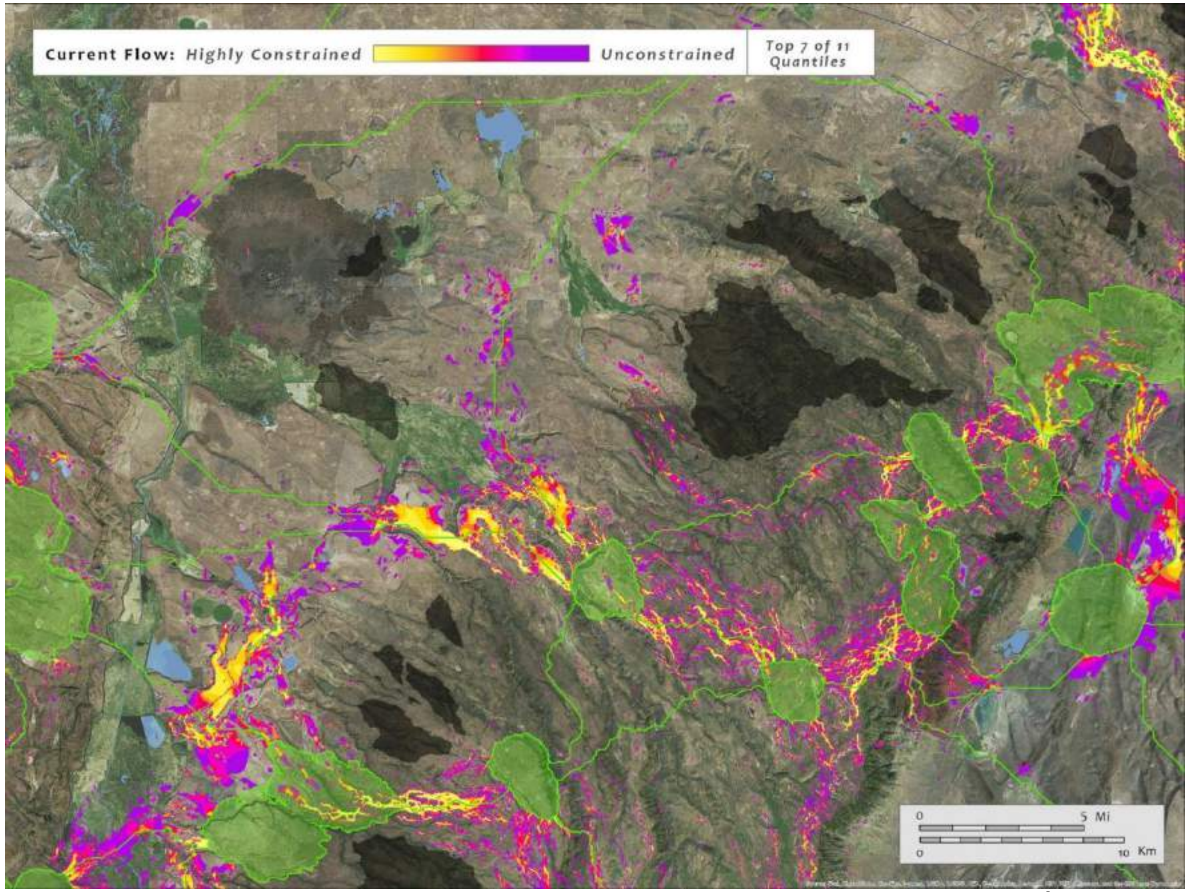
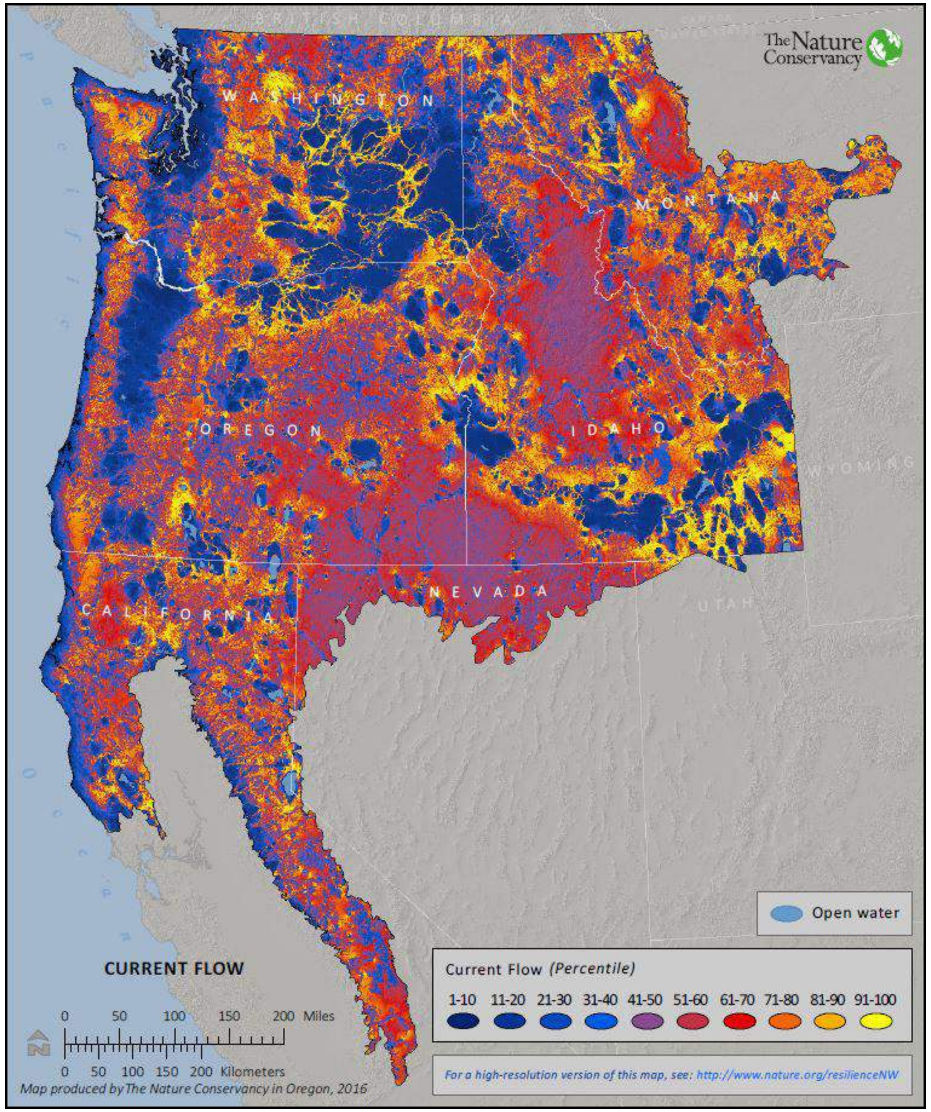
Connectivity modeling with Circuitscape

Kim Hall, The Nature Conservancy &
Ranjan Anantharaman, MIT & formerly Julia Computing
NASA Ecological Forecasting – May 22, 2019

Download Circuitscape 5.0 from download page on Circuitscape.org
Download test data if you like...
Visit Circuitscape.jl on GitHub



Habitat connectivity among sage grouse leks - Jones et al. 2015



Landscape structural connectivity – McRae et al. 2016

Session overview

Terrestrial connectivity modeling -- Kim

- Connectivity context & decisions
- Introduction to Circuitscape
- Resistance grids & workflow for conservation decisions
- Examples & challenges

The Circuitscape Upgrade - (Ranjan)

- Problem statement
- Advantages of Julia & Performance improvements

Questions & discussion

- New ideas and opportunities for using EOs & cross team collaborations

The Circuitscape Team

The Nature Conservancy

Kim Hall – NASA lead (after Brad McRae)
Melissa Clark – Wall-to-Wall Circuitscape
Jim Platt – Coding/GIS/ Arc GIS plug-in
Mark Anderson – Co-Pi, and applications
Carrie Schloss – Omniscape
Aaron Jones – Omniscape / Linkage Mapper

MIT & Julia Computing

Ranjan Anantharaman – lead on update
Viral Shah – co-PI
Alan Edelman - Collaborator

Conservation Science Partners

Brett Dickson - Circuitscape
Dave Theobald – Resistance Grids
Vincent Landau – Circuitscape, Omniscape

Brad McRae

NASA

Wilburforce Foundation

DORIS DUKE CHARITABLE FOUNDATION

Evolution, 60(8), 2006, pp. 1551–1561

ISOLATION BY RESISTANCE

BRAD H. MCRAE
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Abstract.—Despite growing interest in the
available to incorporate data on landscape co
have typically either assumed spatial homog
to compensate for heterogeneity. Here I prop
equilibrium genetic structuring in complex
differentiation and the resistance distance,
times and effective resistances in electronic
is both more theoretically justified and mo
distance measures. Moreover, the metric ca
maps, simple maps of habitat and nonhabi
barriers of differing qualities. The IBR mo
erogeneity in studies of isolation by distan
structuring, and predict genetic and evoluti

Key words.—Gene flow, graph theory, isola
genetics, resistance distance.

Received J

2006

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 theory. Although they have been applied in other disciplines, circuit-theoretic connectivity models are new to ecology. They offer distinct advantages over common analytic connectivity models, including a theoretical basis in random walk theory and an ability to evaluate contributions of multiple dispersal pathways. Resistance, current, and voltage calculated across graphs or raster grids can be related to ecological processes (such as individual movement and gene flow) that occur across large population networks or landscapes. Efficient algorithms can quickly solve networks with millions of nodes, or landscapes with millions of raster cells. Here we review basic circuit theory, discuss relationships between circuit and random walk theories, and describe applications in ecology, evolution, and conservation. We provide examples of how circuit models can be used to predict movement patterns and fates of random walkers in complex landscapes and to identify important habitat patches and movement corridors for conservation planning.

Key words: circuit theory; dispersal; effective distance; gene flow; graph theory; habitat fragmentation; isolation; landscape connectivity; metapopulation theory; reserve design.

