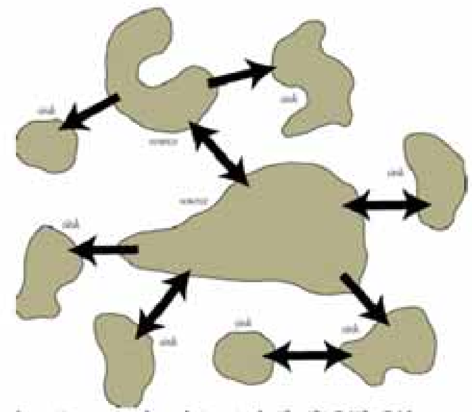
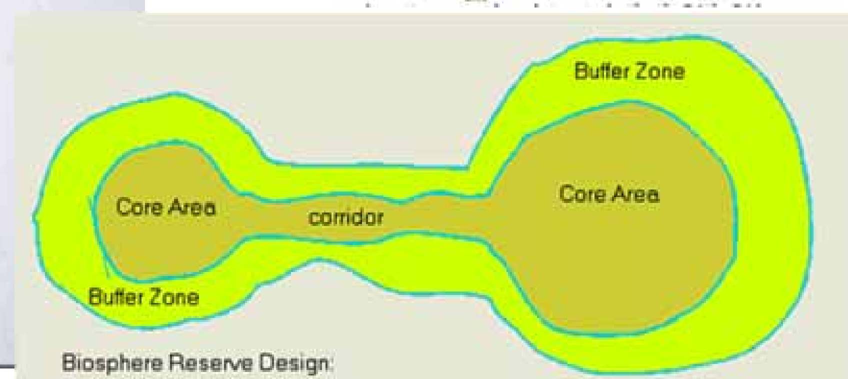
The Connectivity Analysis Toolkit (CAT): New methods to enhance effectiveness of conservation planning in dynamic ecosystems





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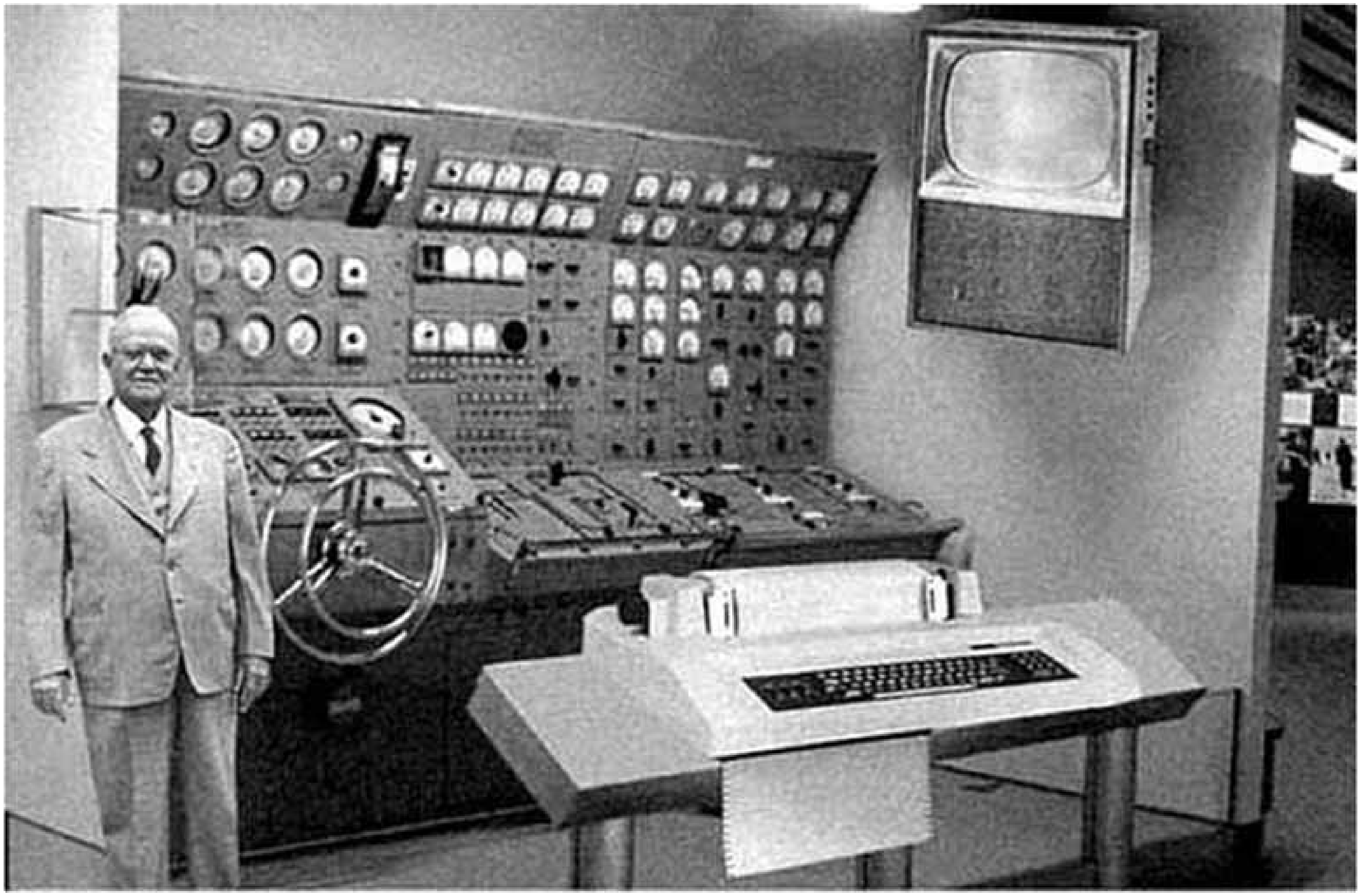
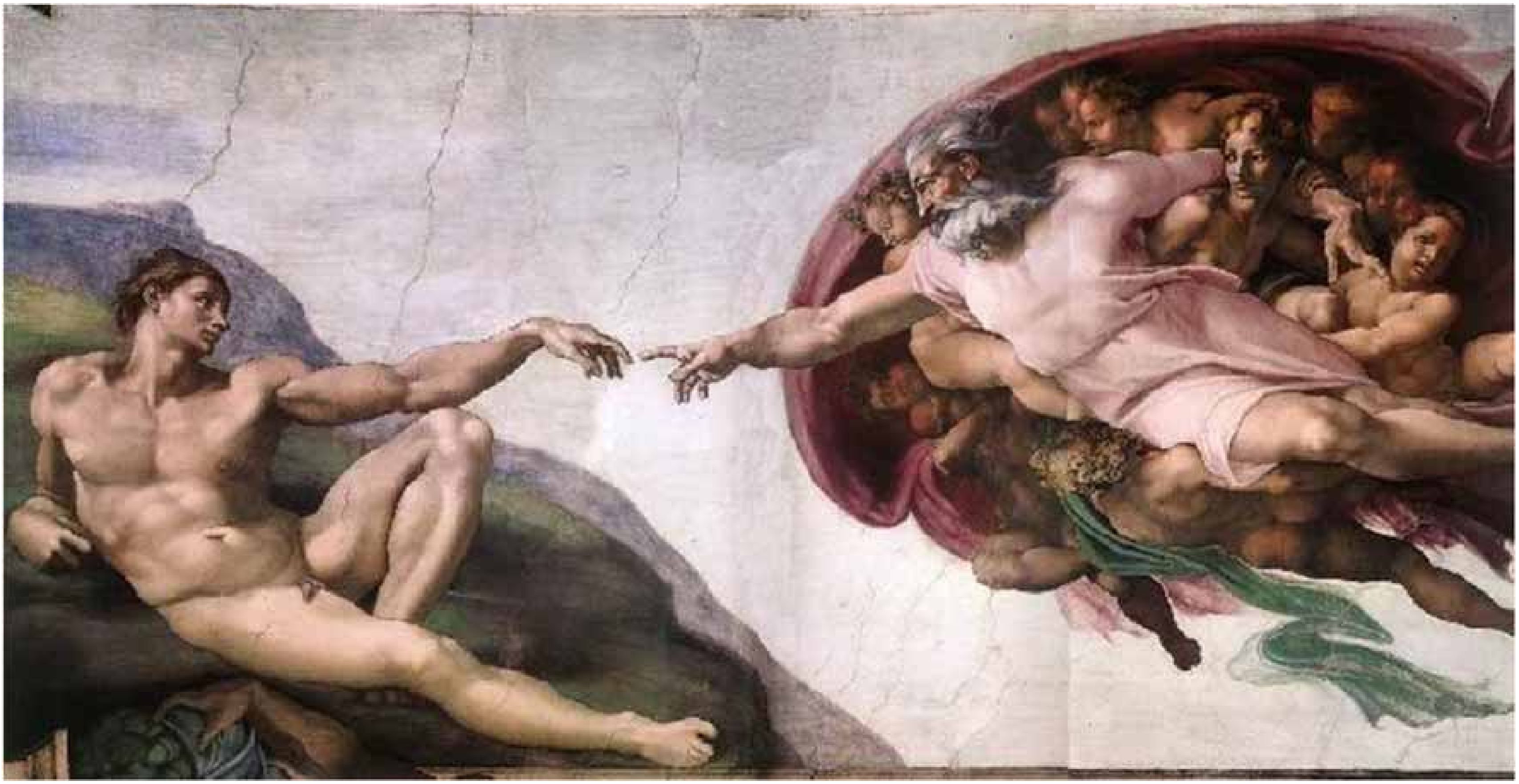


CAT development was supported by the Wilburforce Foundation and the NCEAS Connectivity Working Group, especially P. Beier, S. Phillips, N. Schumaker, and D. Theobald

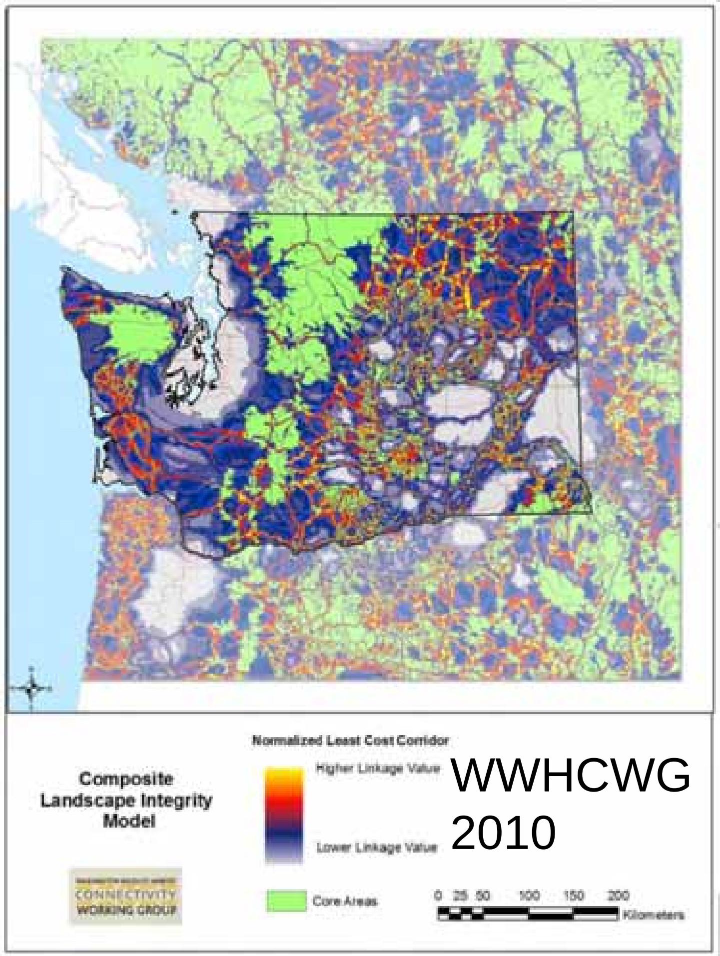
Connectivity is increasingly the ‘Holy Grail’ of conservation

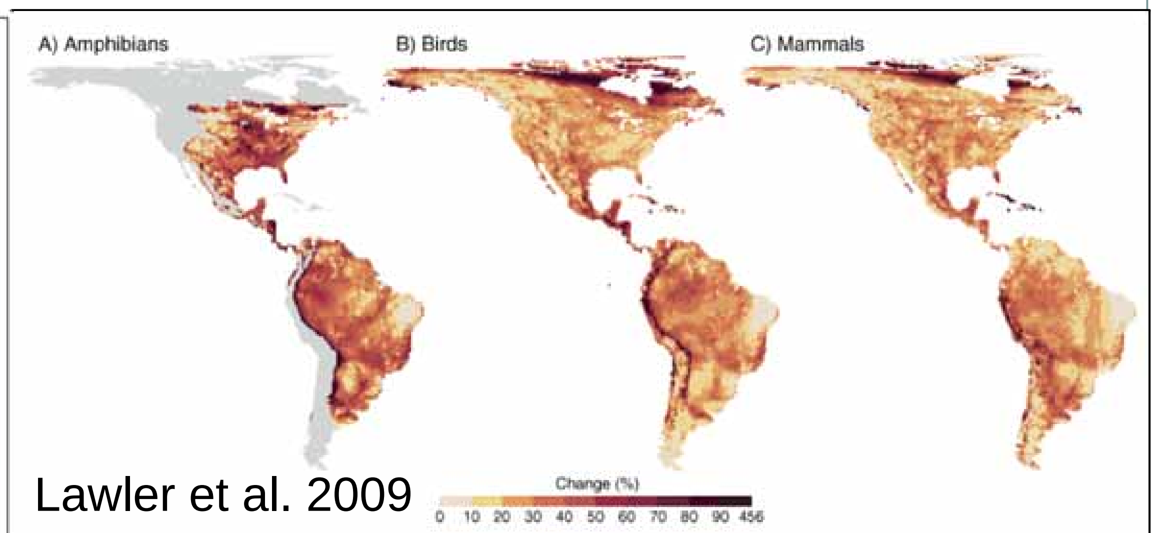


But it has been difficult to integrate into conservation planning efforts

Y2Y and other initiatives have sought to conserve linkages but have not had a good means of prioritizing which linkages were most important for goals such as maintaining populations of large carnivores.

Connectivity planning can help make landscapes more resilient to both current fragmentation and to future change





Planning to conserve connectivity helps facilitate

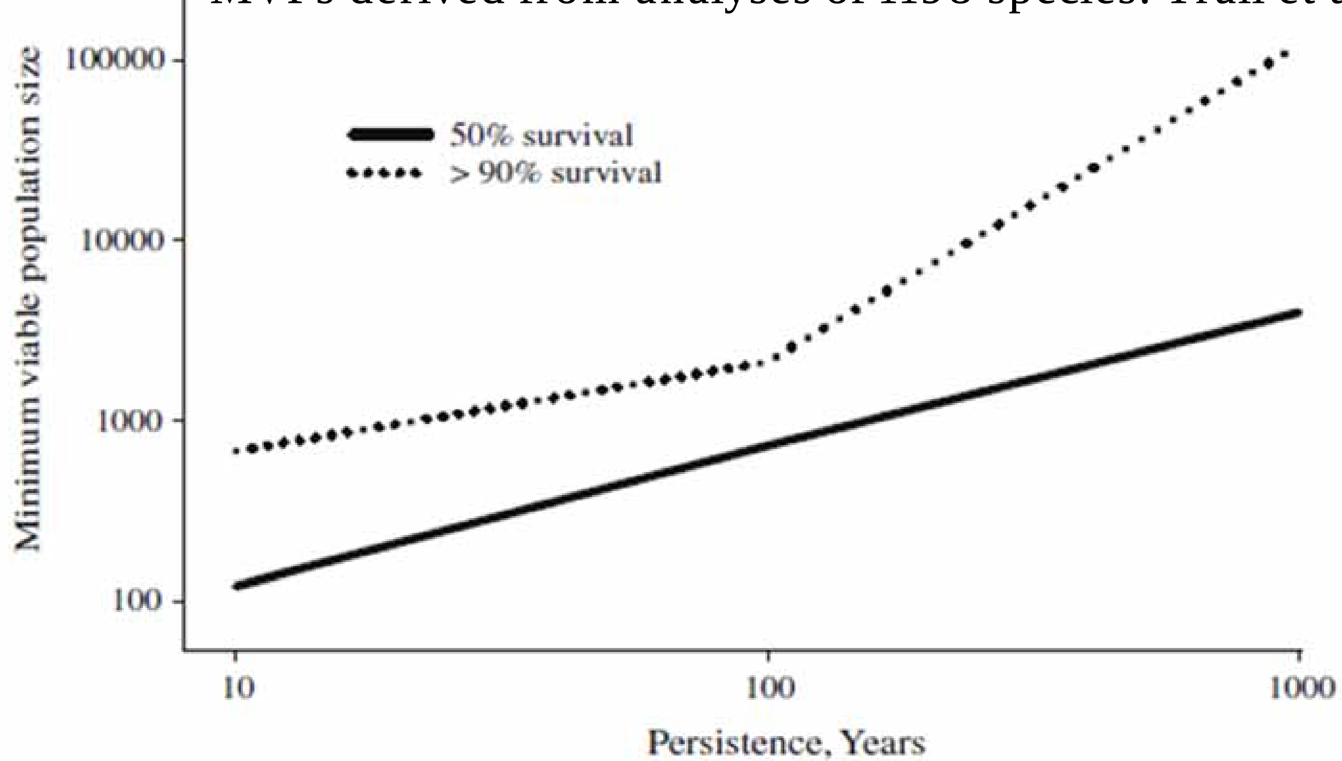
1) Demographic flows (the rescue effect of dispersal)
2) Genetic flows (avoidance of inbreeding depression, long-term maintenance of genetic adaptability)
3) Resilience of populations to the effects of landscape conversion and climate change

Why conserve connectivity?

