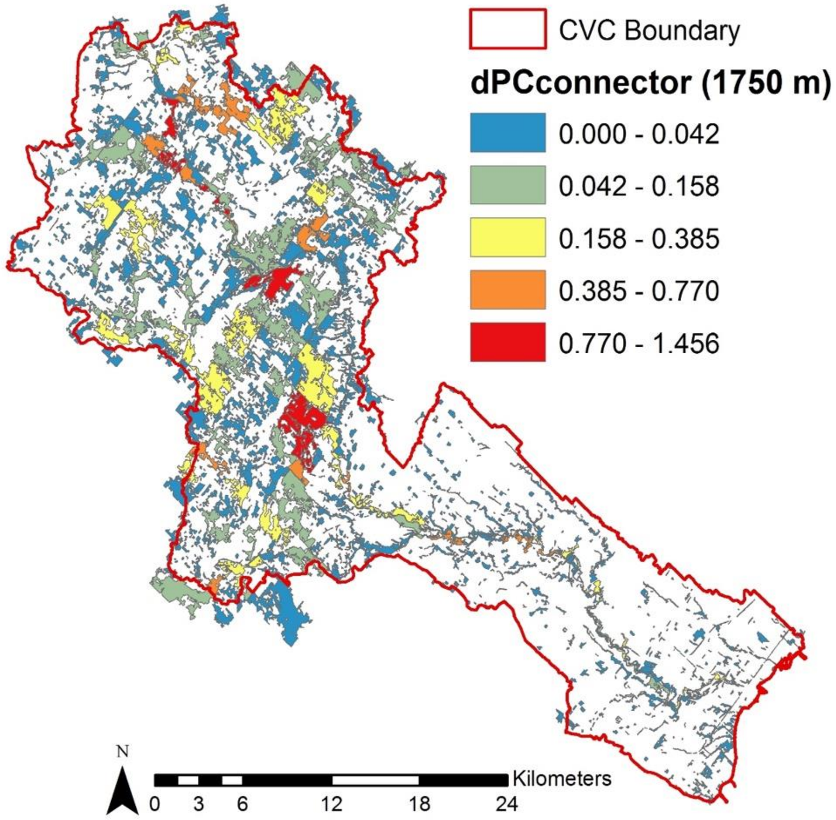
Available area



Connections



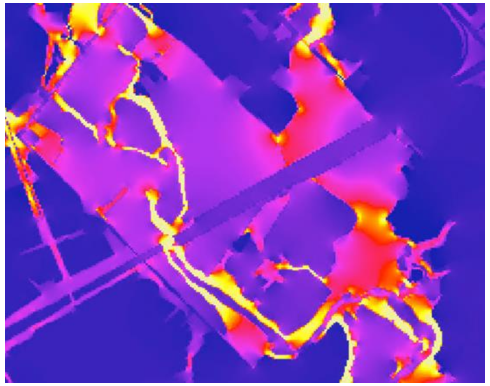
Steppingstones



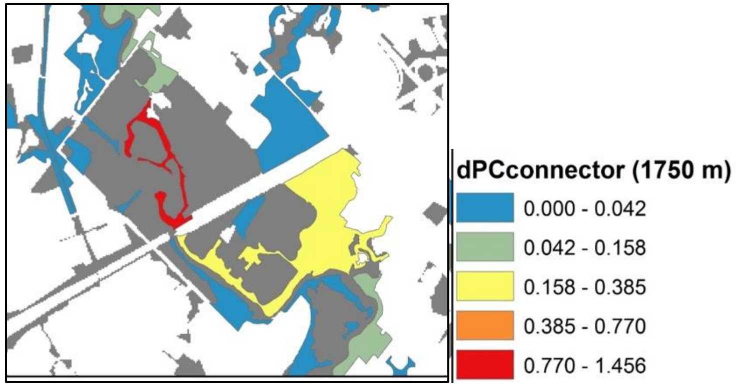
Combining Current Density with Network Analysis: CVC Case Study

Satellite image

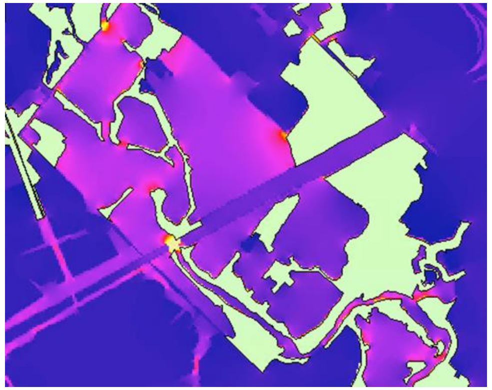
Current density



patch contribution to network



CD & habitat network



- Identify the focus landscapes (AOI, grain, etc.).
- Obtain the HVL data (e.g., important habitat patches in NHS, HVL).
- Decide on the distance measure for network analysis (e.g., Euclidian vs resistance).
- Which connectivity fractions are most meaningful? (e.g., dPC metrics).
- Preferred current density modelling.
- Overlay maps (modelling outputs) to identify important connectivity connections.

Abdel Moniem et al. 2021
Report and manual - CVC

Software Dependencies & Tradeoffs for in-house applications

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Credit Valley Conservation inspired by nature

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NATURE CONSERVANCY CANADA

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