2008

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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[8]U.S. Fish & Wildlife Service, Science Applications, 101 12th Avenue, Number 110, Fairbanks, AK, 99701, U.S.A.
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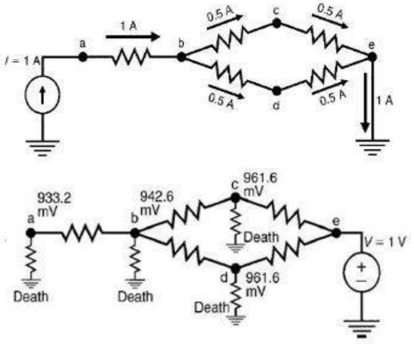
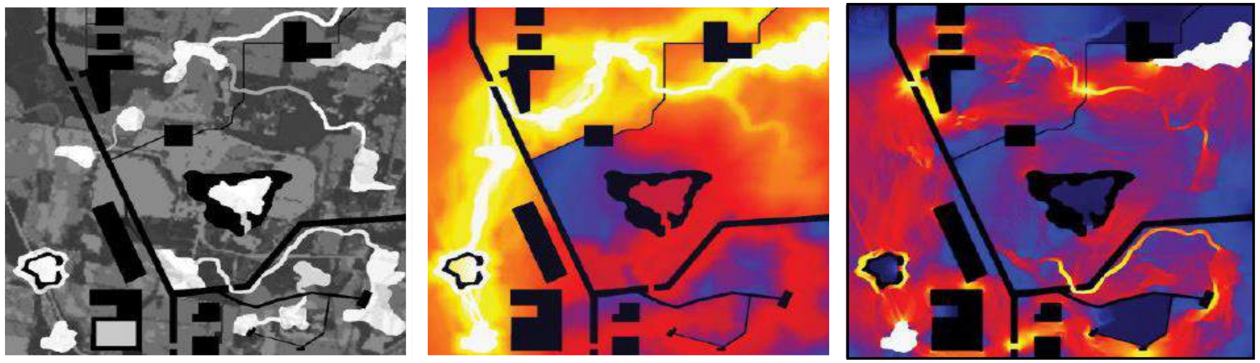
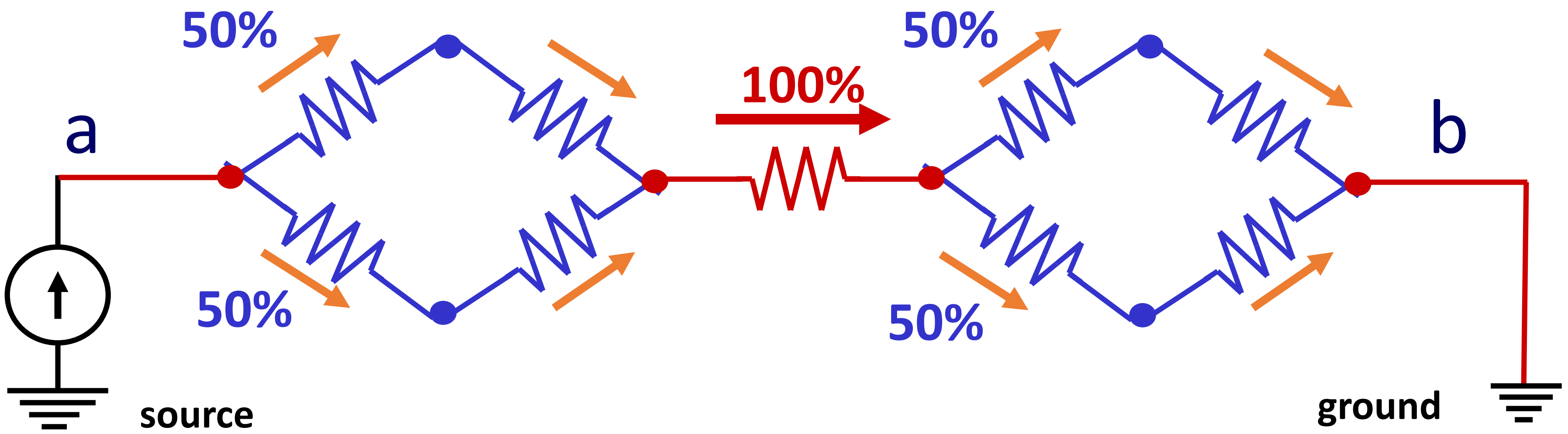
[10]The Nature Conservancy, 201 Mission Street, San Francisco, CA, 94105, U.S.A.
[11]U.S. Environmental Protection Agency, 200 Southwest 35th Street, Corvallis, OR, 97330, U.S.A.

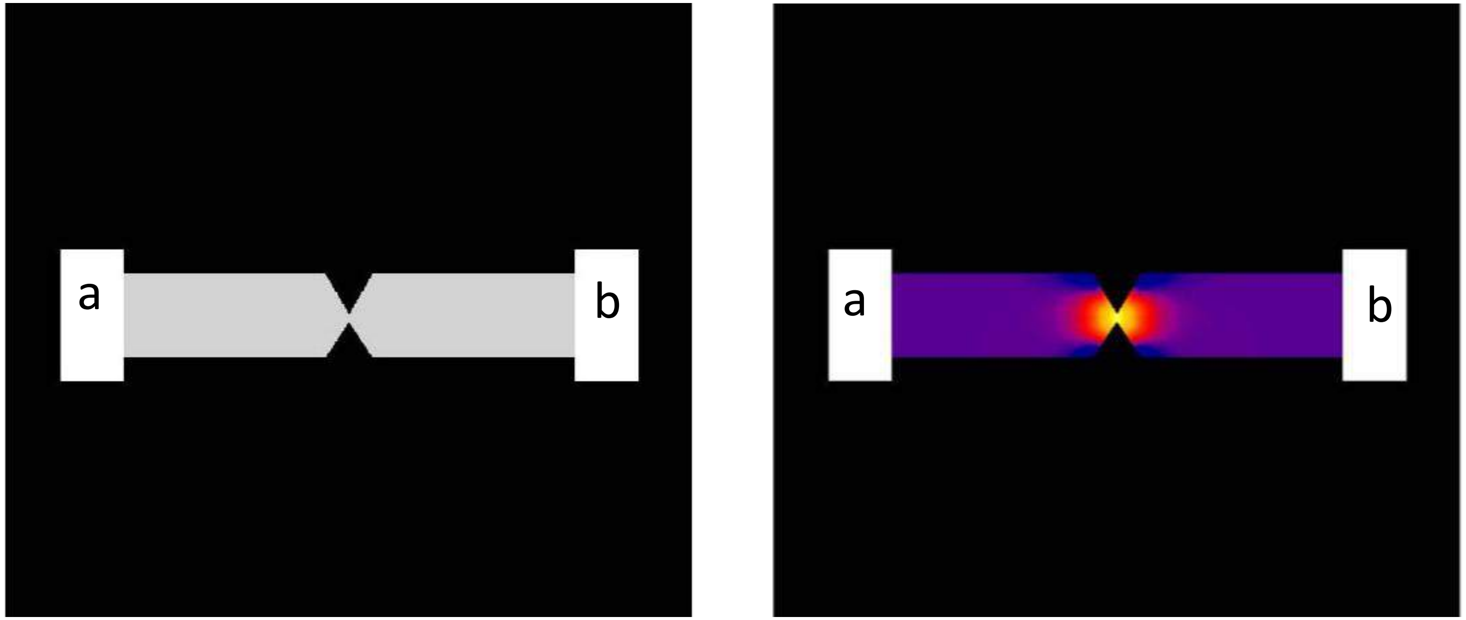
2019

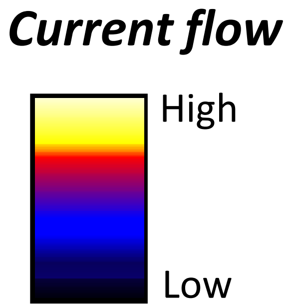




Current flow as model for movement across landscapes







Current
Current responds to number of pathways available & barriers

Why Circuit theory? (from 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
- Redundancy is key - *especially under changing land cover or climate*

Circuit theory helps to, e.g.,:

- Quantify 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 our work protecting and reconnecting landscapes.

Key project stages

1. Characterize Goals and Scope – what decisions do we want to inform?
2. Identify and Engage Partners and Stakeholders
3. Characterize ecology/response to barriers
4. Select Modeling Approach(es) and Tool(s) and Data
5. Develop Model Inputs (Resistance Grids)
6. Model Runs
7. Validate & Interpret Results; Communicate with maps
8. Incorporate into Decision-Making

Connectivity of what? Landscapes, species' habitats....

Gene flow & other ecological processes (fire, disease transmission)

Animal movement

Structural connectivity: a measure of habitat permeability based on the physical features and arrangement of habitat patches, disturbances & barriers...more of landscape feature.

Functional connectivity – incorporates species movement characteristics; based on field observations

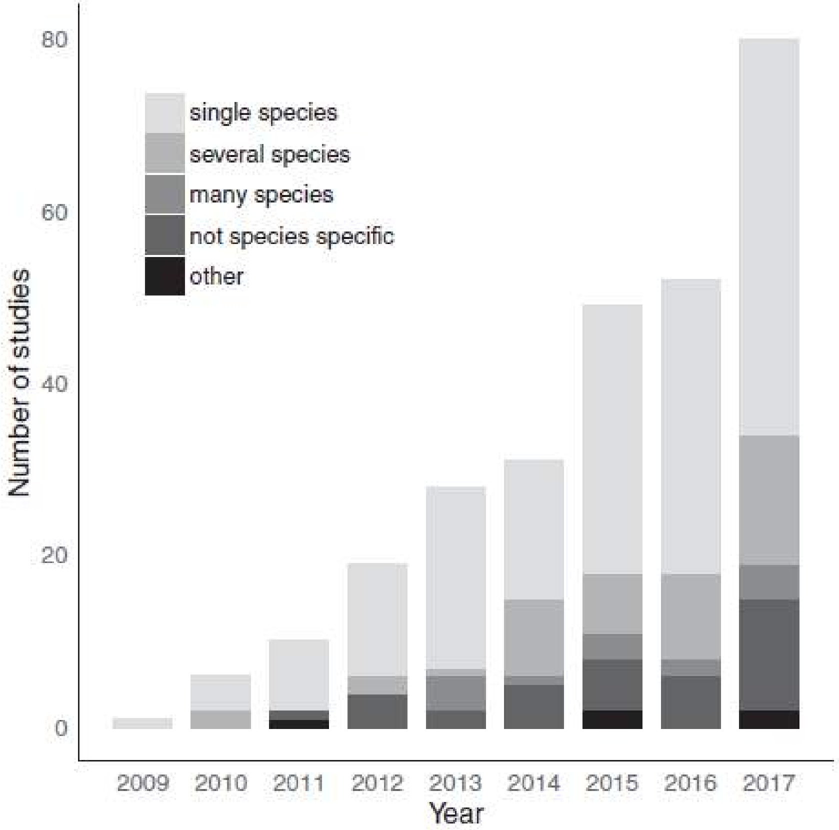
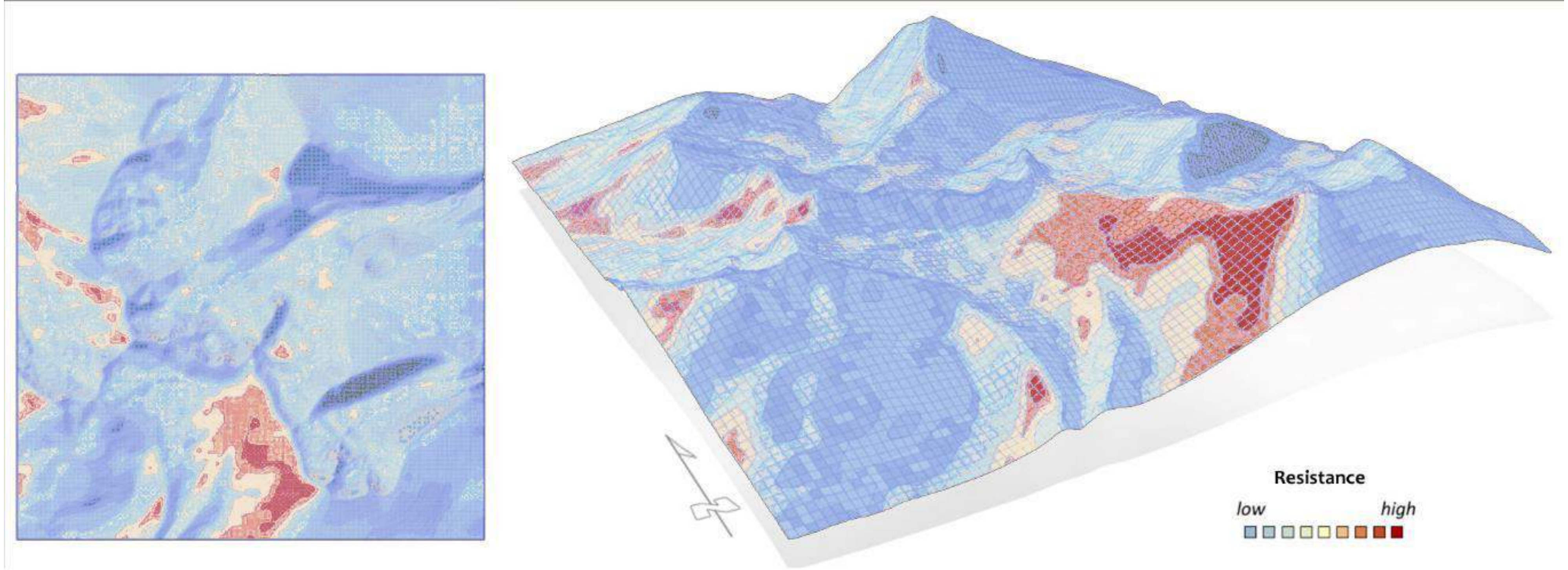


Figure 2. Number of peer-reviewed studies of 5 types that used Circuitscape from 2009 to 2017 (several species, 2-10; many species, >10; not species specific, specific species not targeted; other, models compared or physical processes modeled [e.g., hydraulic resistance in roots [Zeppenfeld et al. 2017]).