Genetic viability varies with population size

Large metapopulations allow long-term persistence

MVPs derived from analyses of 1198 species: Trail et al. 2009

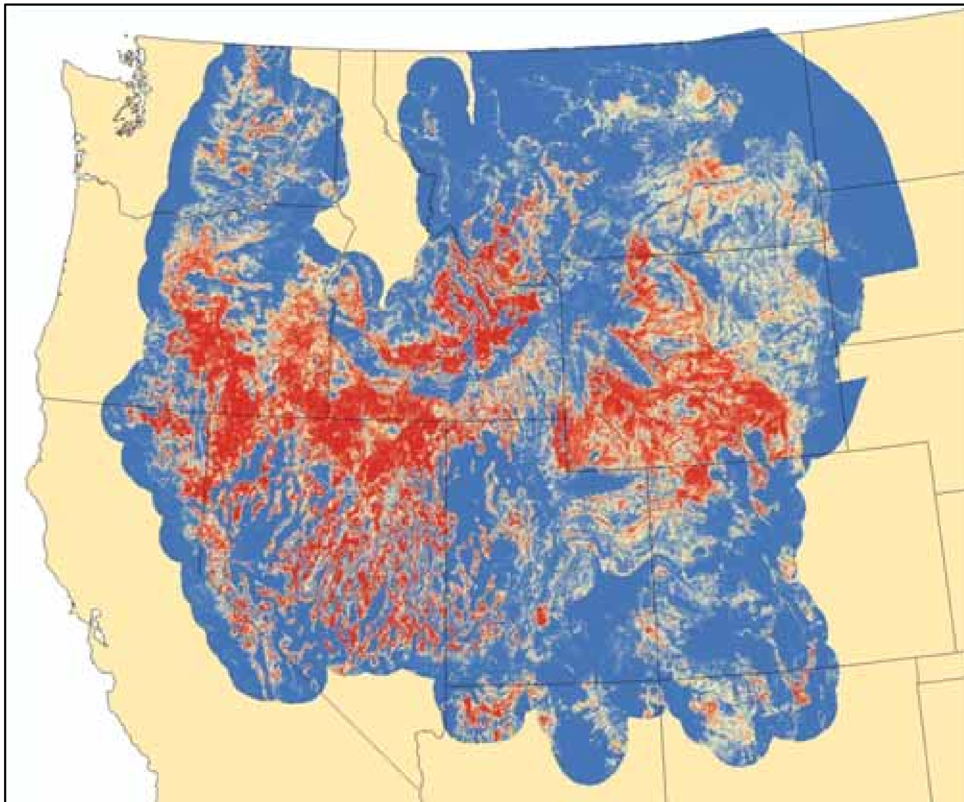


Example: Mexican gray wolf

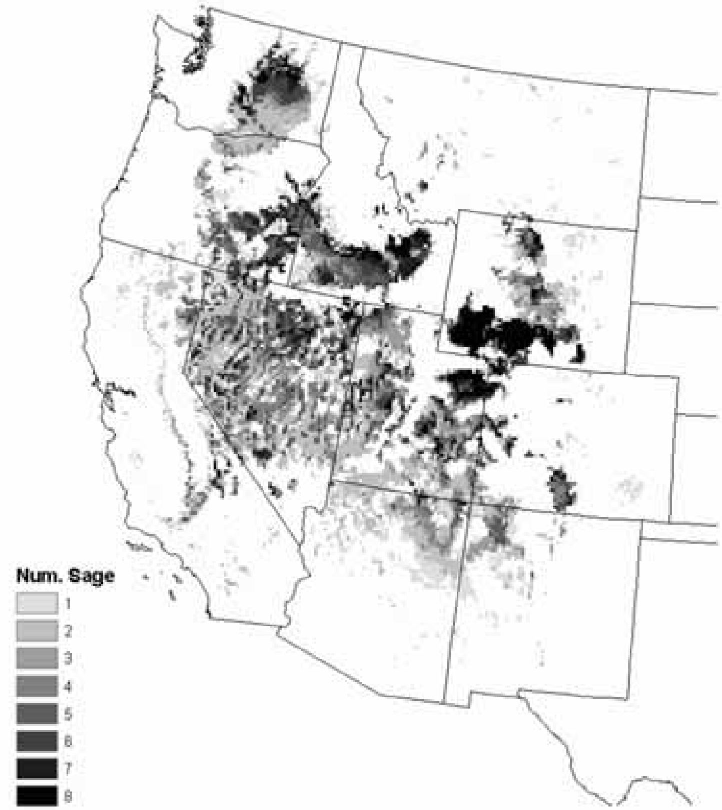
1) Demographic rescue - many small subpopulations vulnerable to extirpation
2) Genetic rescue – need for population interchange due to small founder population
3) Resilience to climate change – potential change in prey availability in arid lands habitat

Example: Sage grouse

1) Demographic rescue - peripheral leks may be sustained by immigration
2) Genetic rescue - long-term maintenance of genetic adaptability important for resilience
3) Resilience to climate change – response to shift in sagebrush biome (Neilson et al. 2005)



Future distribution of sagebrush under climate change - Neilson et al. 2005



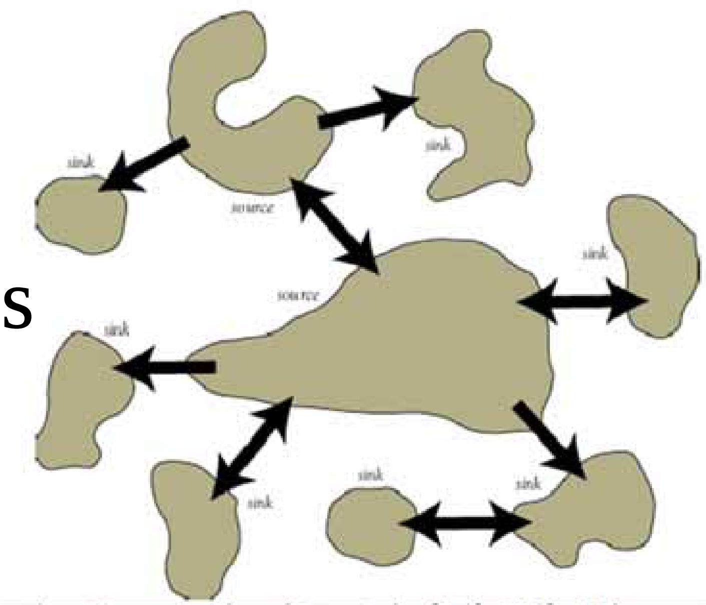
Analysis of sage grouse habitat connectivity

Goals of this presentation

1) Describe the new software tools
2) Place these tools in the context of connectivity planning: how can they contribute to conservation outcomes?
3) Describe how climate change adaptation planning can consider connectivity

As connectivity planning has evolved, limitations of early corridor-mapping methods have become more problematic:

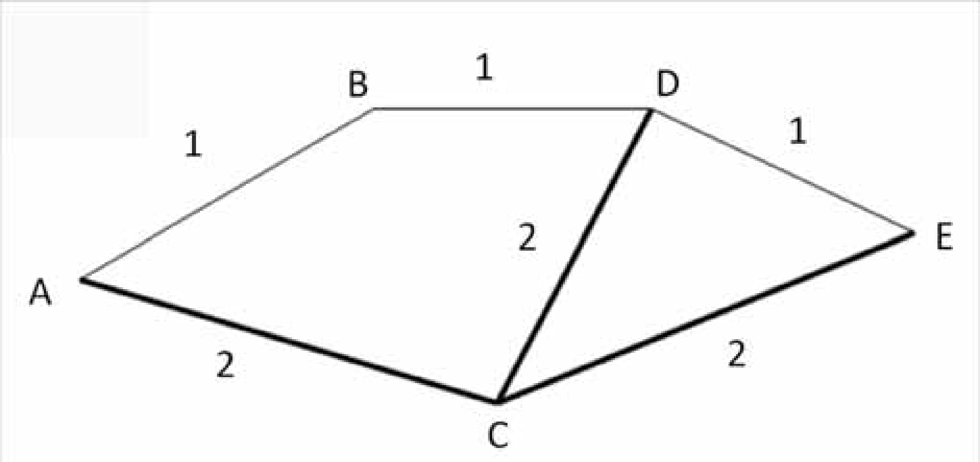
1) The identification of a single 'best' linkage.
2) The need to identify the source and target patch first, and conduct a separate linkage analysis for each pair
3) Lack of clear connection between mapping methods and dispersal behavior



Goal: Develop methods that can

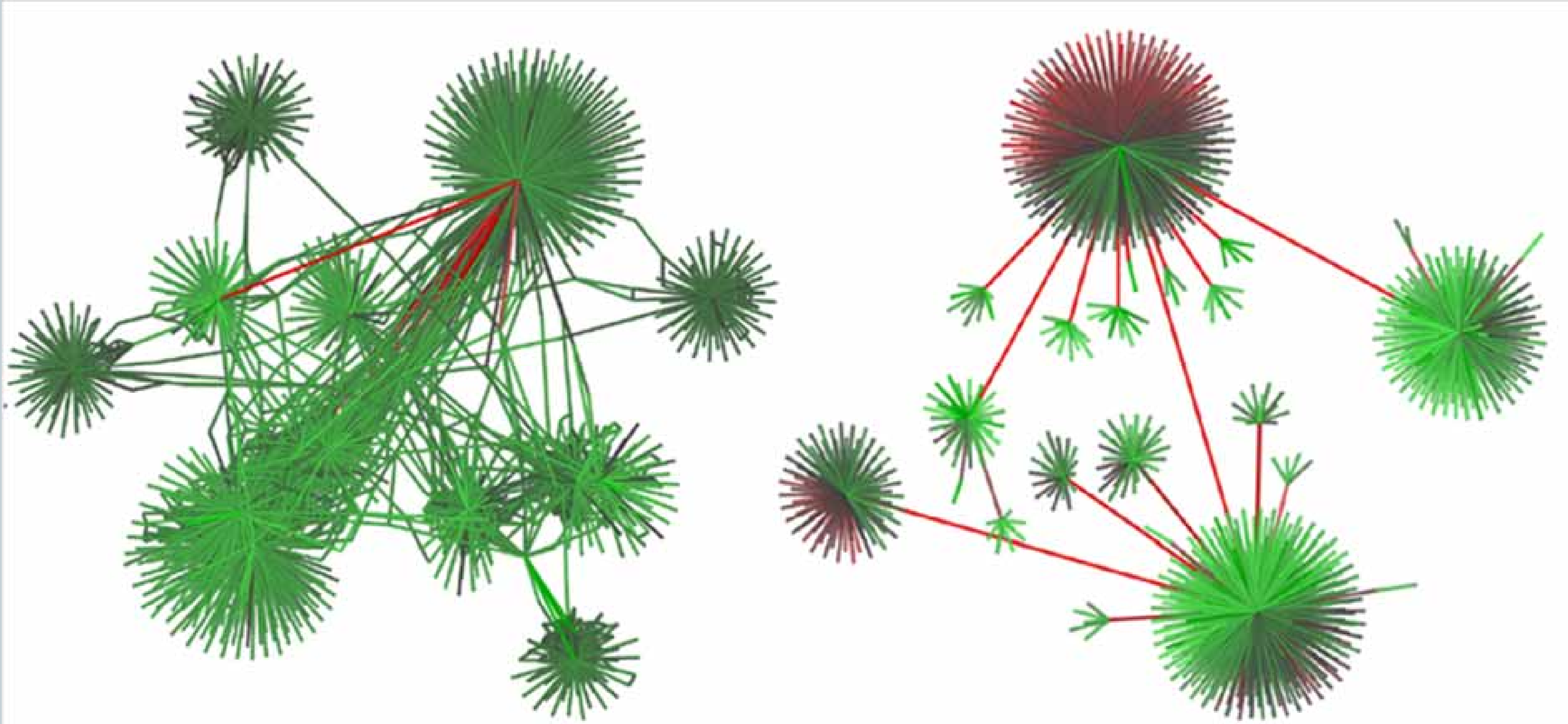
1) simultaneously identify a complete linkage network between many areas rather than between two patches,
2) account for the effect of redundant linkages,
3) allow ranking of the importance of different linkages

Analysis of landscape networks is based on graph theory



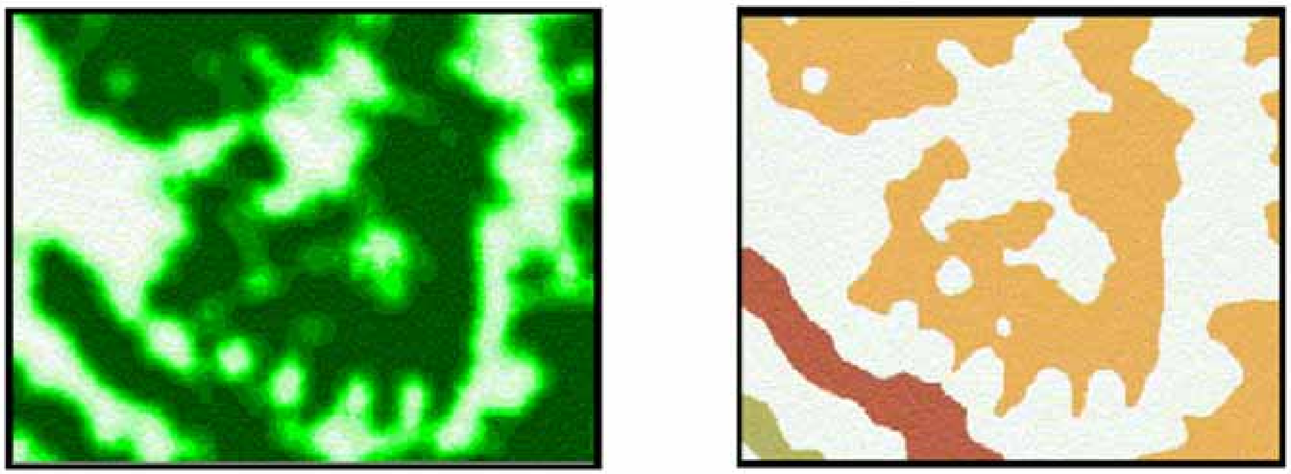
A graph is a set of **nodes** connected by **edges** that represent connections such as dispersal

New graph-theory-based methods allow analysis of large networks



Internet structure (Google PageRank)
Social networks (Twitter, Facebook)