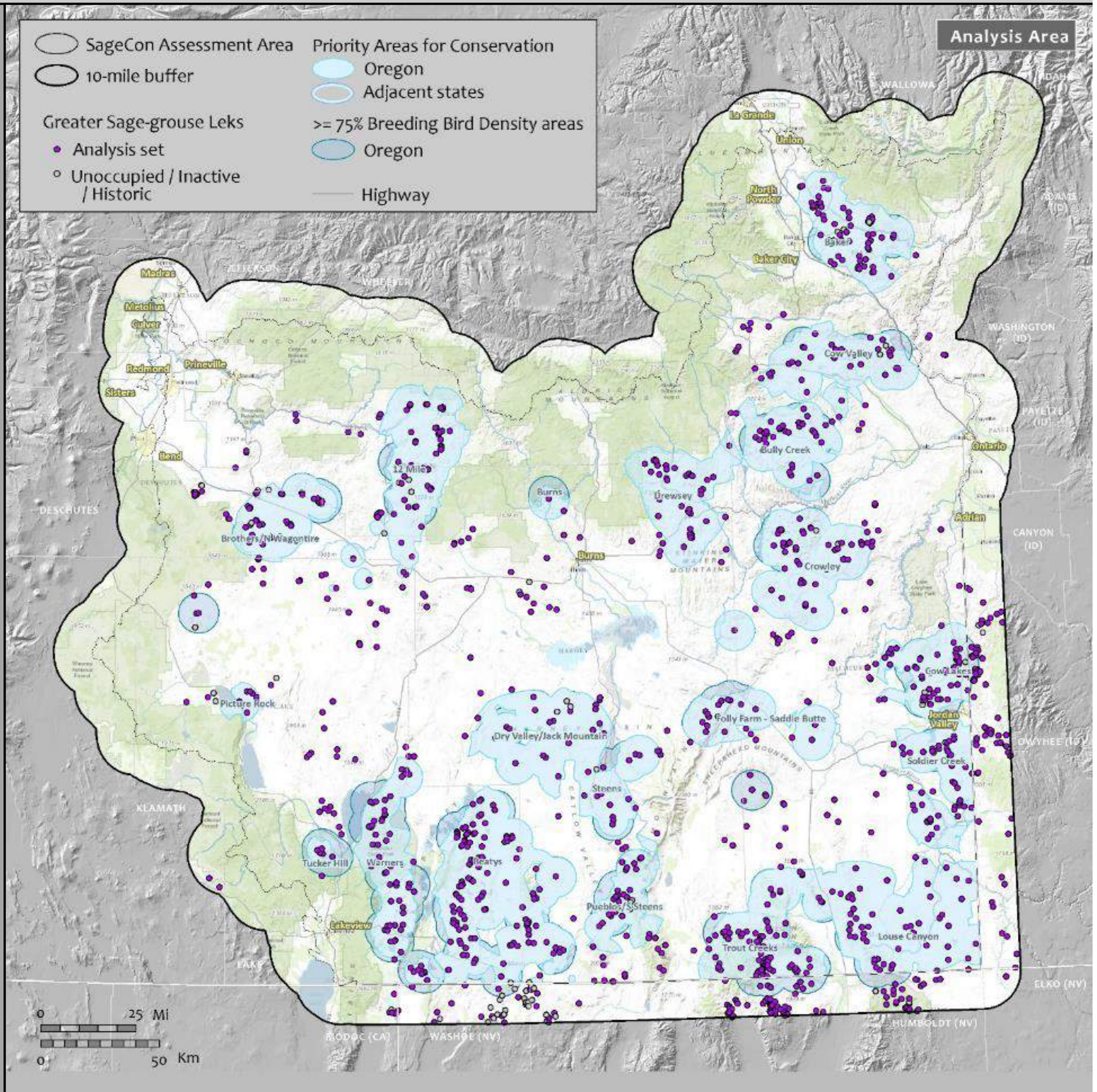
From Dickson et al. 2019



Resistance surface: a grid in which each cell value reflects the landscape permeability (structural connectivity) or the energetic cost, movement difficulty, mortality risk, and/or avoidance behavior associated with species movement through that cell (functional connectivity).

Also commonly used for least-cost path analyses – what's the shortest path between patches when travel is weighted by resistance score?

Analysis Extent:
SageCon Assessment Area



Resistance: Data preparation by resistance type

I. Energy cost / Movement difficulty:

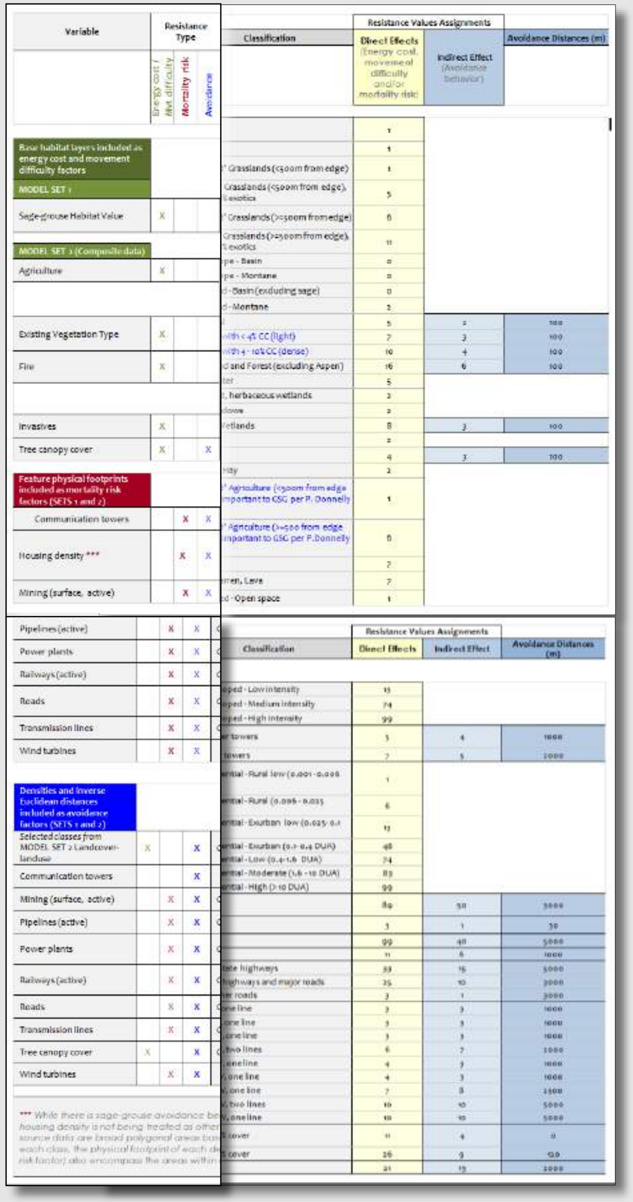
Includes base habitat layers

II. Mortality risk:

Physical footprints of anthropogenic landscape features

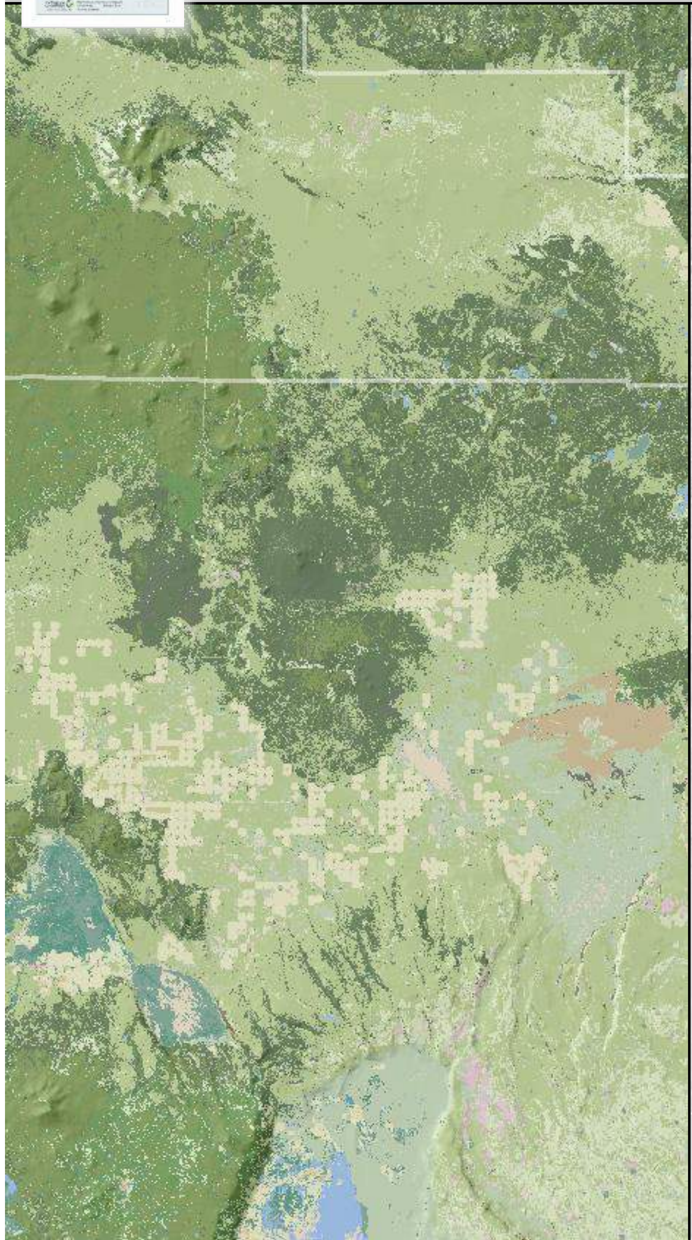
III. Avoidance:

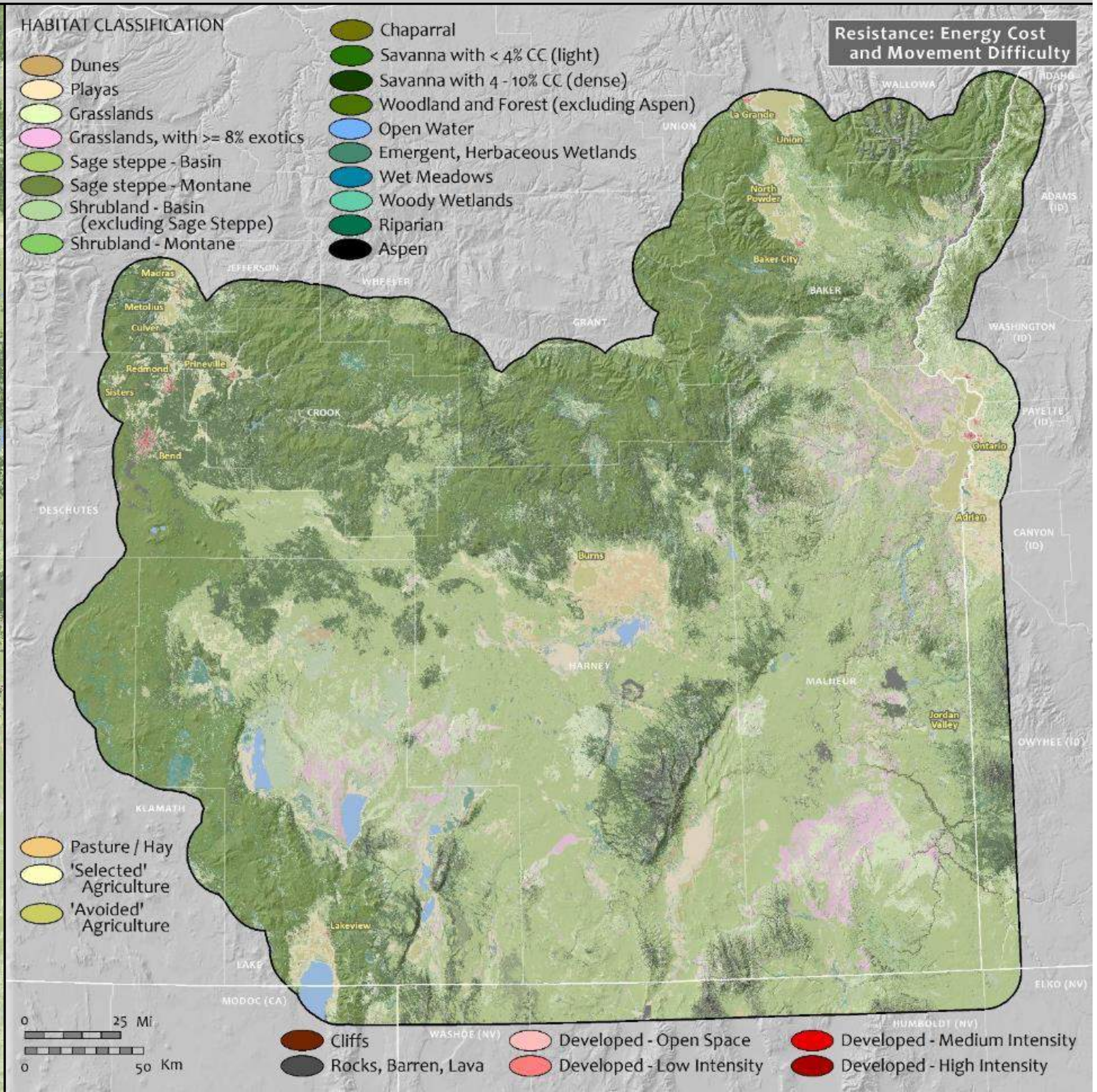
Densities / inverse Euclidean distances of anthropogenic features



Variable	Energy cost / Mvt difficulty	Mortality risk	Avoidance
Base habitat layers included as energy cost and movement difficulty factors			
MODEL SET 1			
Sage-grouse Habitat Value	X		
MODEL SET 2 (Composite data)			
Agriculture	X		
Existing Vegetation Type	X		
Fire	X		
Invasives	X		
Tree canopy cover	X		X
Feature physical footprints included as mortality risk factors (SETS 1 and 2)			
Communication towers		X	X
Housing density ***		X	X
Mining (surface, active)		X	X
Pipelines (active)		X	X
Power plants		X	X
Railways (active)		X	X
Roads		X	X
Transmission lines		X	X
Wind turbines		X	X
Densities and inverse Euclidean distances included as avoidance factors (SETS 1 and 2)			
Selected classes from MODEL SET 2 Landcover-landuse	X		X
Communication towers			X
Mining (surface, active)		X	X
Pipelines (active)		X	X
Power plants		X	X
Railways (active)		X	X
Roads		X	X
Transmission lines		X	X
Tree canopy cover	X		X
Wind turbines		X	X