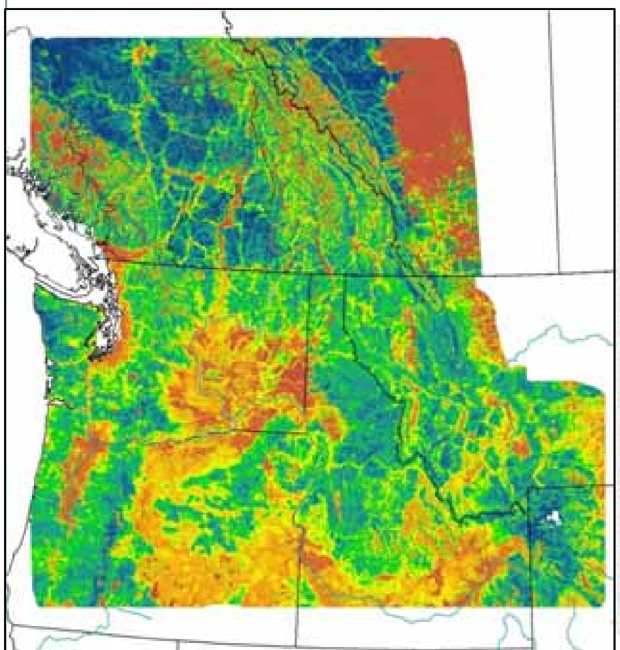
But graph-based methods have



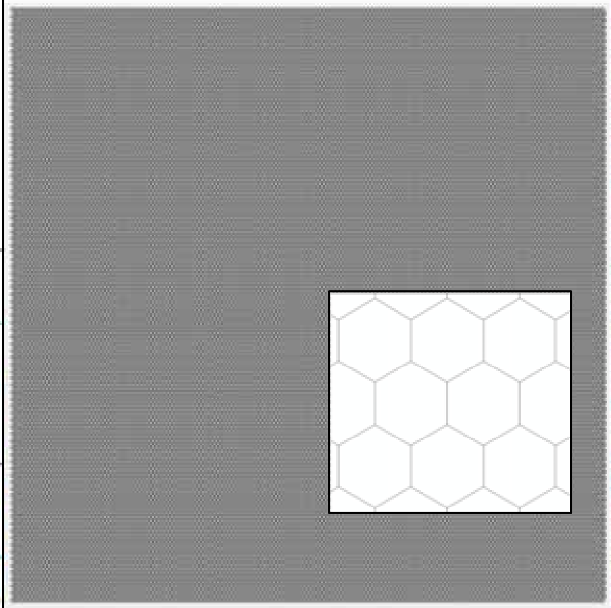
a) Map of continuous habitat quality b) Discrete patches derived from habitat map

typically require simplification of habitat gradients to a binary patch/matrix

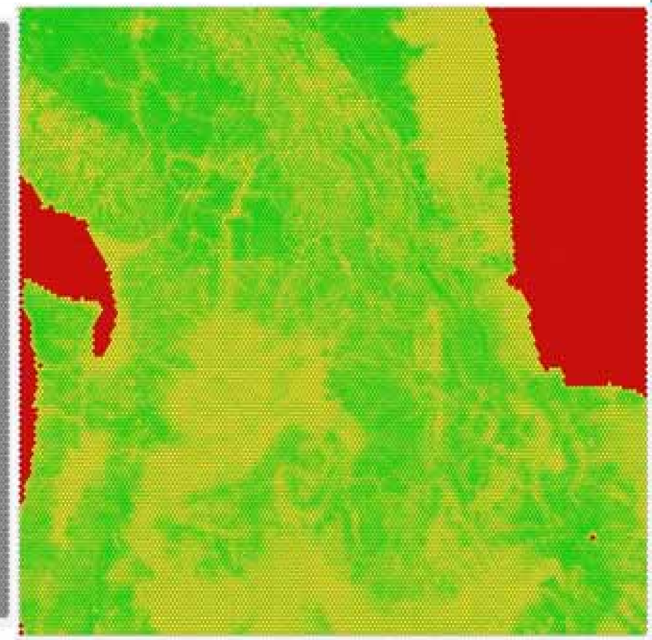
Faster computers and more efficient graph algorithms now allow analysis of habitat gradients represented as 'landscape lattices' at a reasonably high resolution



Habitat Map

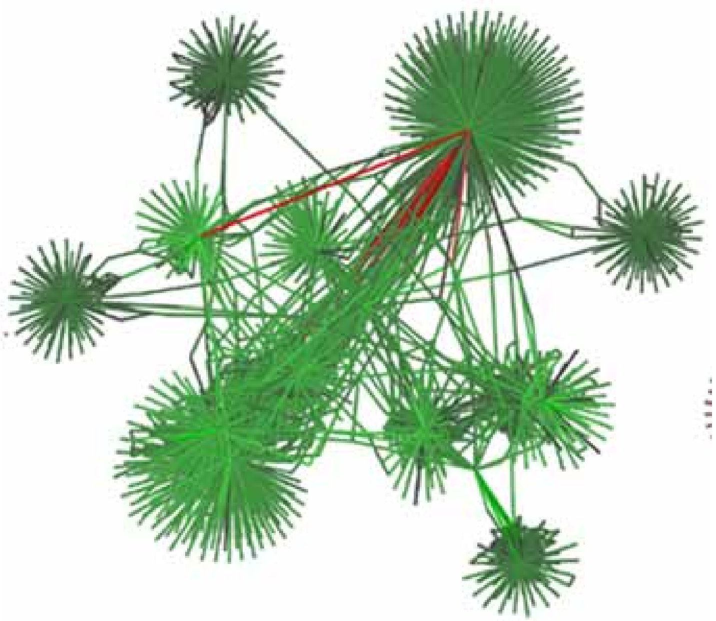


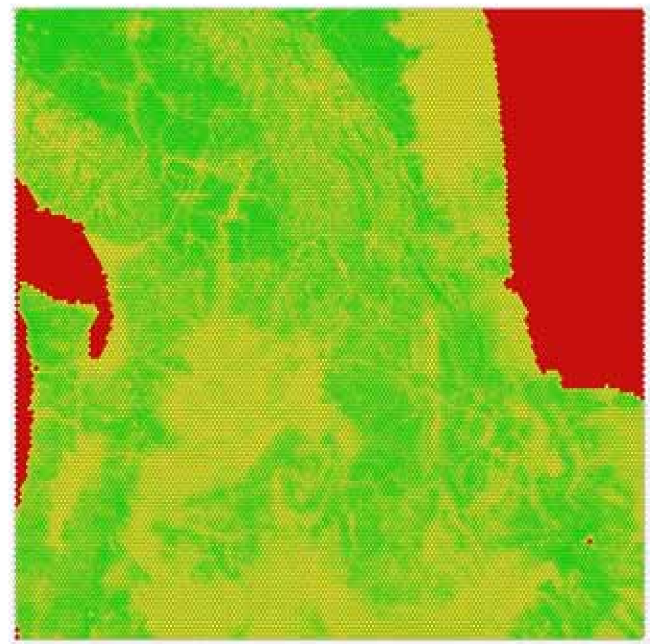
Lattice



Graph

Centrality is a measure of the role a node plays in facilitating movement across a graph. Nodes with high centrality are ‘gatekeepers’.





NetworkX – (Hagberg et al. - Los Alamos National Lab)

LEMON Graph Library – (EGRES – Budapest)

New tools for centrality analysis offers a method of analyzing ‘whole-landscape’ connectivity.

Different centrality methods allow different assumptions about dispersal

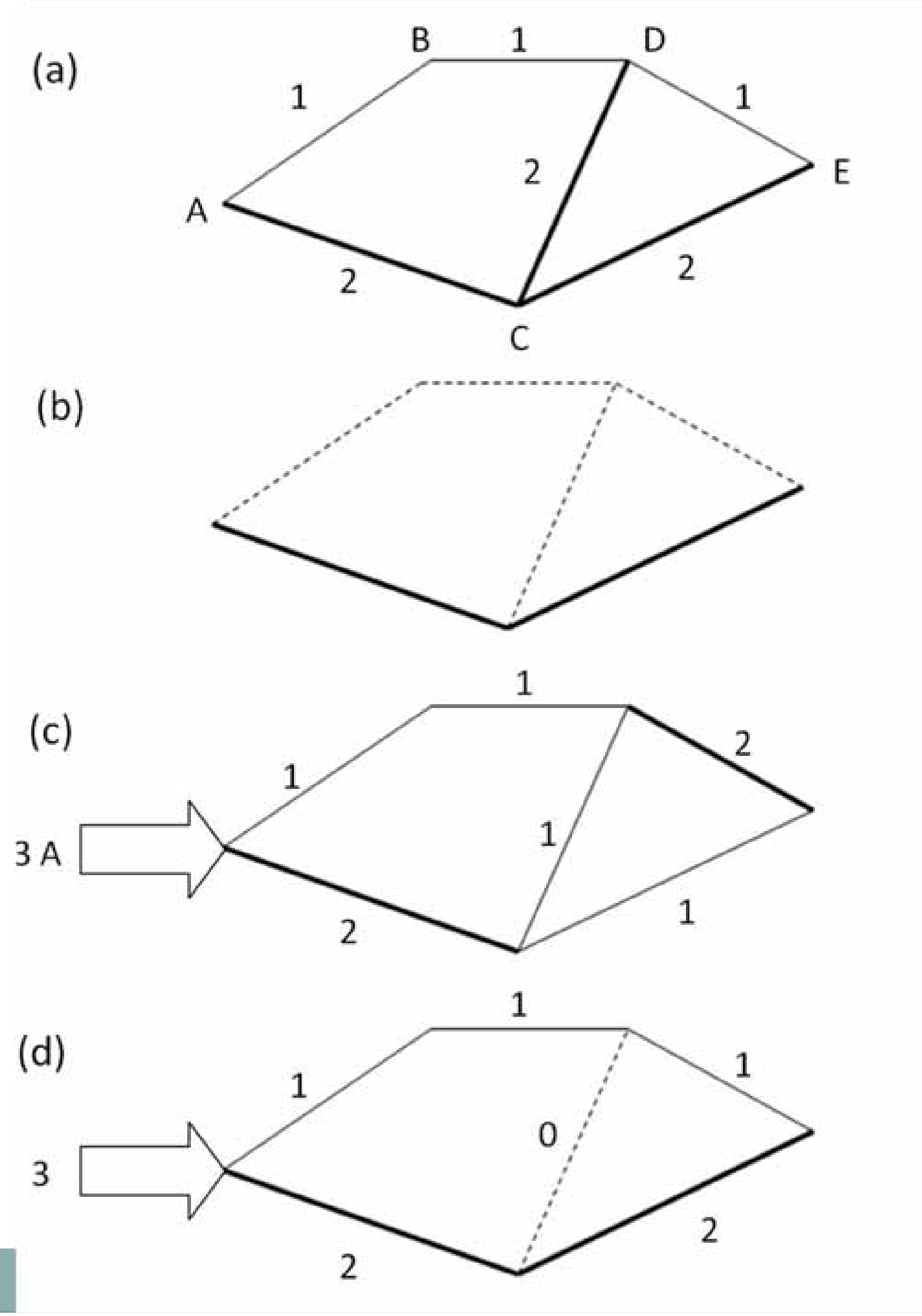
- Betweeness identifies a single ‘best’ path, assuming that a disperser has complete knowledge of the landscape.
- Current flow models the movement of ‘random walkers’ with knowledge of only their immediate neighborhood.
- Network flow resembles current flow, but maps ‘optimal flow’ rather than random dispersal.
- Methods are not ‘right’ or ‘wrong’ but instead offer complementary perspectives.

Simple graph

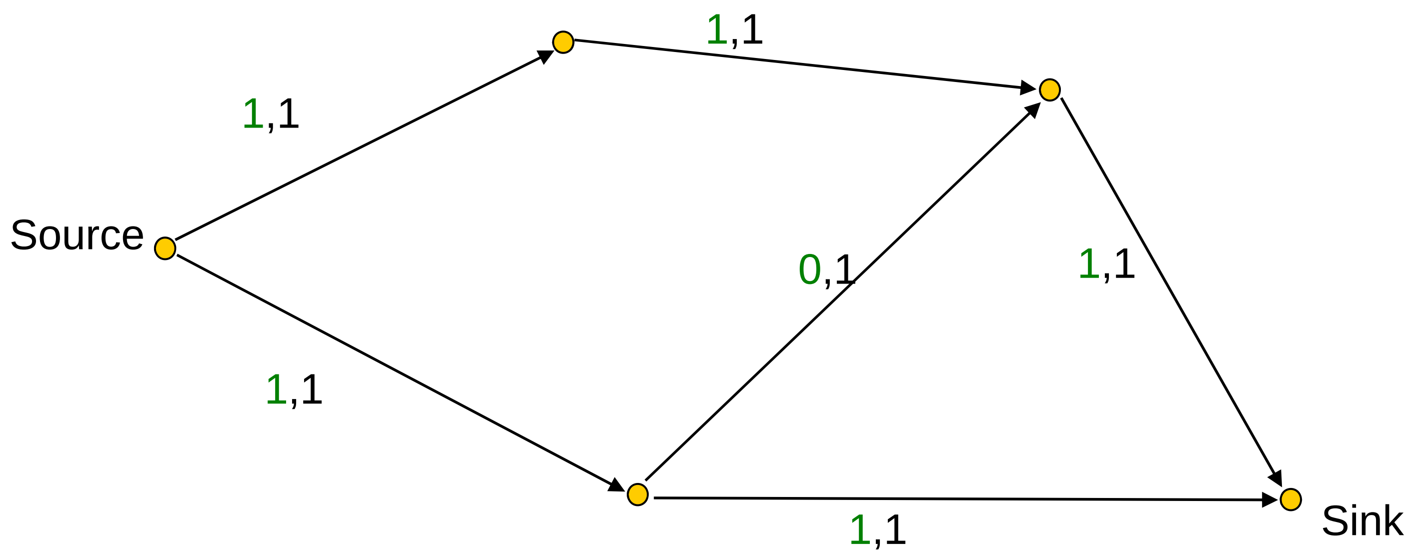
Shortest path

Current flow

Network flow



Network flow concepts



A directed graph with a "source" (of dispersers) and a "sink" (destination).

Two major principles:

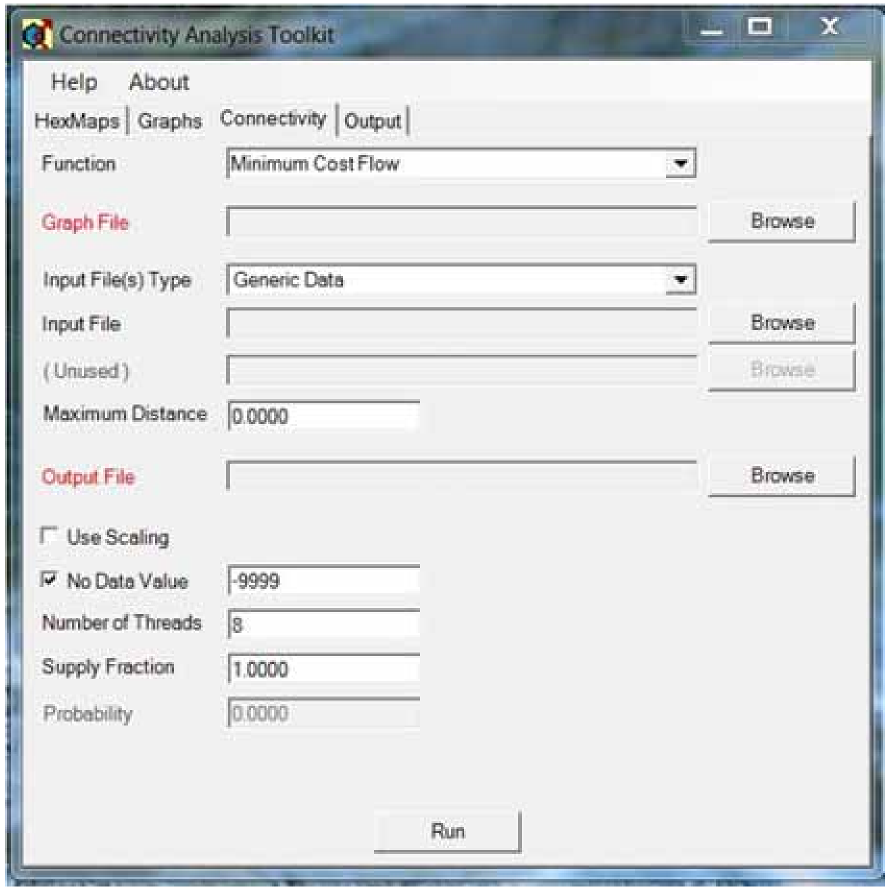
- Flow conservation
- Capacity constraints (similar to diameter of water pipe)

Network flow functions

- "Maximum flow" problems ask
  - What is the maximum rate of flow of individuals / genes?
  - What is the bottleneck that most limits dispersal?

- "Min-cost flow" asks more complex questions
  - Combines cost of "least-cost-path" distance with capacity of maximum flow
  - What is the linkage of lowest cost that will allow sufficient dispersal?