Resistance: Energy Cost and Movement Difficulty





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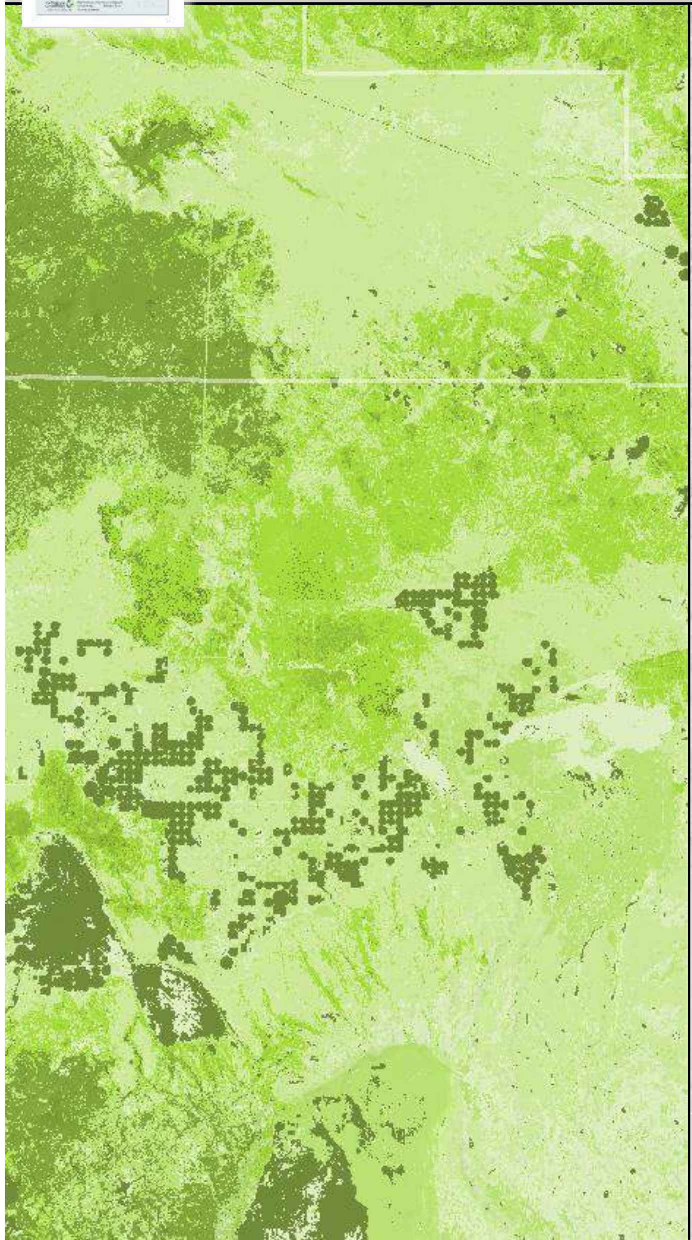
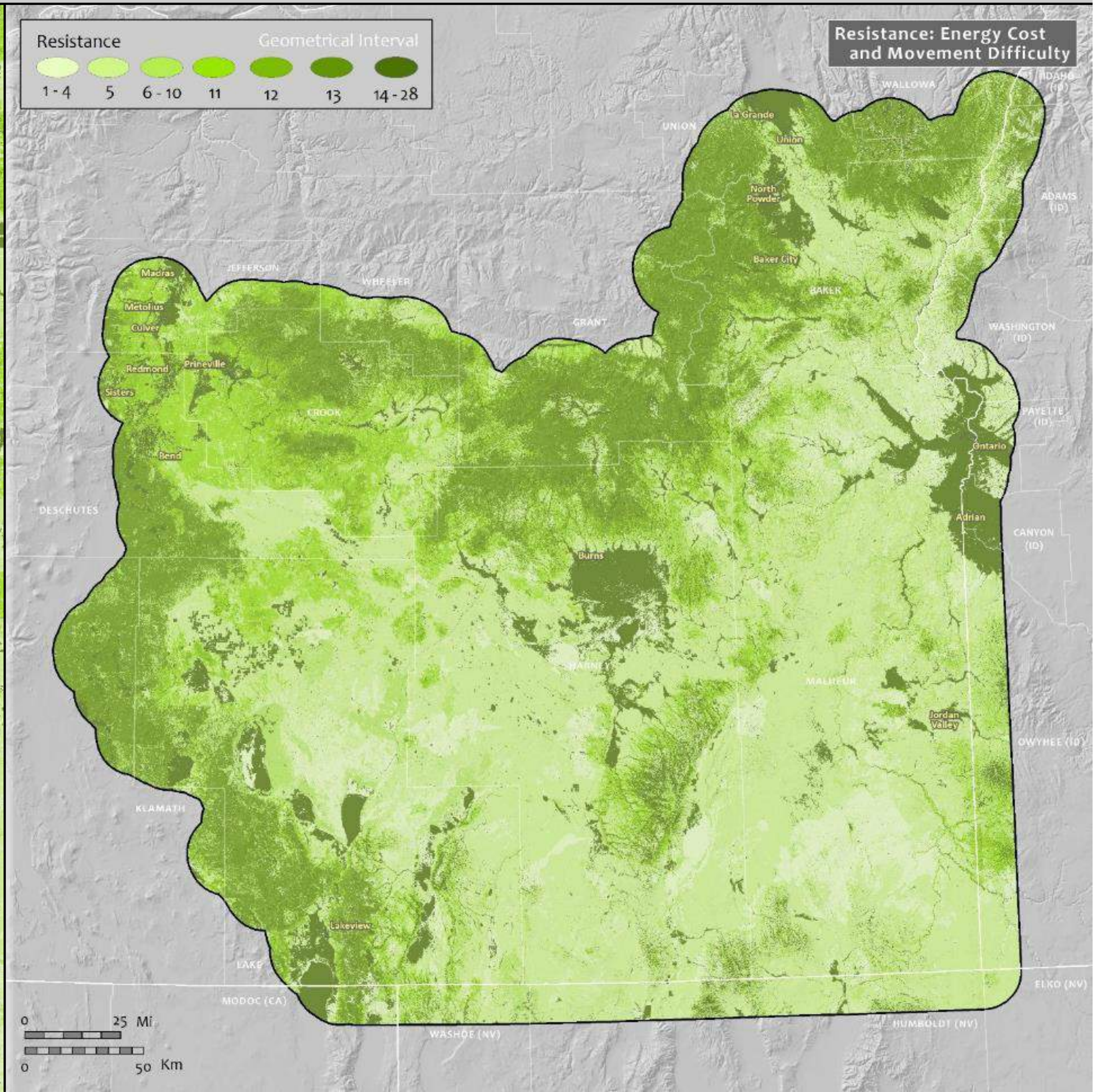
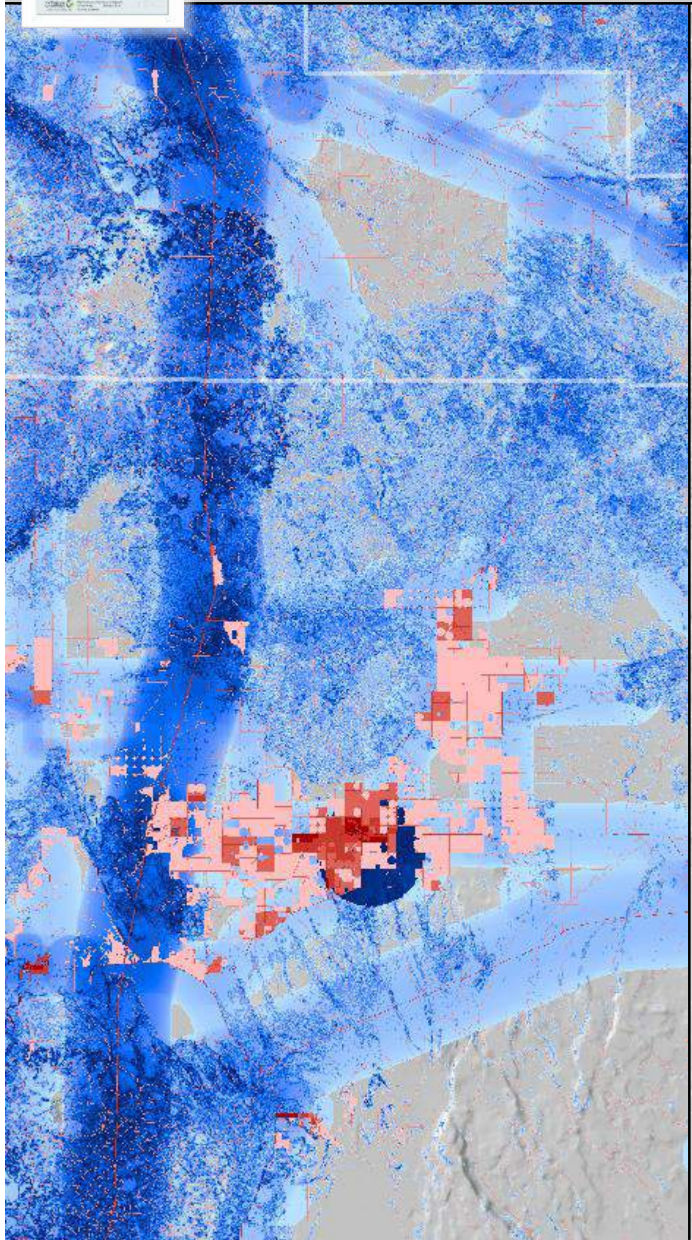
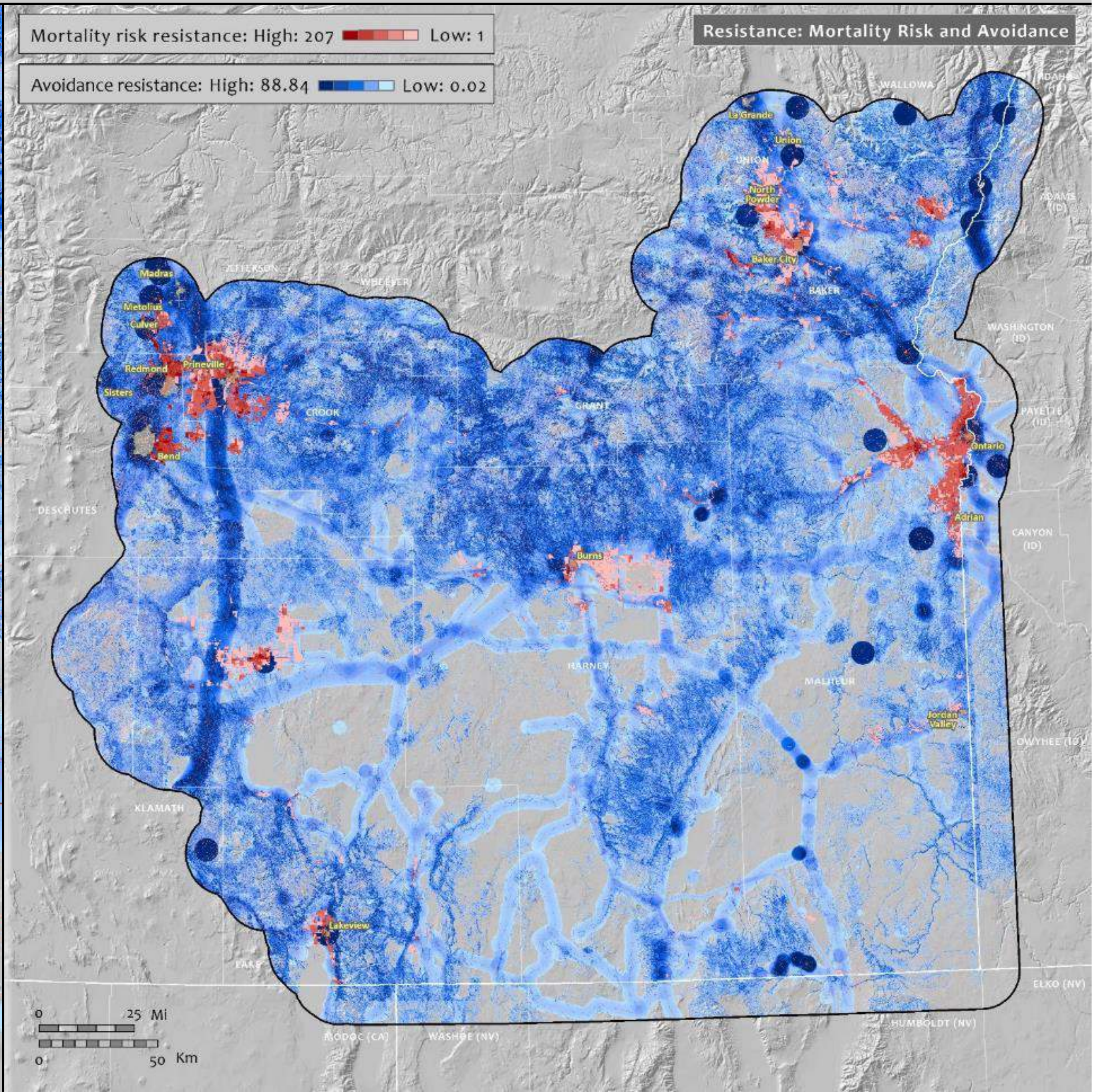