Connectivity Analysis Toolkit (CAT)



Freely available at www.connectivitytools.org
We encourage others to incorporate and extend the methods in other conservation planning applications

Connectivity Analysis Toolkit available in two versions

Carlos Carroll <carlos@klamathconservation.org>
To: klamathconservation@gmail.com

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Thanks for your interest in the Connectivity Analysis Toolkit. The installer for the Toolkit comes in two versions. If you plan to install the Toolkit on a 32-bit Microsoft Windows operating system, download this version:

http://www.klamathconservation.org/CAT/v1_0/Setup32.exe

If you plan to install the Toolkit on a 64-bit Microsoft Windows operating system, download this version:

http://www.klamathconservation.org/CAT/v1_0/Setup64.exe

Please do not forward these links as they will become outdated.

Instead direct people to the Download Request page:

http://www.connectivitytools.org

If you encounter any problems, or have comments, please post them to the support and discussion forum:

http://groups.google.com/group/connectivitytoolkit?hl=en

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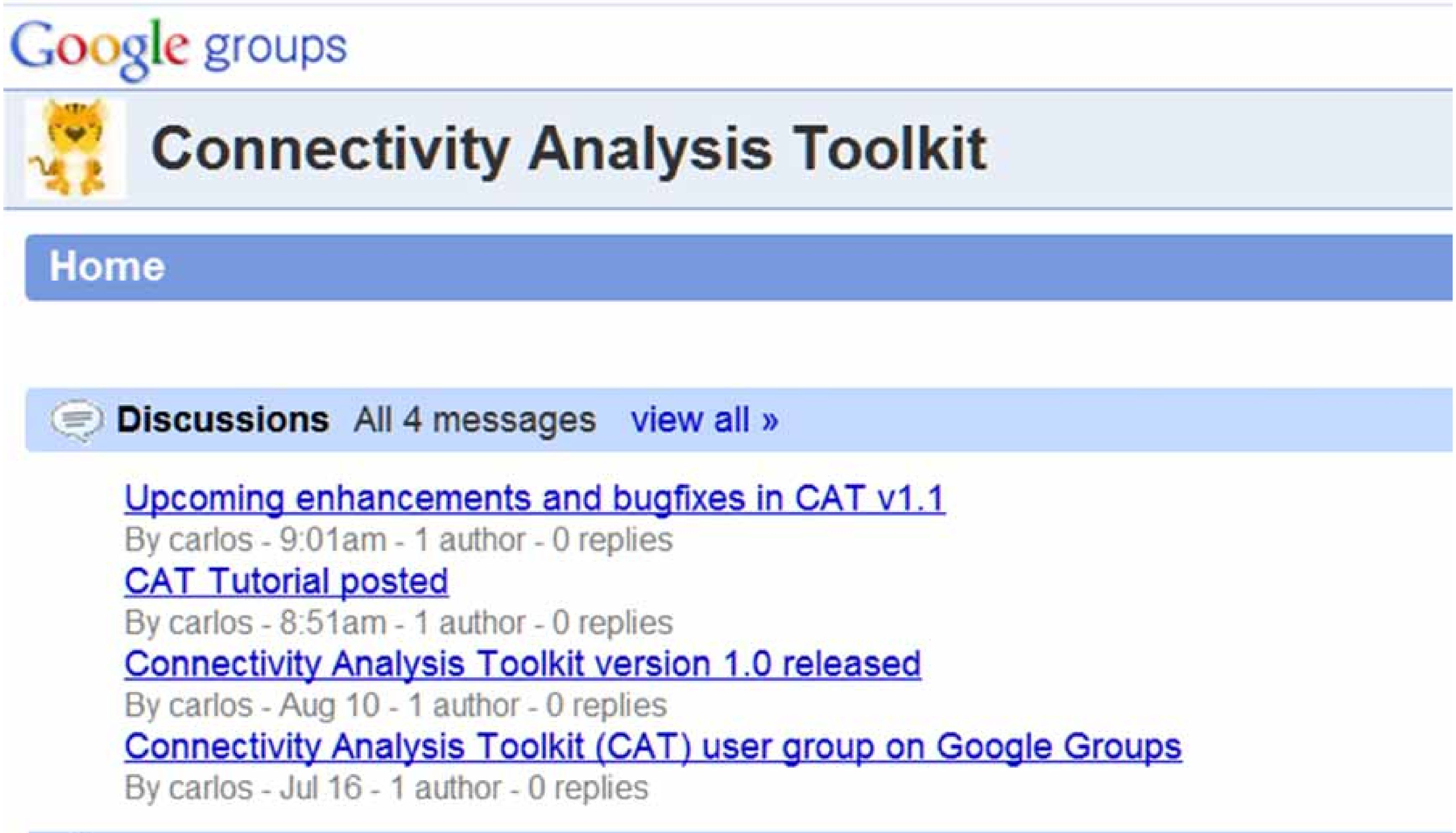
This mail is sent via contact form on The Conservation Science Blog http://klamathconservation.org/scienceblog

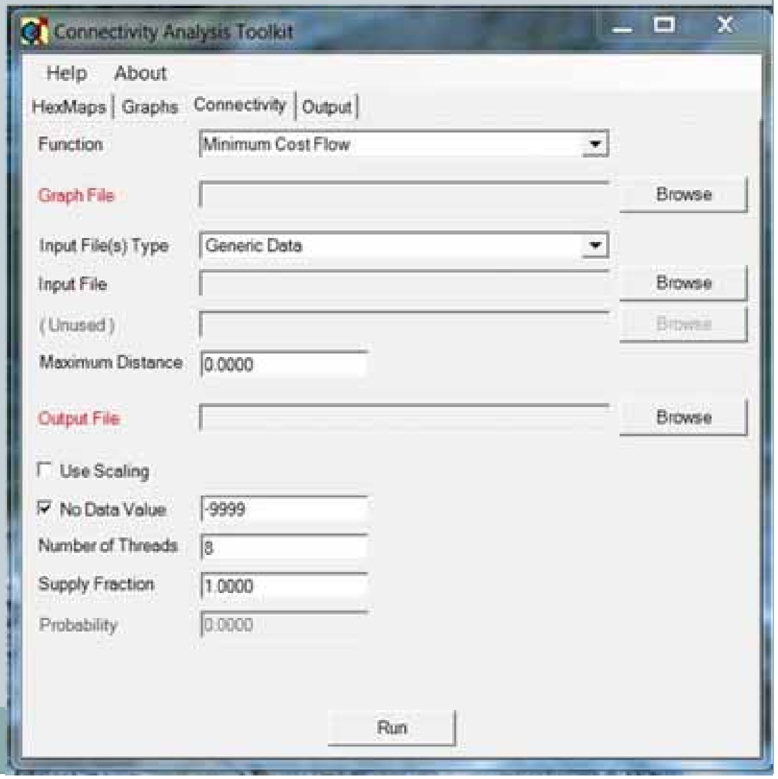
Request download info at www.connectivitytools.org

CAT discussion and support forum on Google Groups



Connectivity Analysis Toolkit (CAT)

1) Import habitat layers from GIS
2) Create graph network from habitat data
3) Run suite of centrality analysis methods:
    a) Betweeneness
    b) Current flow
    c) Min-cost flow
4) Export results to GIS

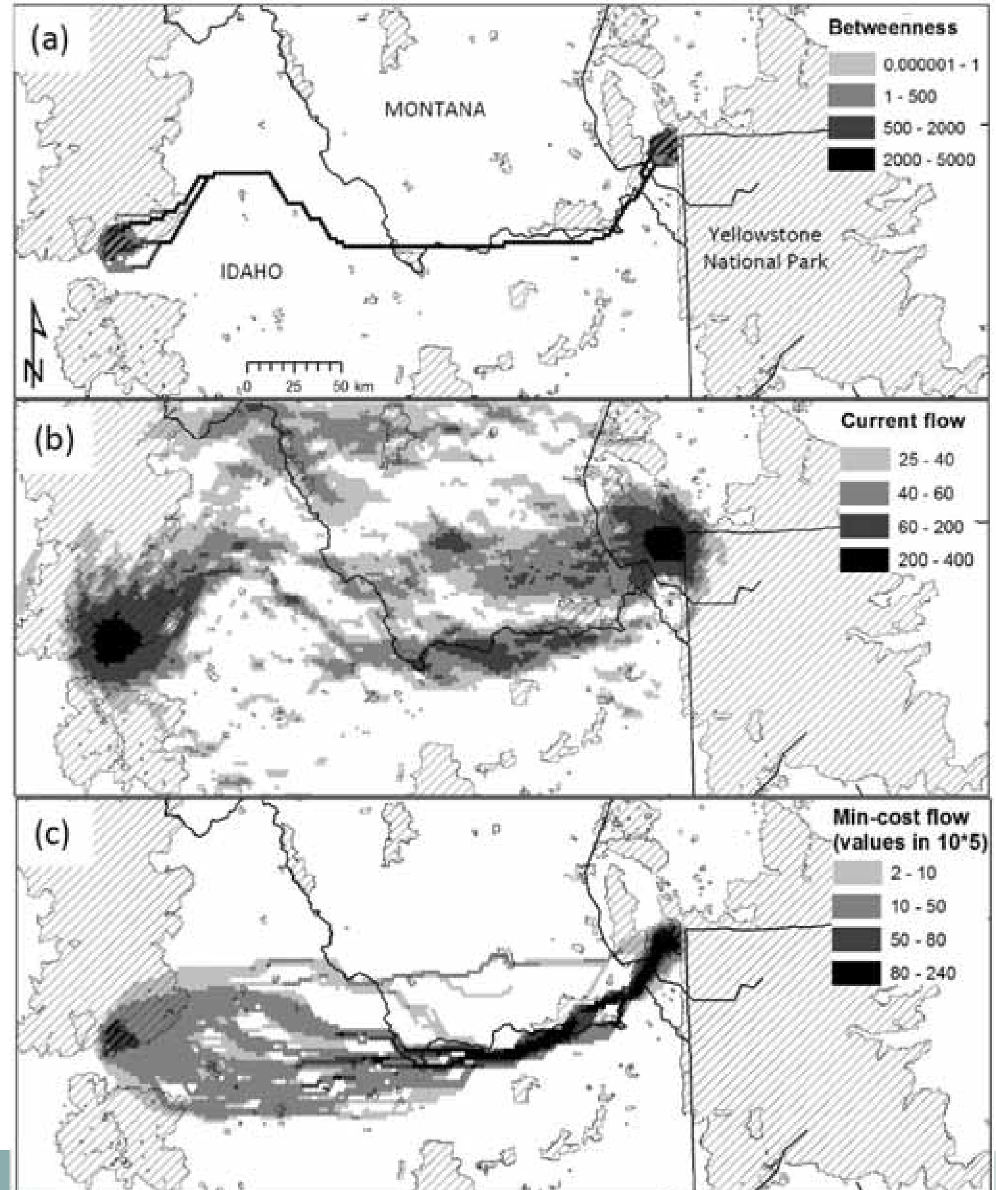


Linkage design using 'subset centrality' analysis

Betweenness centrality (a) identifies a minimal network of linkages.

Current flow centrality (b) identifies a more diffuse landscape network of redundant linkages.

Min-cost flow centrality (c) integrates consideration of both land cost and habitat capacity.
Here a simple cost value was used that assigned private lands four times the cost of public lands.
The results thus identify a linkage allowing maximum-flow that lies preferentially on public lands.



Each approach to linkage analysis has an analagous centrality method

Pairwise method	Centrality metric	Edge attributes
Shortest or least-cost path	Betweenness	Cost; distance
Circuit flow	Current flow	Conductance; resistance
Maximum flow	Flow betweenness	Capacity
Min-cost flow	Min-cost flow	Cost and capacity

Types of input data

1) Non-species-based:
   landscape integrity, land types

2) Species-based:
   a) Habitat model output
   b) Occurrence data

Linkage design using expert-based or non-species-based information

Planners may want to use information that's not based on habitat for a particular species.

Connectivity may be relevant to planning in different ways in this situation.

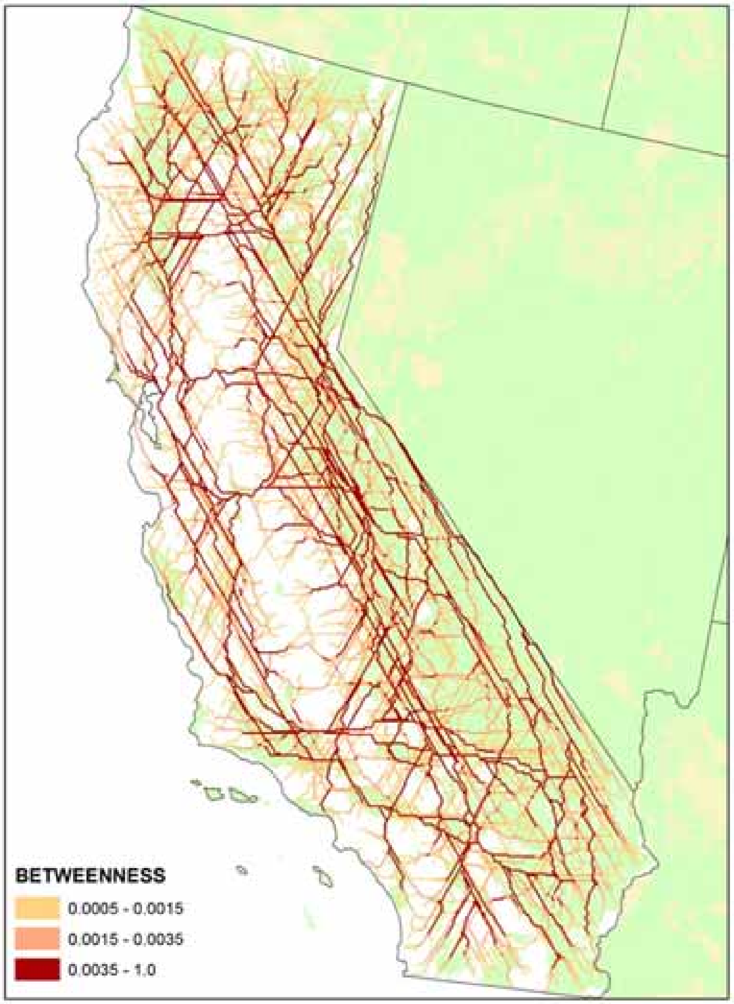
The information may be describing

1) Attributes such as landscape intactness or permeability that are thought to influence many species.

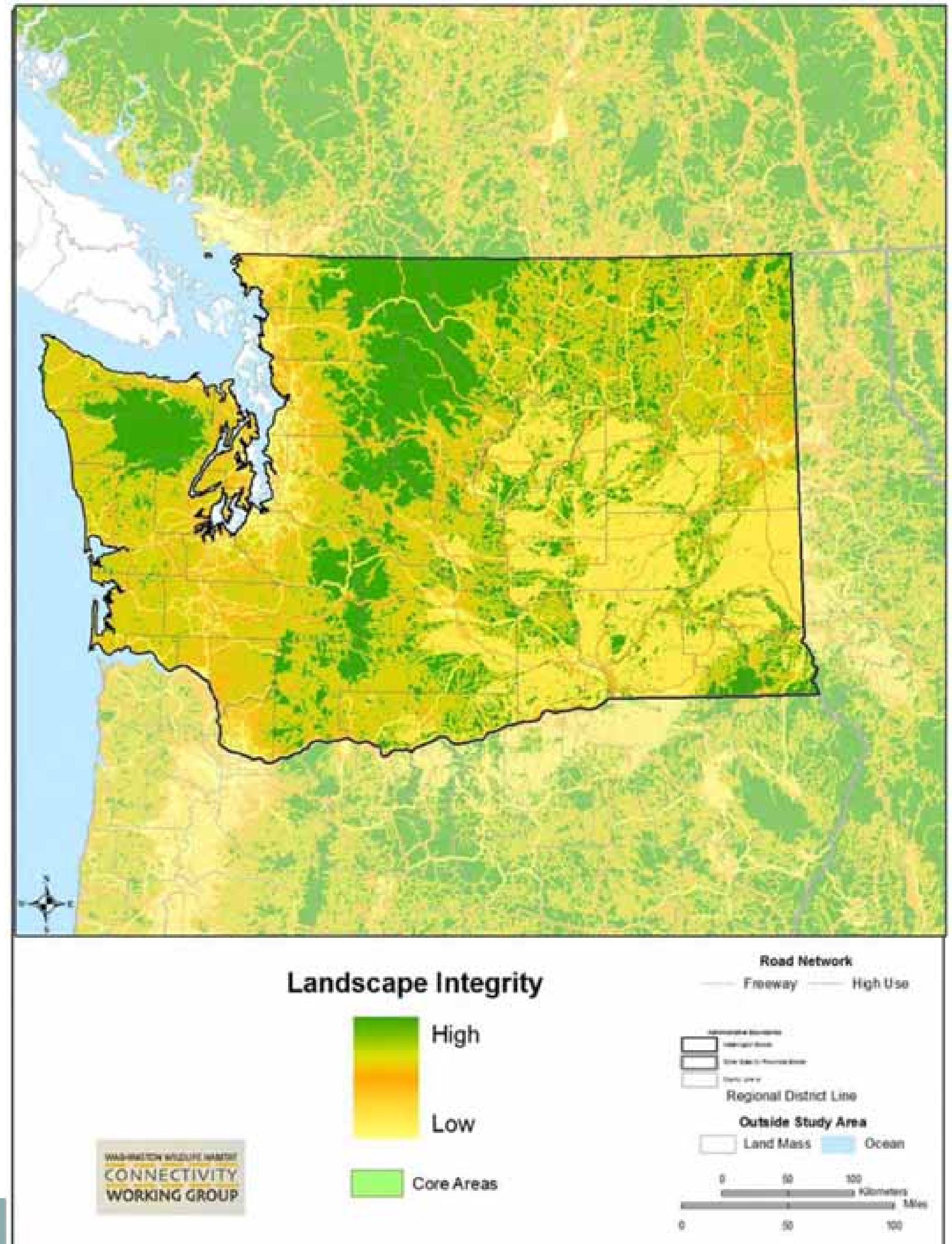
2) "Coarse-filter" conservation targets such as physical habitat (enduring features) or vegetation types.

Betweenness centrality results can inform expert-based linkage design

A data layer representing landscape resistance for the state of California, based on features such as vegetation, roads, and human land use, developed by the CEHC project. We first inverted the scaling, then squared the values. 82,000 hexagons of 5 square kilometers each were used to represent the region in a graph format.

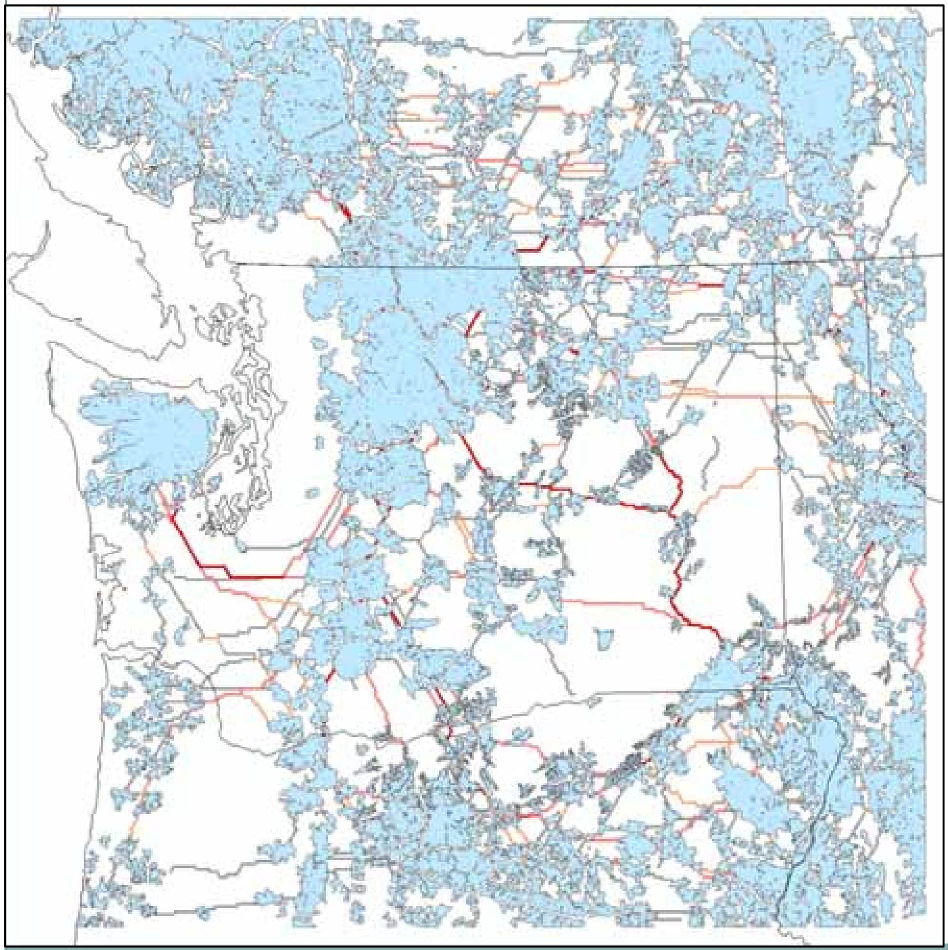


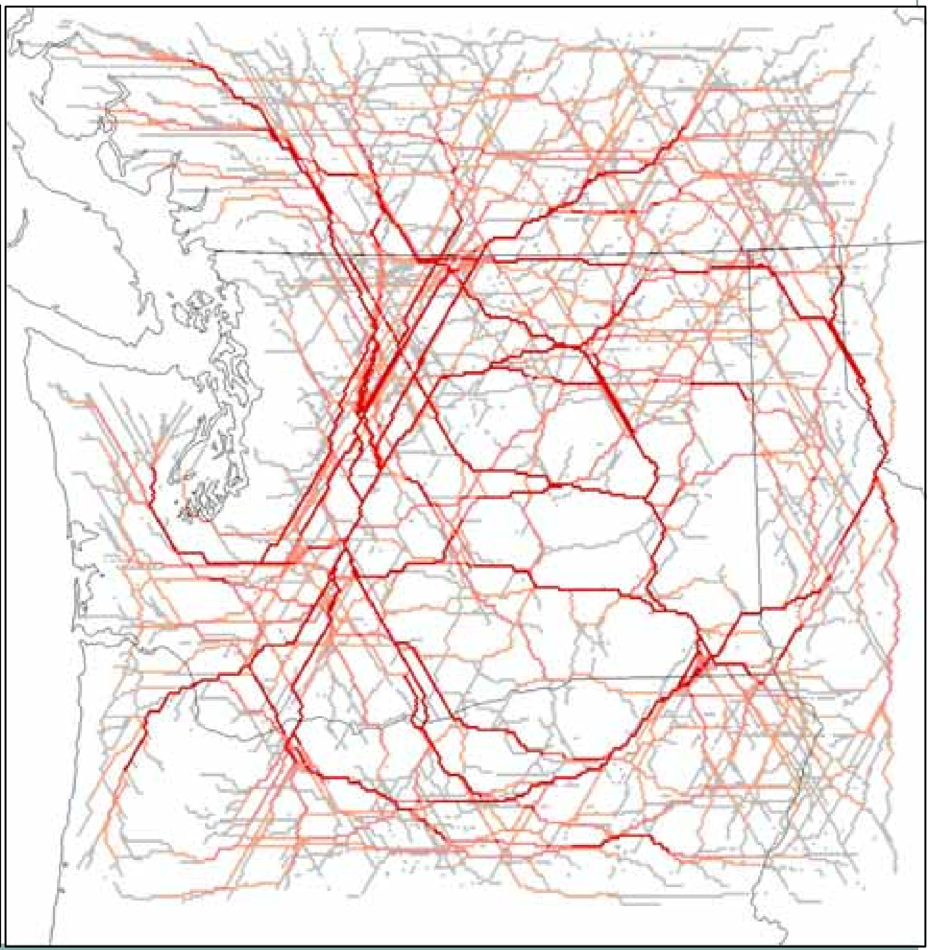
Example of betweenness centrality analysis applied to landscape integrity data for Washington - data developed by WWHCWG



Results can be used to rank importance of linkages

Method can be used with or without pre-defined core areas





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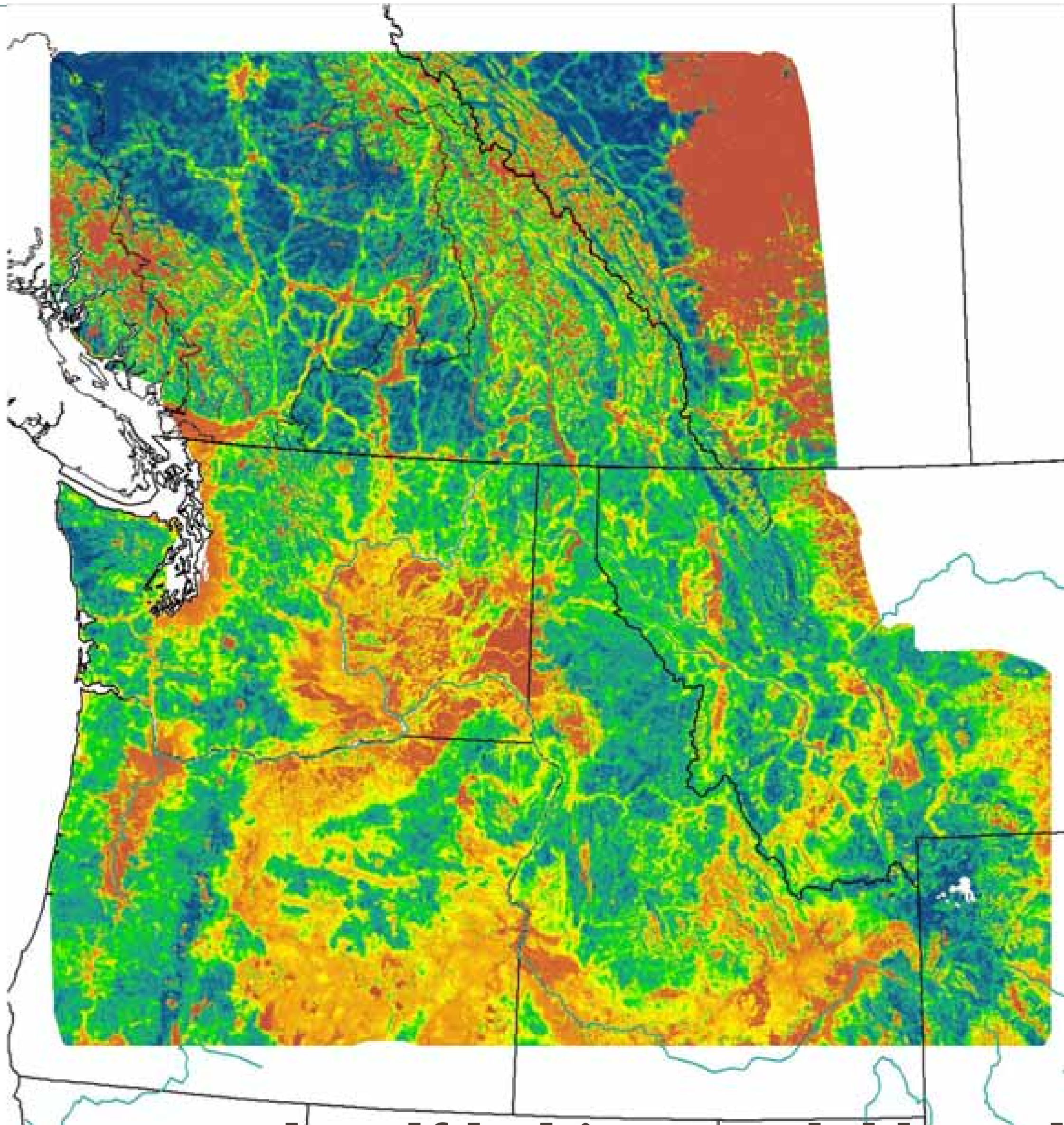
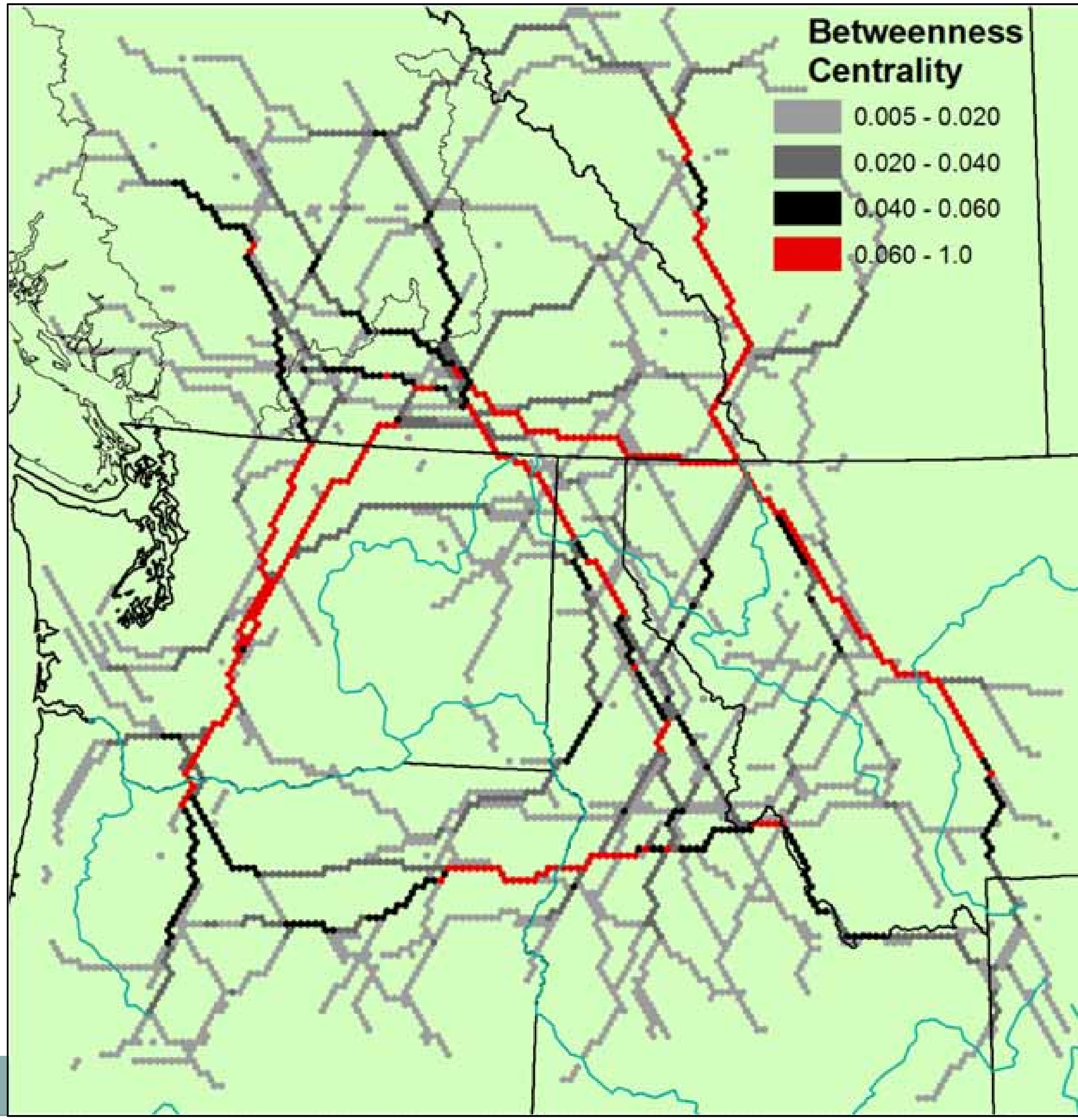