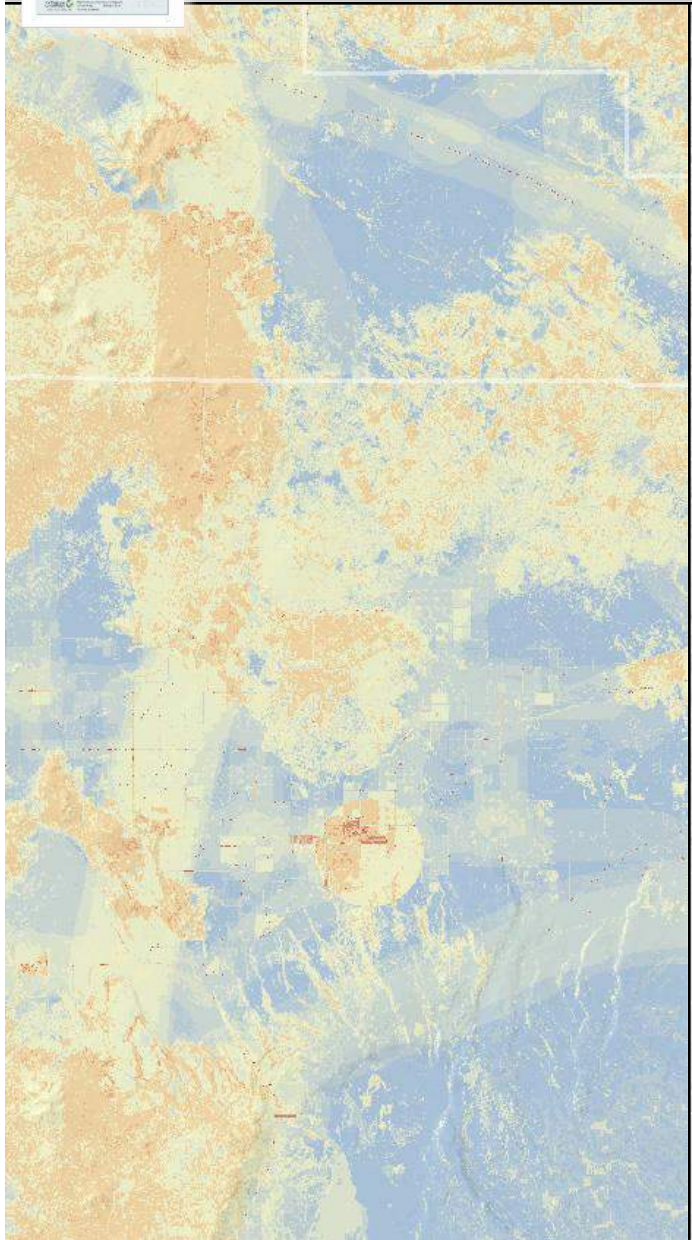


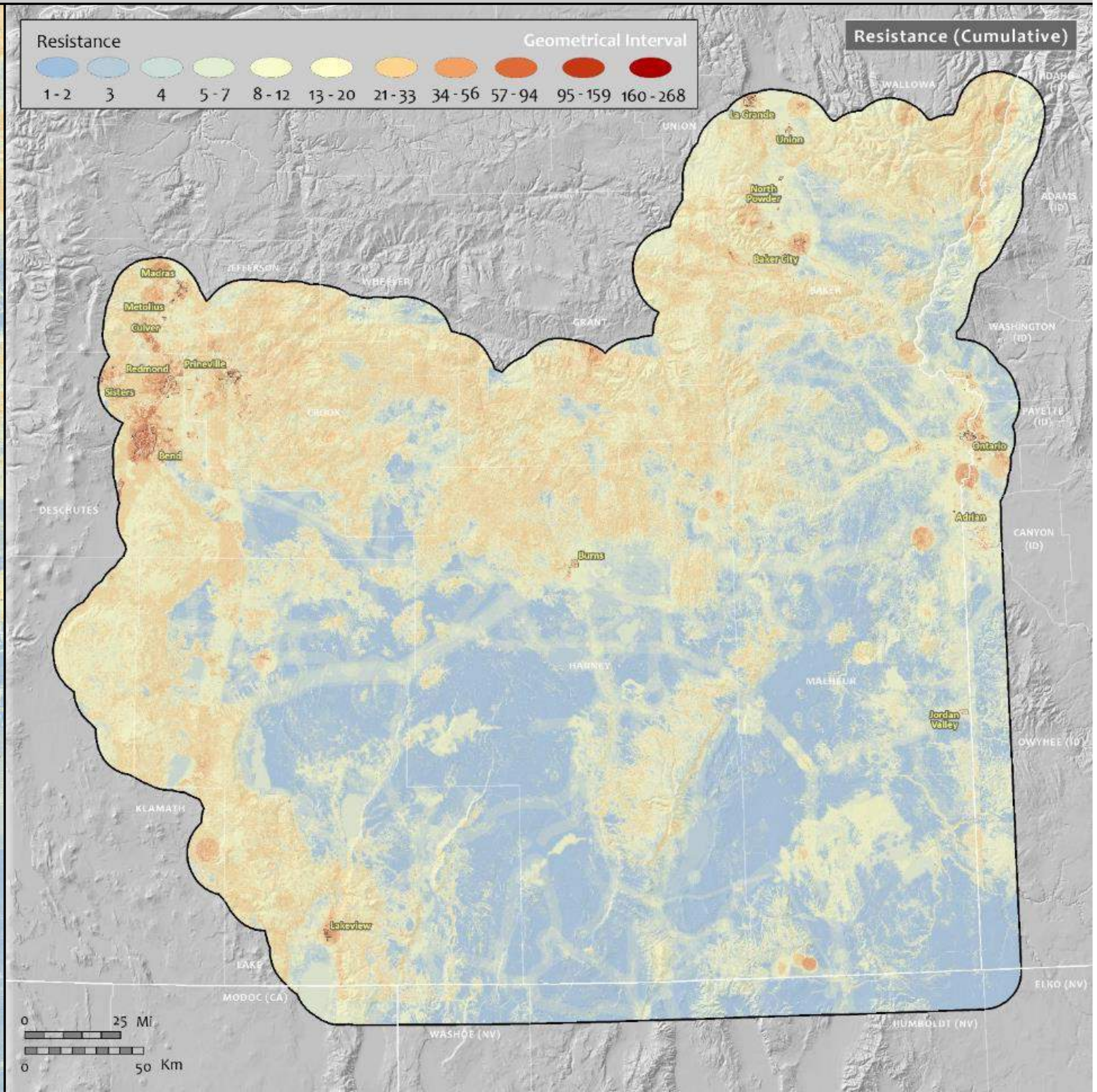
Resistance: Mortality and Risk Avoidance





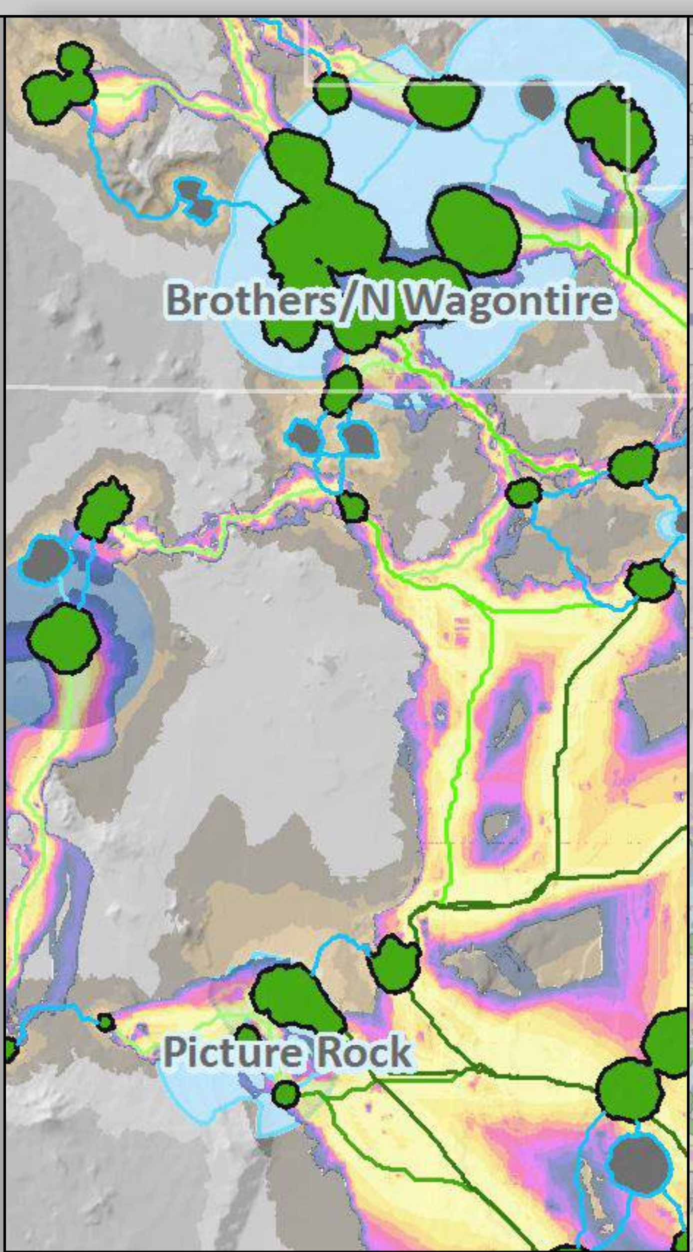
Resistance: Cumulative

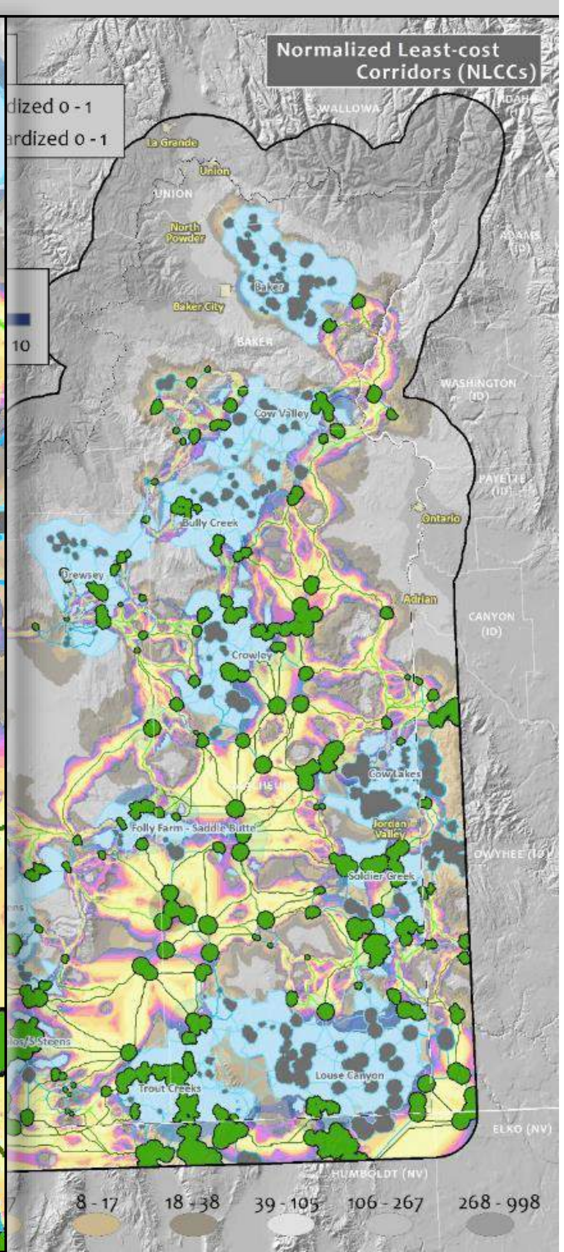




Normalized Least-cost Corridors (NLCCs)

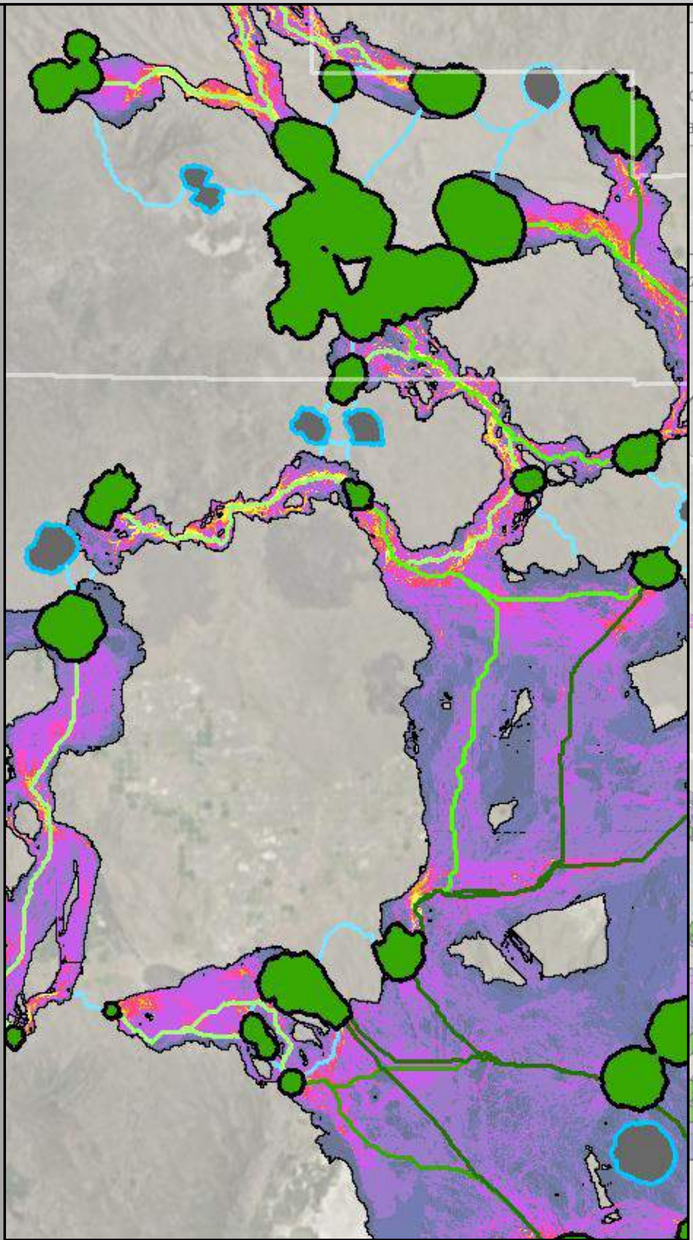
- ***NLCCs (Corridors) :*** *Each defined by cumulative movement costs relative to its respective LCP.*
- ***'Linkage zone':*** *Broad belts of land with relatively greater habitat continuity. (Here, NLCCs = linkage zones)*
- ***Framework for Circuitscape runs***

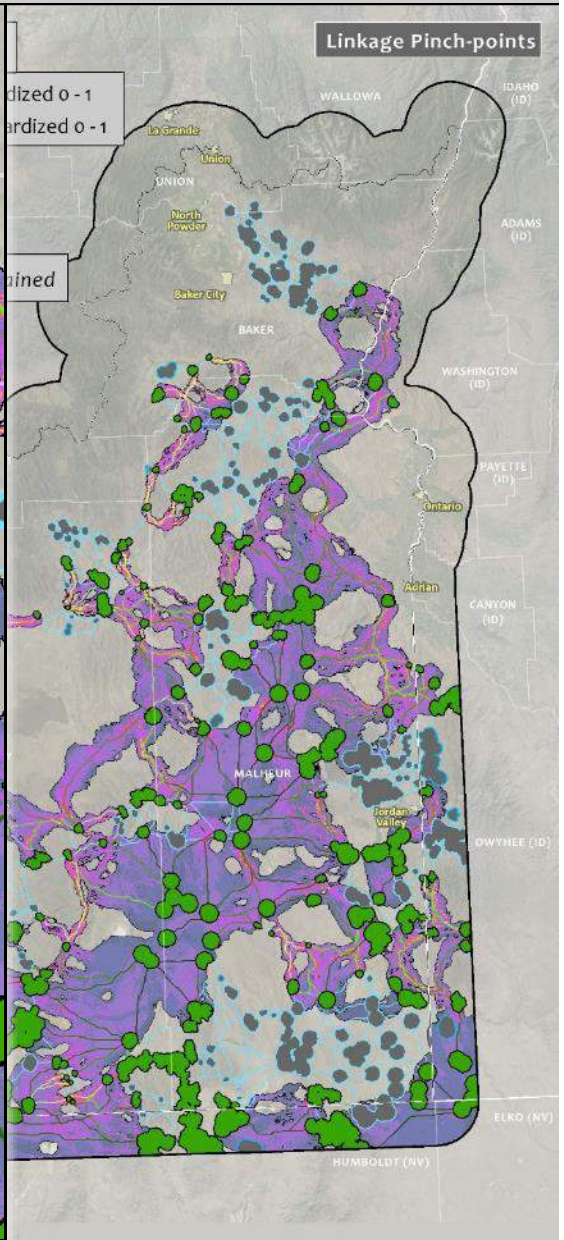


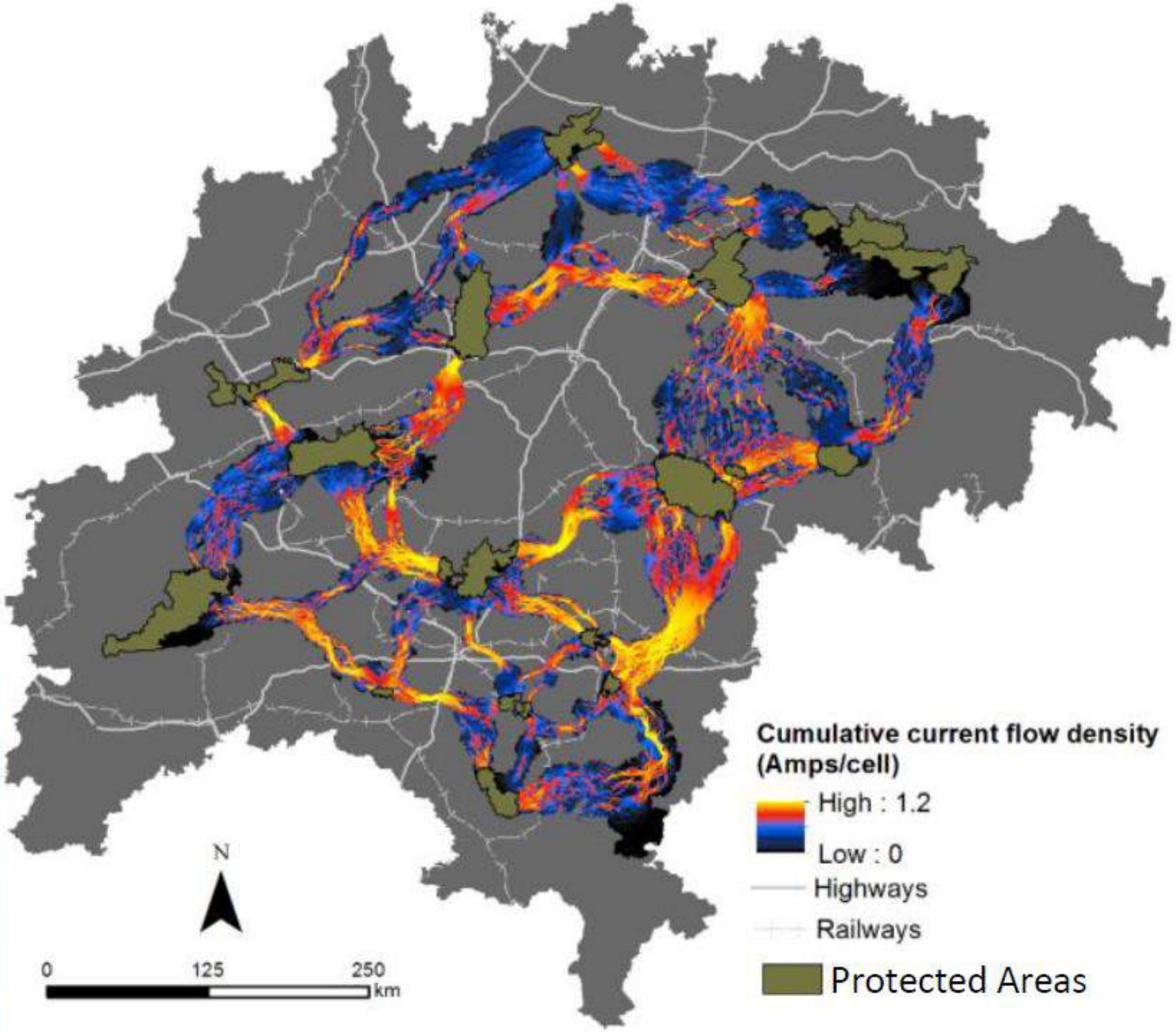


Circuitscape: Linkage Pinch-points / Protection Opportunities

- ***Pinch-points:***
  - *Locations of highly constricted (and thus strong) current flow*
  - *Network severance possible with loss of small amount of movement habitat*
  - *Potential areas for protection from habitat loss or degradation*







Dutta et al. (2015) combined Circuitscape with least-cost paths to map pinch points within corridors connecting protected areas for tigers in central India.

High current areas = priorities for protection

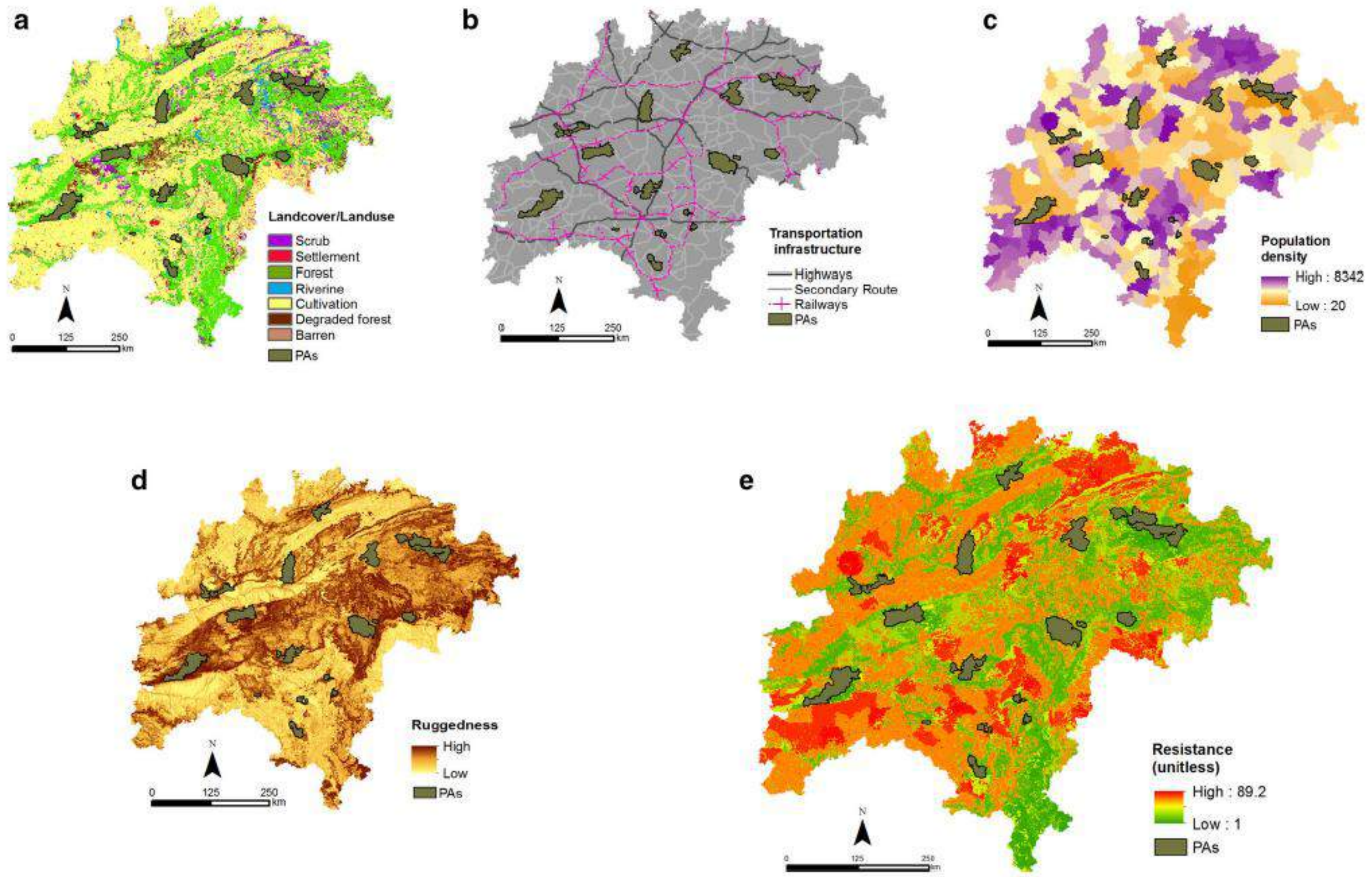
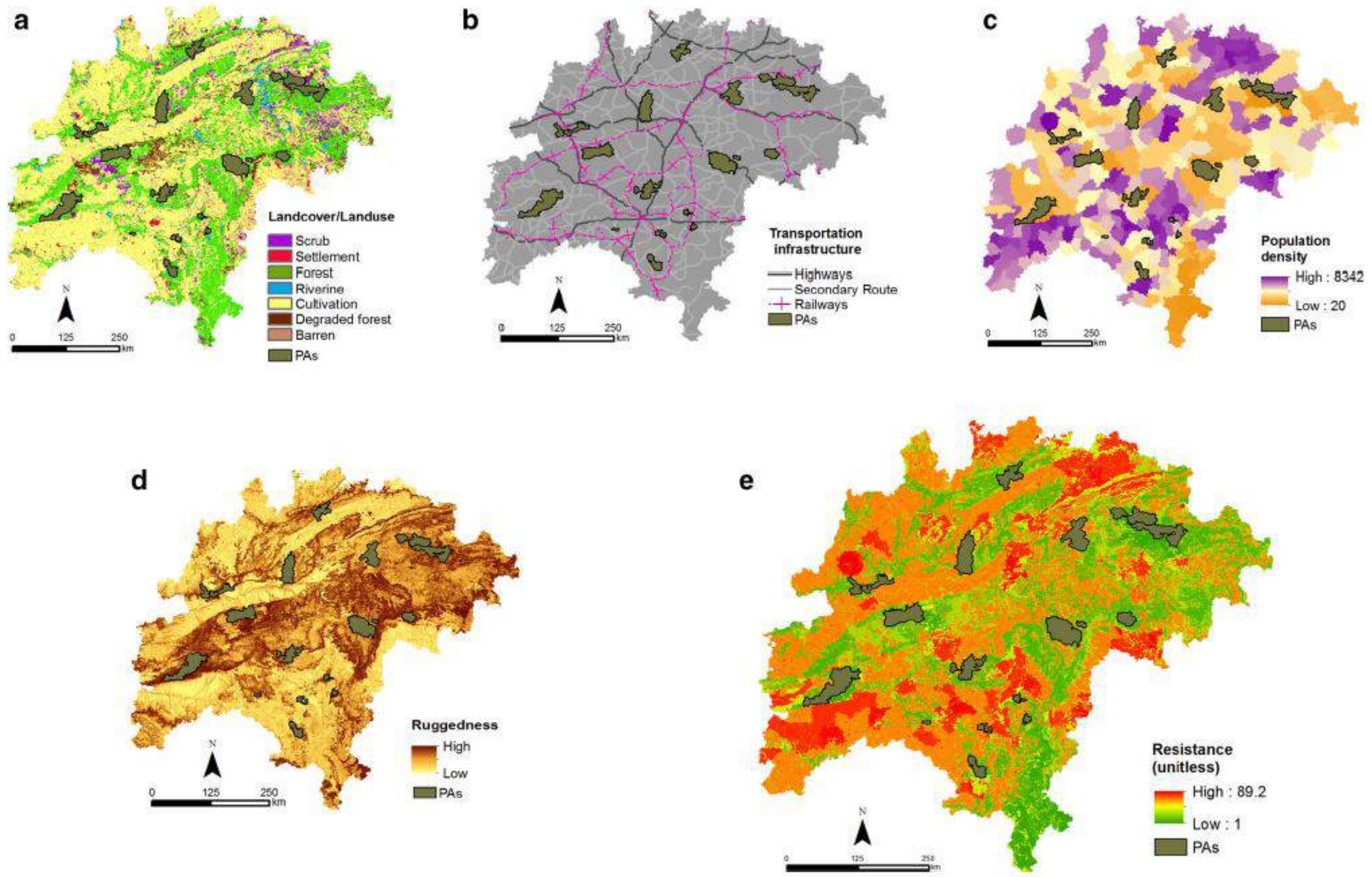