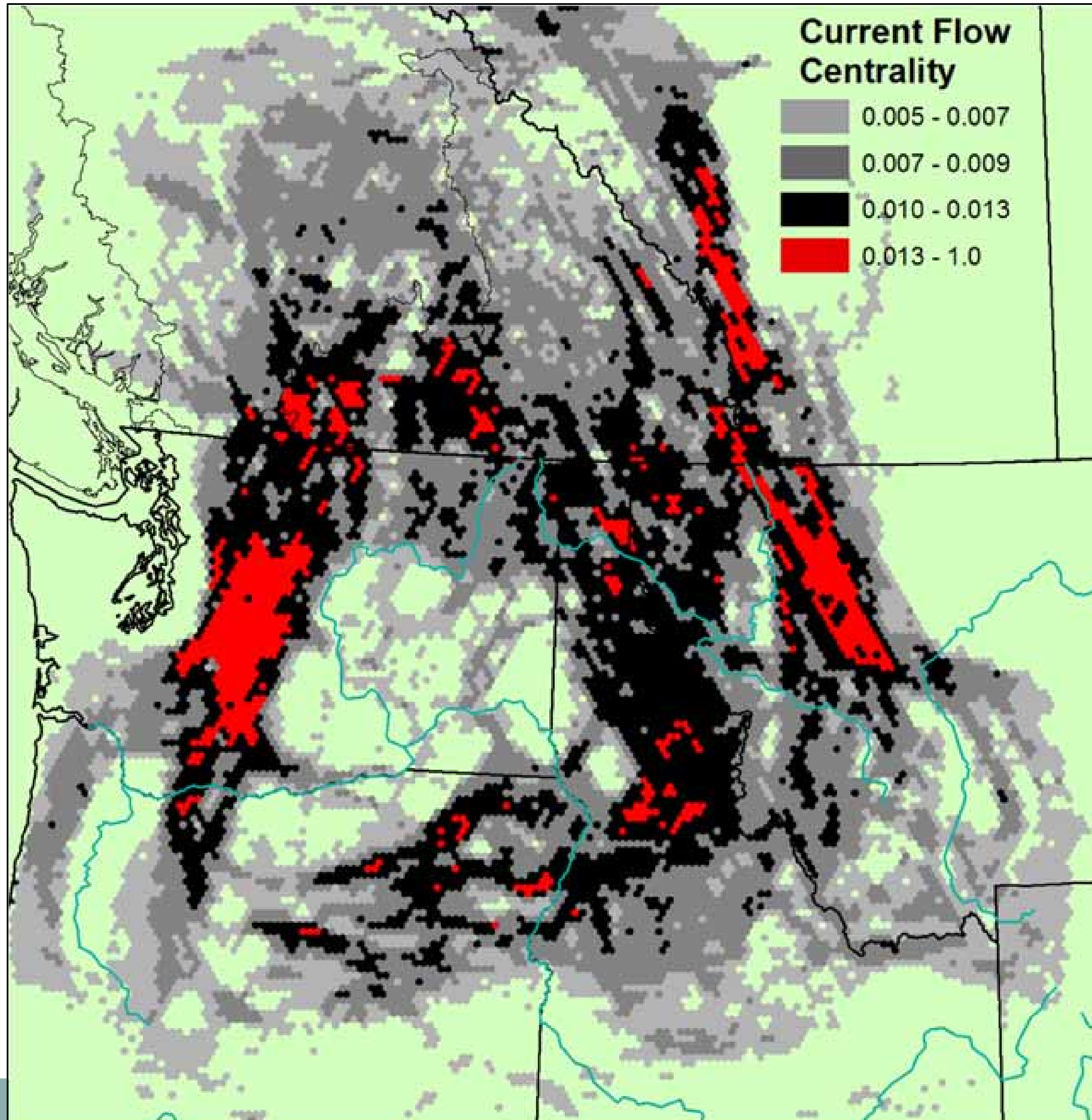
Conceptual wolf habitat model based on vegetation, slope, roads, and human population

(from Carroll et al. 2006 *Bioscience*)

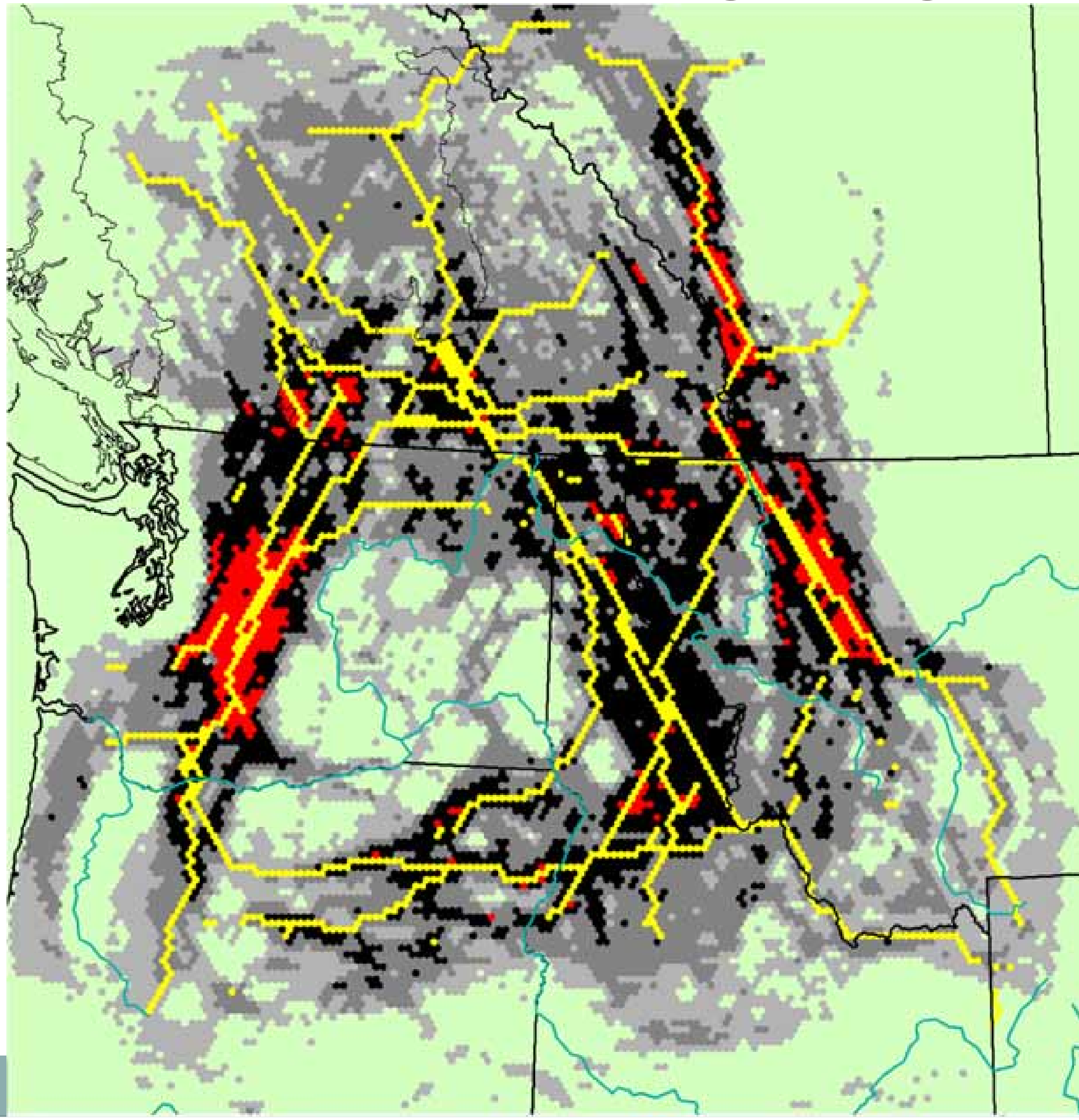
Betweenness centrality identifies habitat 'backbone'



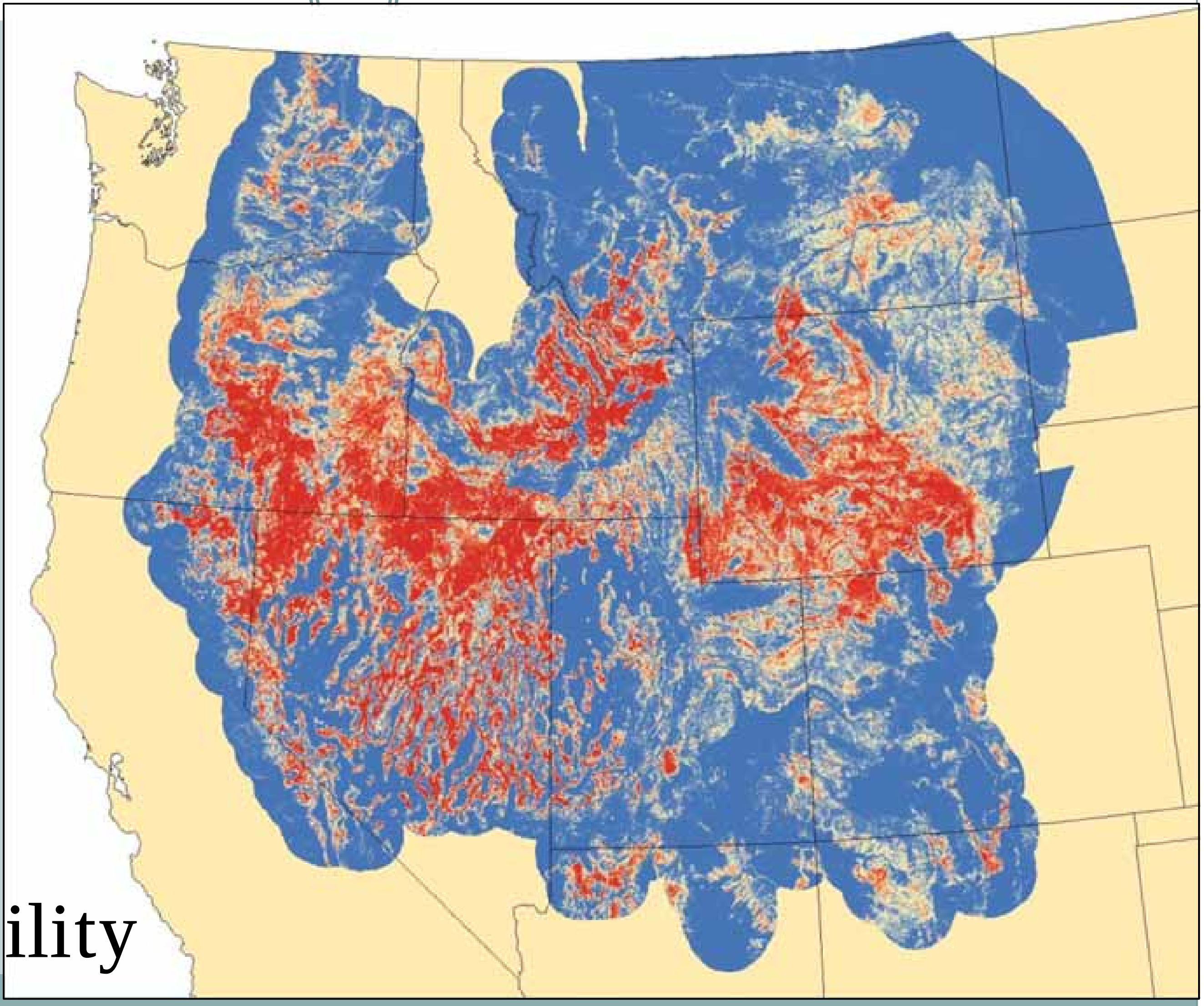
Current flow centrality identifies diffuse linkages



Betweenness and current flow provide complementary information for linkage design

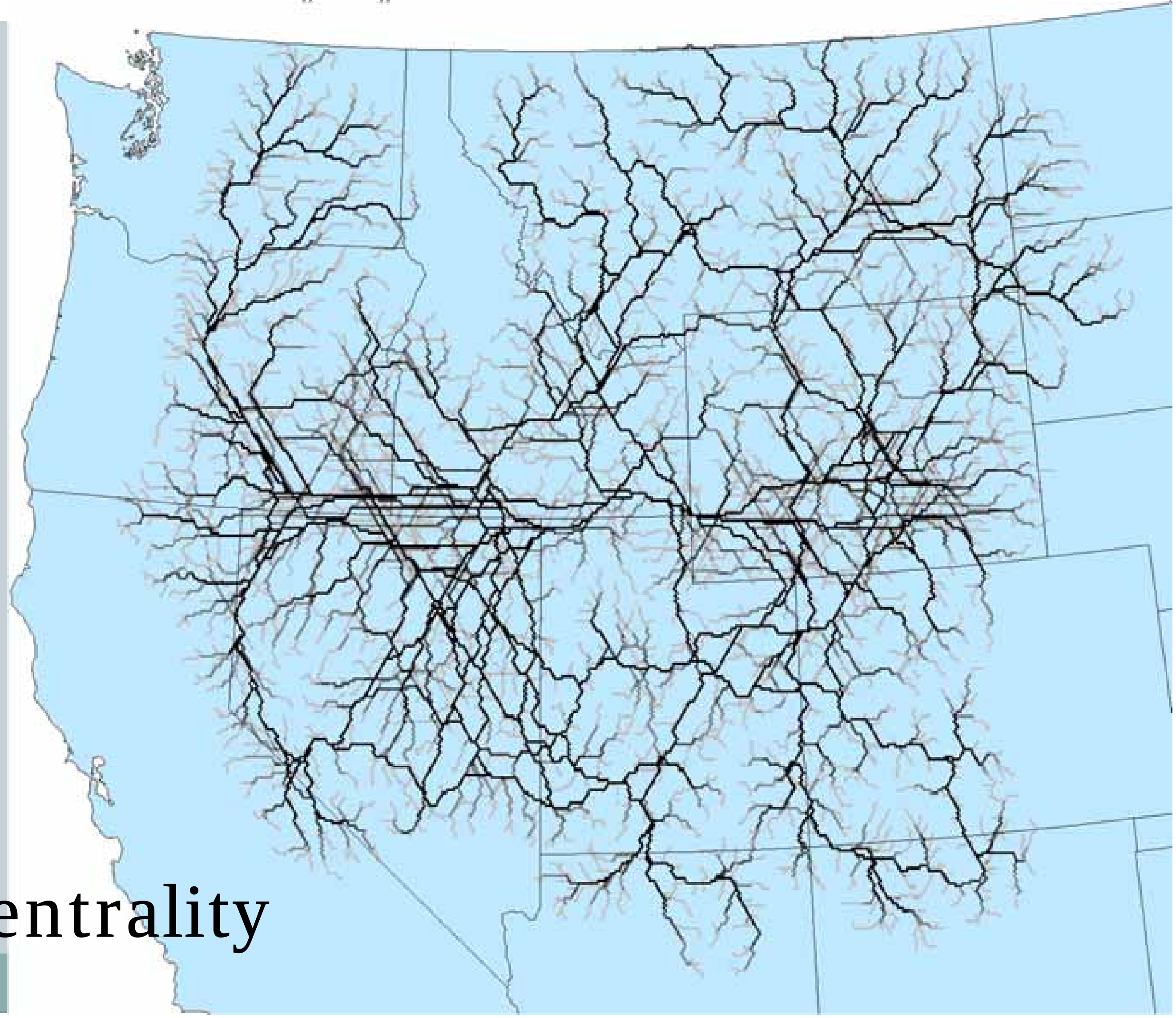


Analysis of sage grouse habitat connectivity



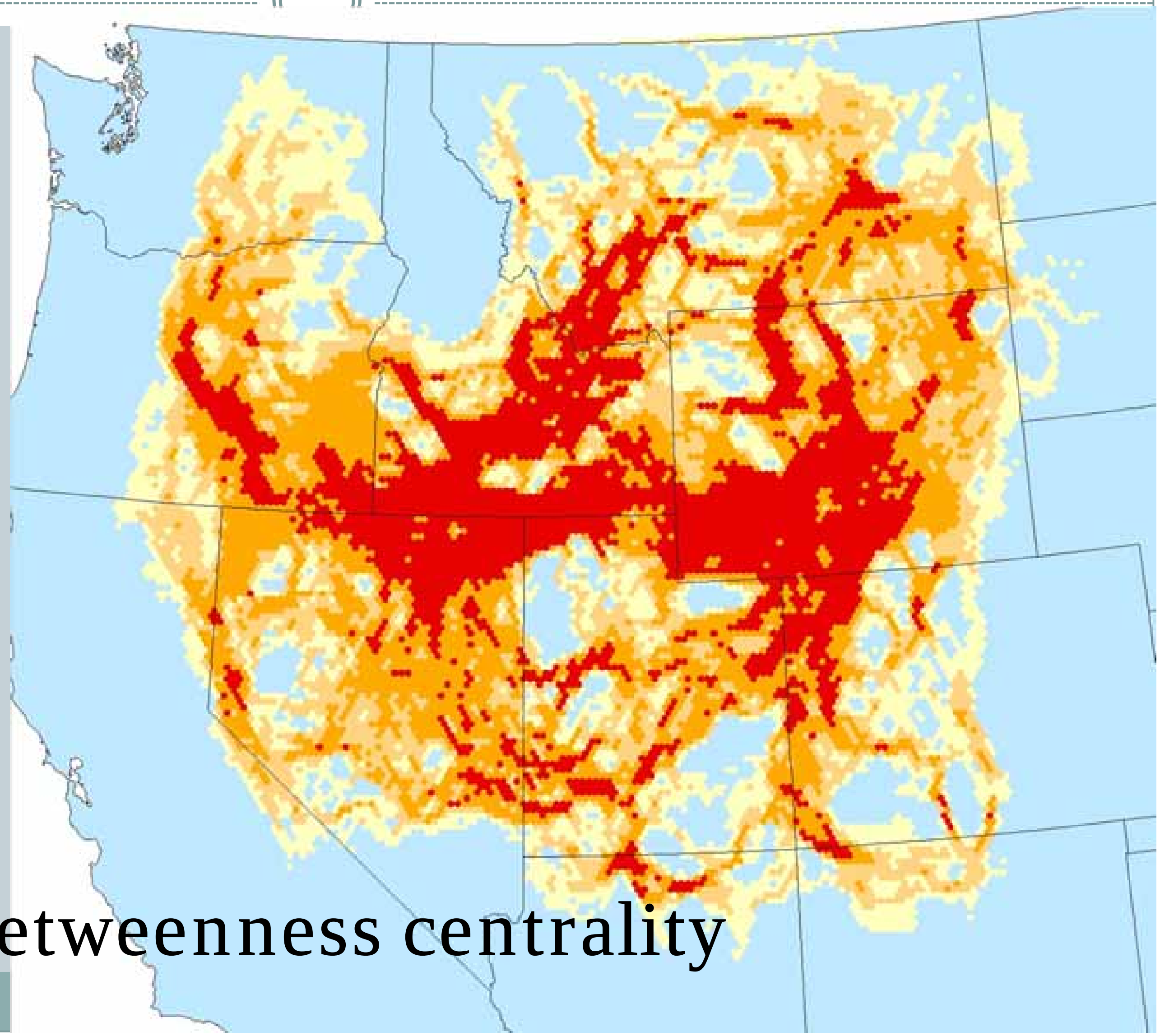
Sage grouse habitat suitability

Analysis of sage grouse habitat connectivity



Betweeness centrality

Analysis of sage grouse habitat connectivity



Current flow betweenness centrality

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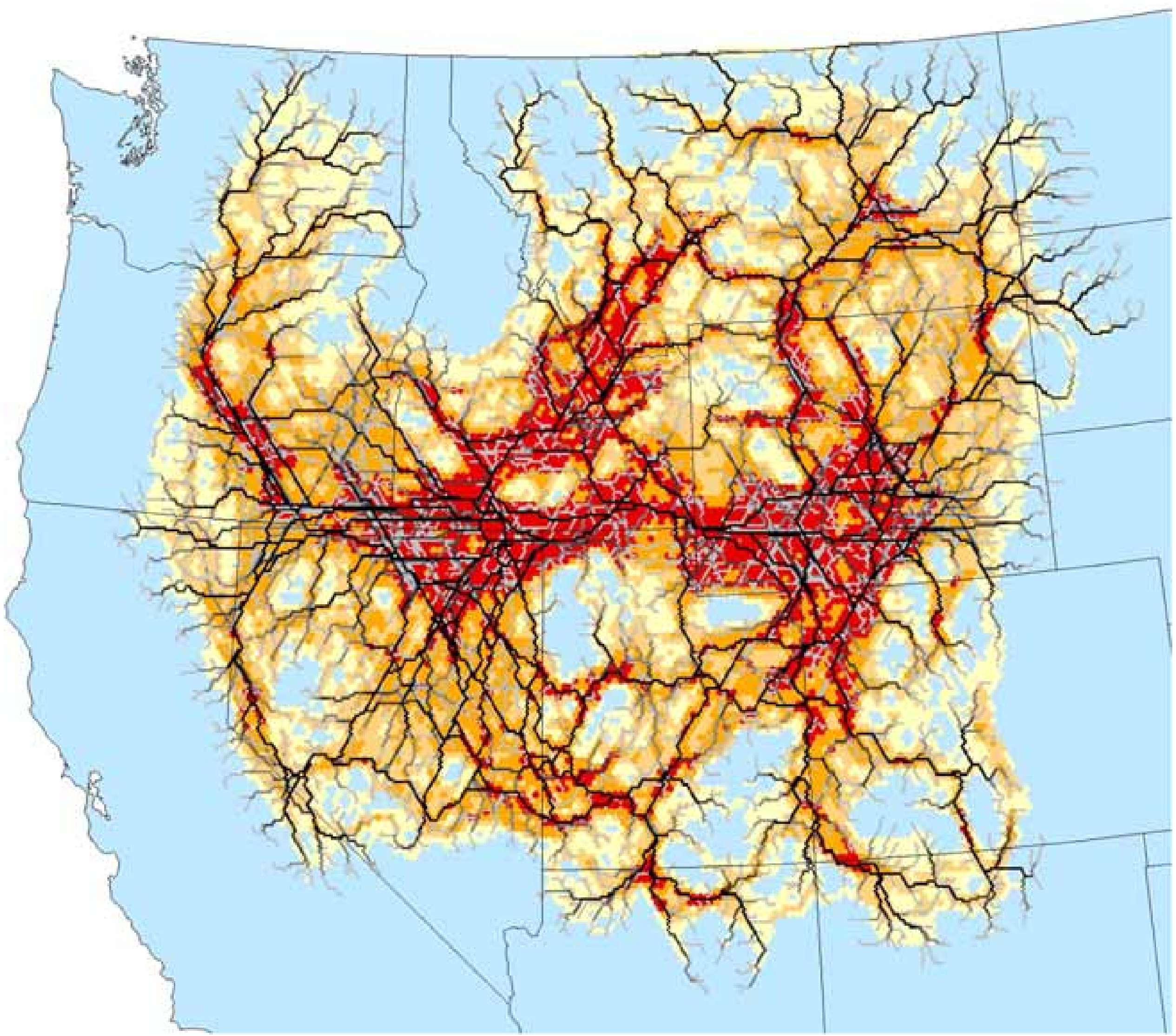

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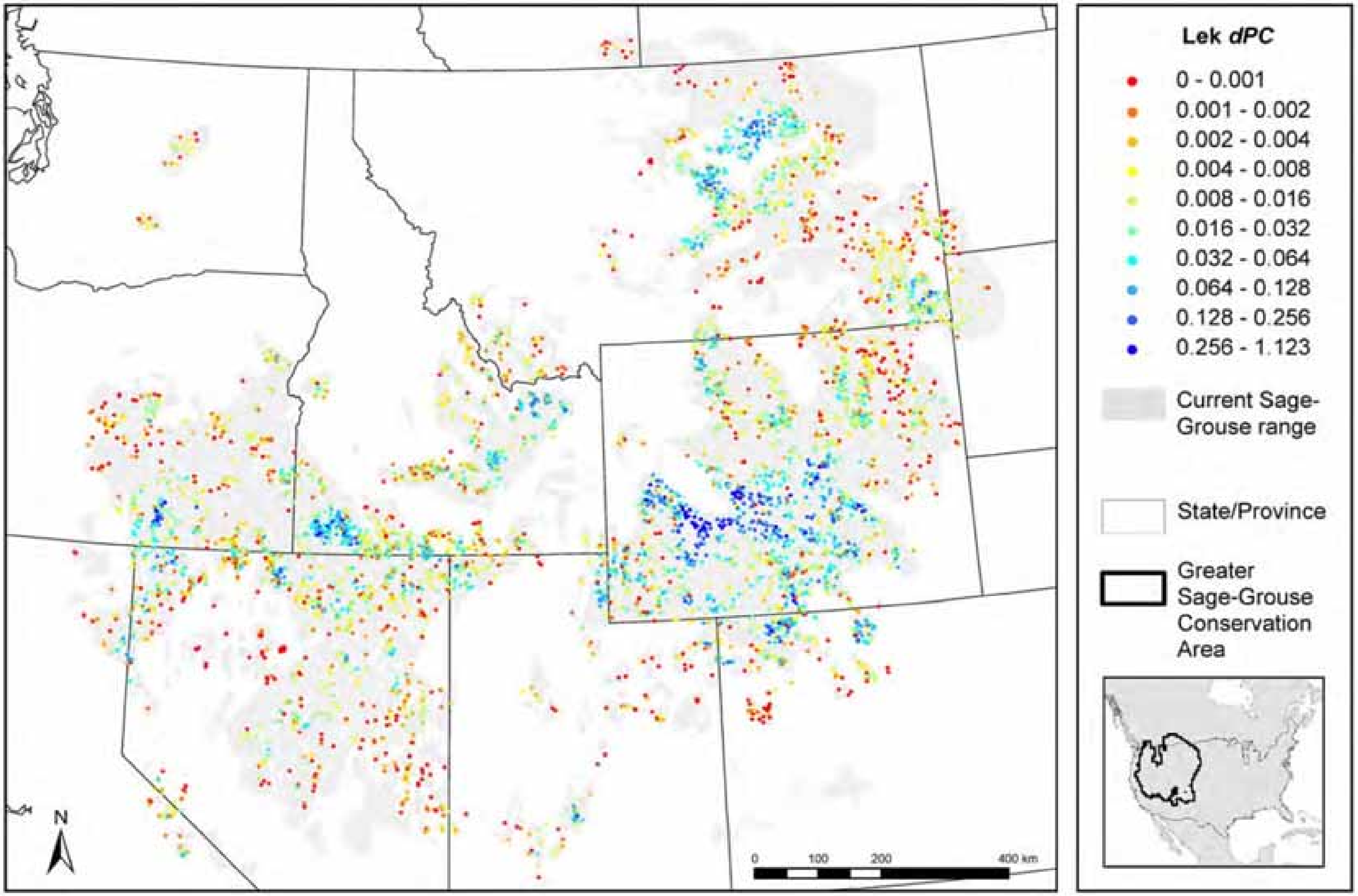
Importance of individual leks in maintaining connectivity in the range-wide distribution of Greater Sage-Grouse. From Knick and Hanser 2010



Linkage mapping results can be applied to

Single-species recovery plans, such as for the Northern Spotted Owl, Sage Grouse, and Mexican wolf.

Regional multi-species planning efforts by agency working groups (Western Governors Association) or NGOs (The Nature Conservancy, Wildlands Network).

Two methods of "testing" connectivity models

1) Compare with empirical data on connectivity

2) Compare with results from more complex models (SEPM)

Maps as hypotheses – How can we test connectivity models?

- Direct tracking of animals.
- Remote cameras and other passive detection devices.
- Genetic analysis from scat and other sources using molecular fingerprinting and assignment tests to evaluate levels of migration and gene flow.
- Stable isotopes to passively track dispersal of seeds and animals consuming marked plants.

Using Genetic Data to Assess Connectivity

Mountain goat, Cascades (Shirk 2009) Wolverine (Schwartz et al. 2009)

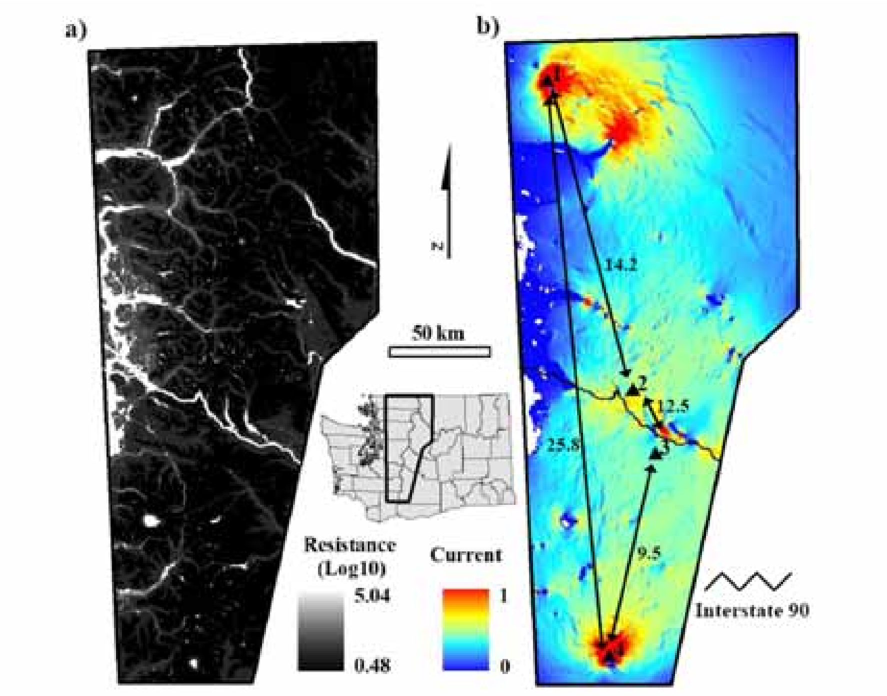


Figure 10. (a) The IBR model most highly correlated with genetic distance is depicted on a log base 10 scale, with the highest resistance in white and low resistance in black. **(b)** The color scale represents the current flowing between points 1 and 4 according to circuit theory, given the landscape resistance surface on the left. Also, the landscape resistance between the four points (black triangles labeled 1-4) is represented next to arrows connecting each pair of points. Interstate 90 is represented by a black line running east-west between points 2 and 3.

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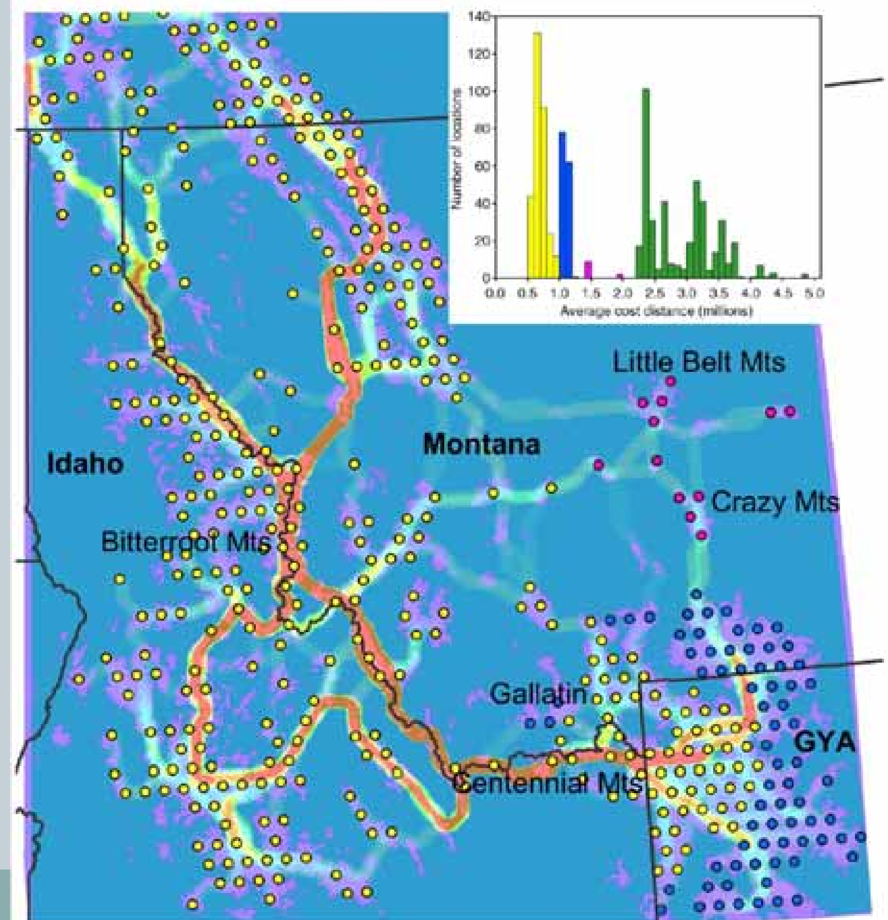
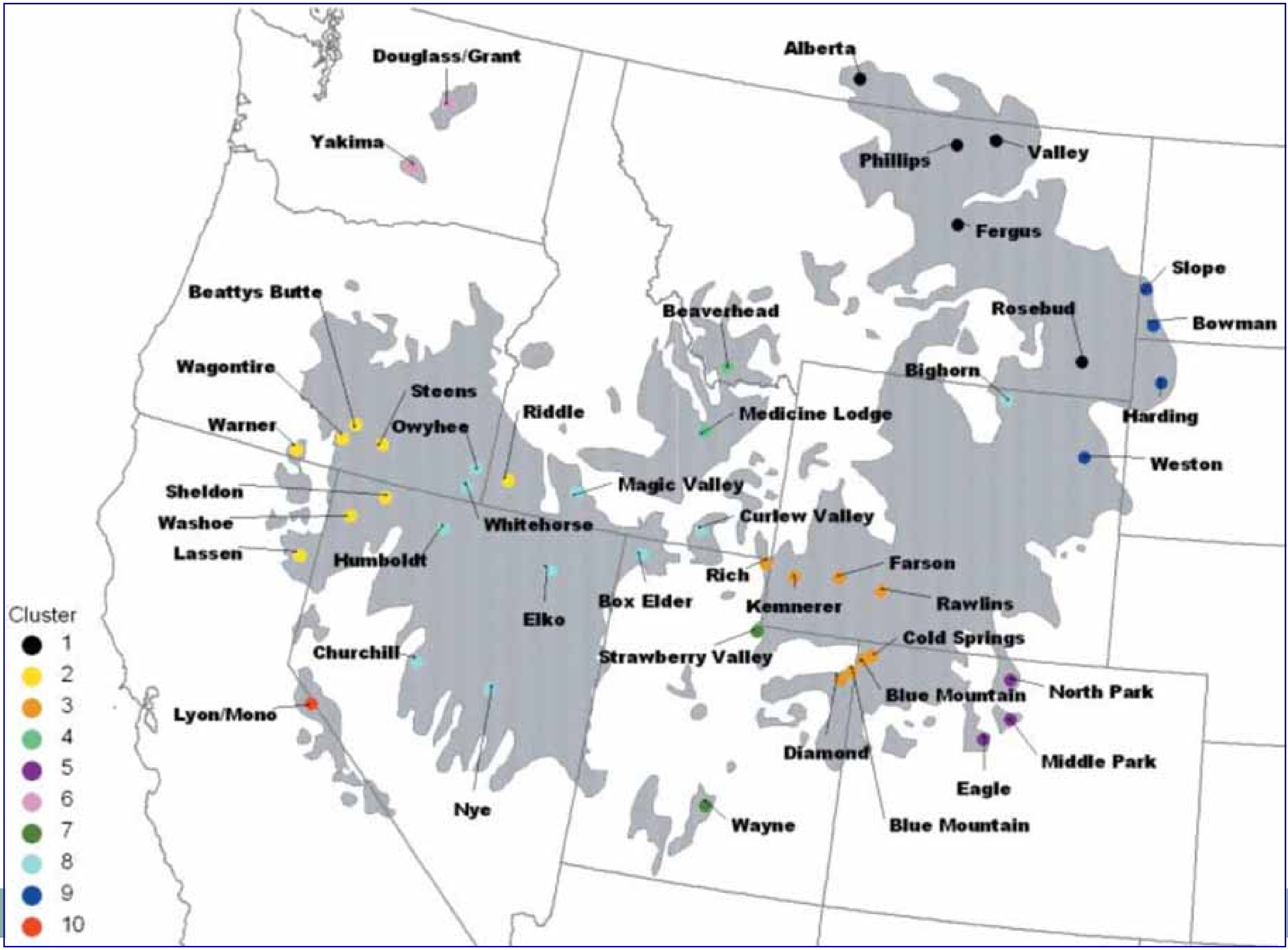
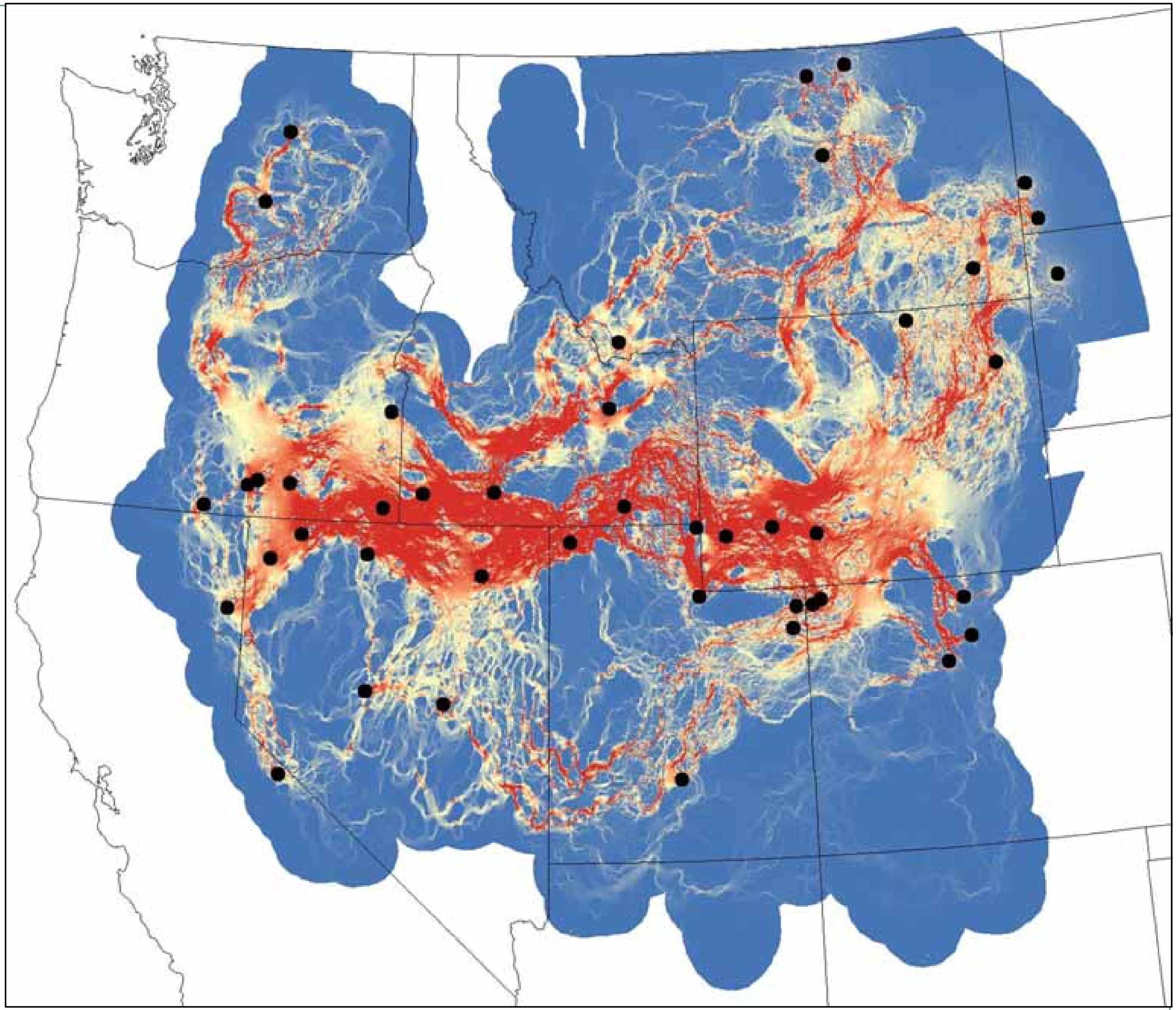


Sage-grouse data (Oyler-McCance et al. 2005)





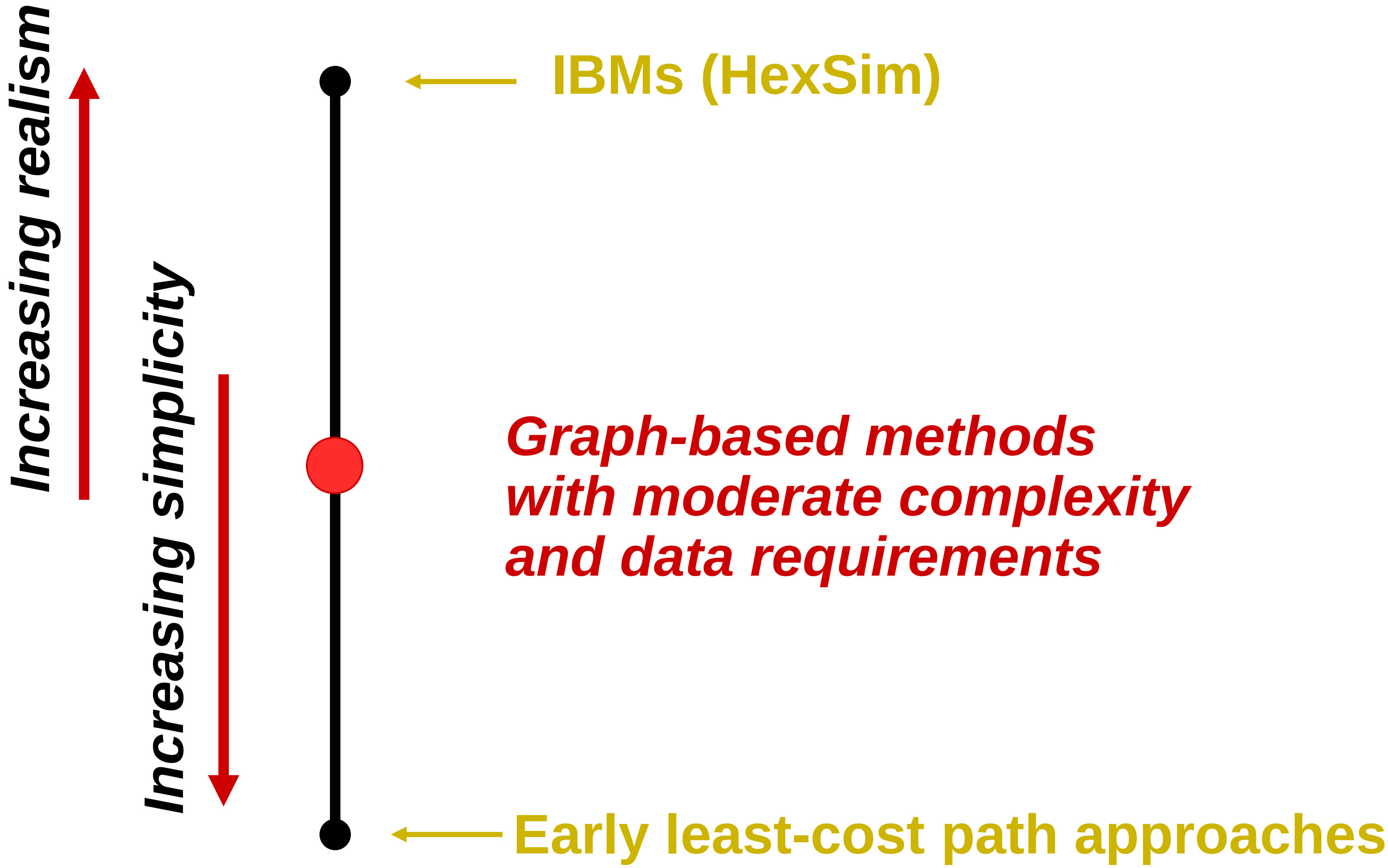
Analysis of sage grouse habitat connectivity

Two methods of "testing" connectivity models

1) Compare with empirical data on connectivity

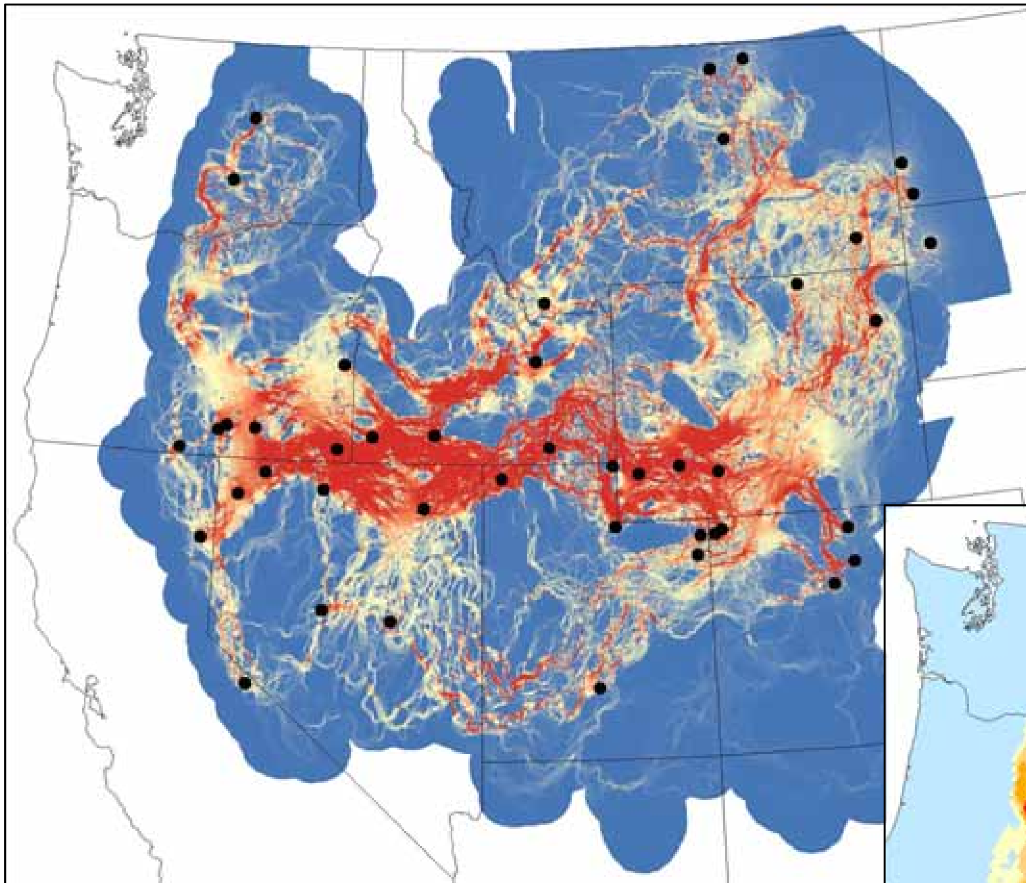
2) Compare with results from more complex models

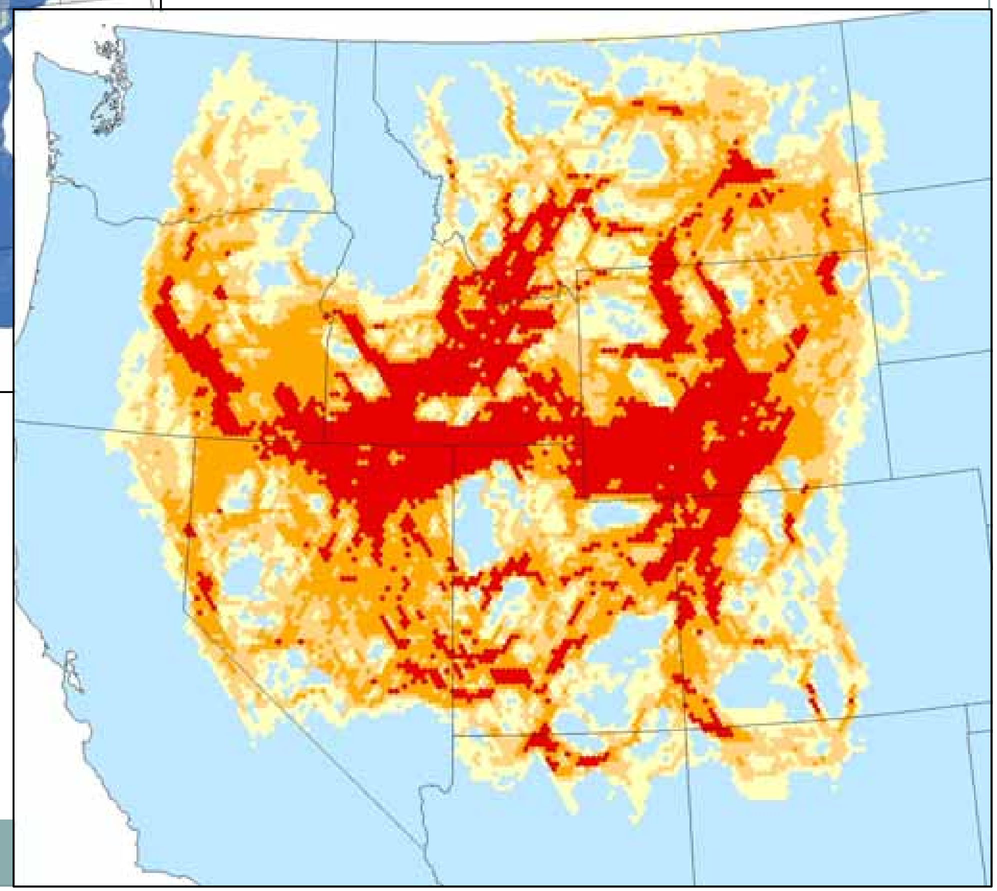
Realism vs. simplicity in connectivity models



Complementarity of the CAT and Circuitscape

Circuitscape is a software designed for analyzing current flow between two or more source locations on high-resolution raster surfaces (habitat maps). It complements the functionality of the CAT, which is instead designed for analyzing current flow between many or all node pairs, but because of RAM limitations, is practically limited to graphs with up to 20,000 nodes.





Circuitscape and CAT analyses of sage grouse habitat connectivity

THE END