Fig. 2 Different data layers used to derive resistance map. Protected areas are shown in *green*. **a** landuse/landcover map, **b** major roads and railway lines, **c** population density, **d** surface ruggedness (not used in the model, but notice the high correspondence between ruggedness and forest cover), **e** combined resistance map (from the weighted scheme) (color figure online)

Table 2 Resistance values used for this study

Layer (weight)	Category	Resistance score
LULC (0.44)	Forest	0
	Degraded	2
	Scrub	2
	Barren	6
	Water	6
	Agriculture	49
	Settlement	100
Road (0.13)	Absent	0
	Other Roads	50
	Highways	100
Population density (0.33)	Absent	0
	Low	30
	Mod	60
	High	100
Railway (0.09)	Absent	0
	Present	100

Resistance values were derived, rescaled, and standardized from published sources (Wikramanayake et al. 2004; Areendran et al. 2012; Rathore et al. 2012). After calculating resistances, we added 1 to account for Euclidean distance



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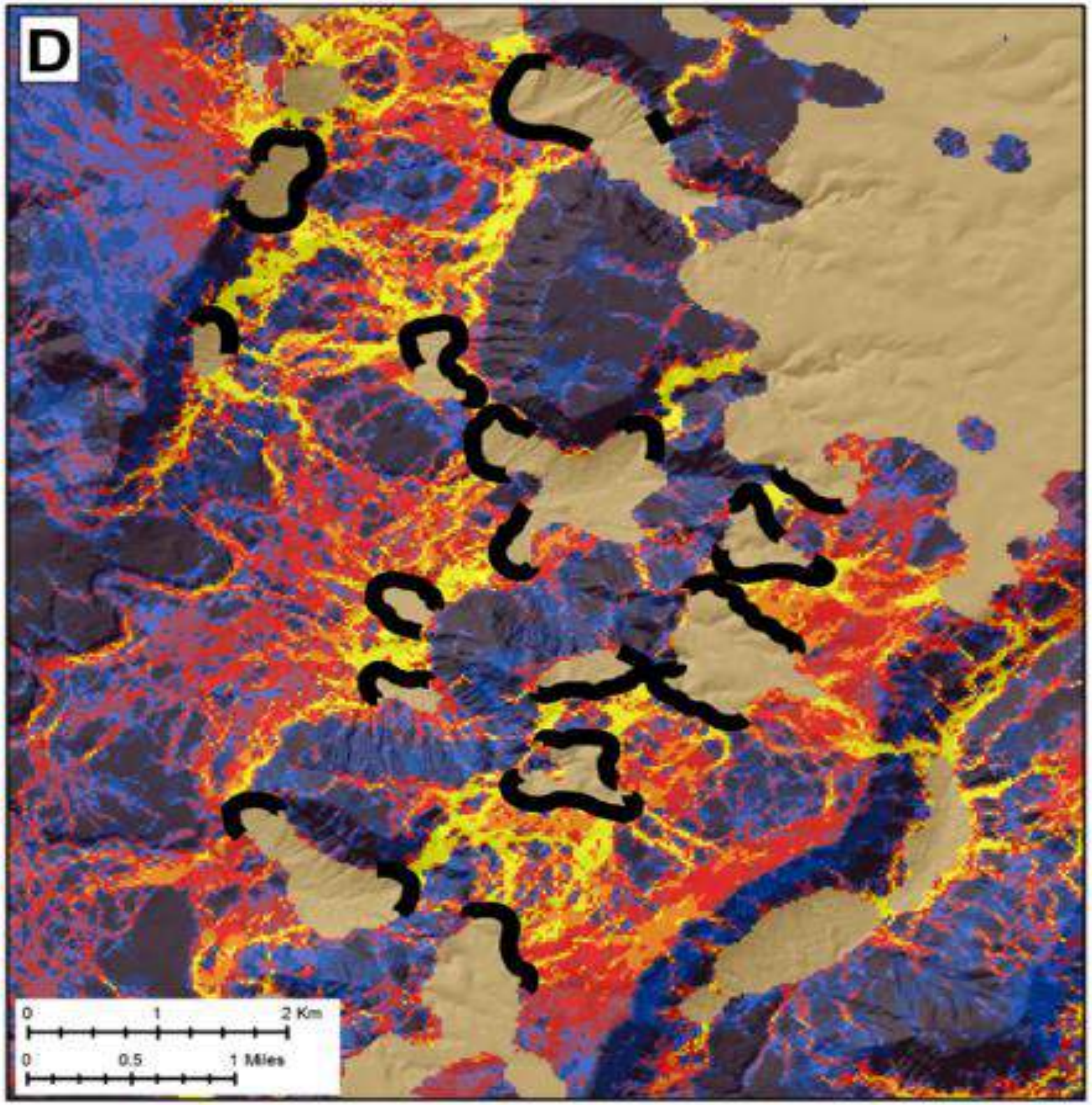
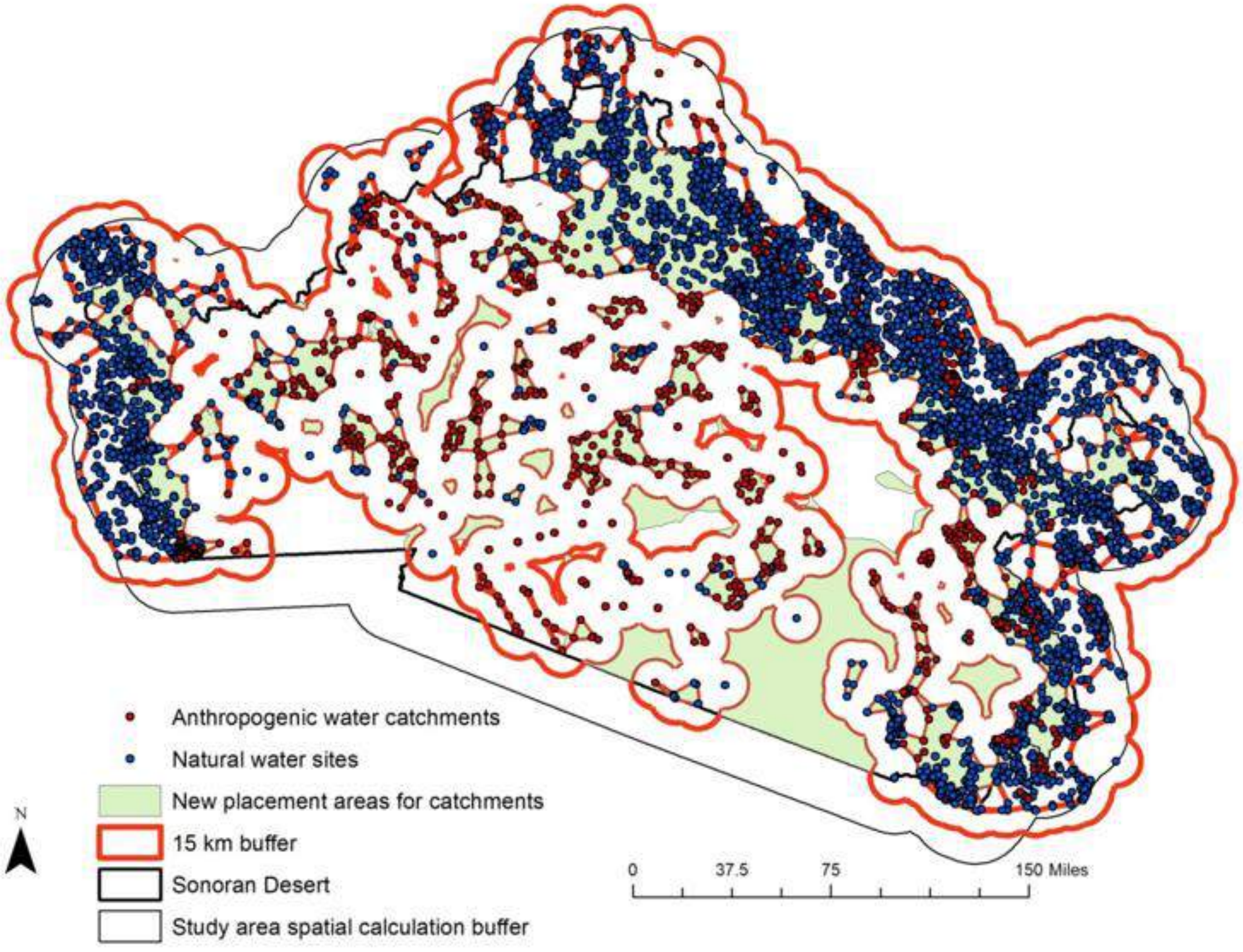
Constraint – had to coarsen habitat data from 24 to 72 m



Gray & Dickson (2016) mapped fire connectivity on a cheatgrass- invaded landscape in northern Arizona (68 patches – “all to all” runs)

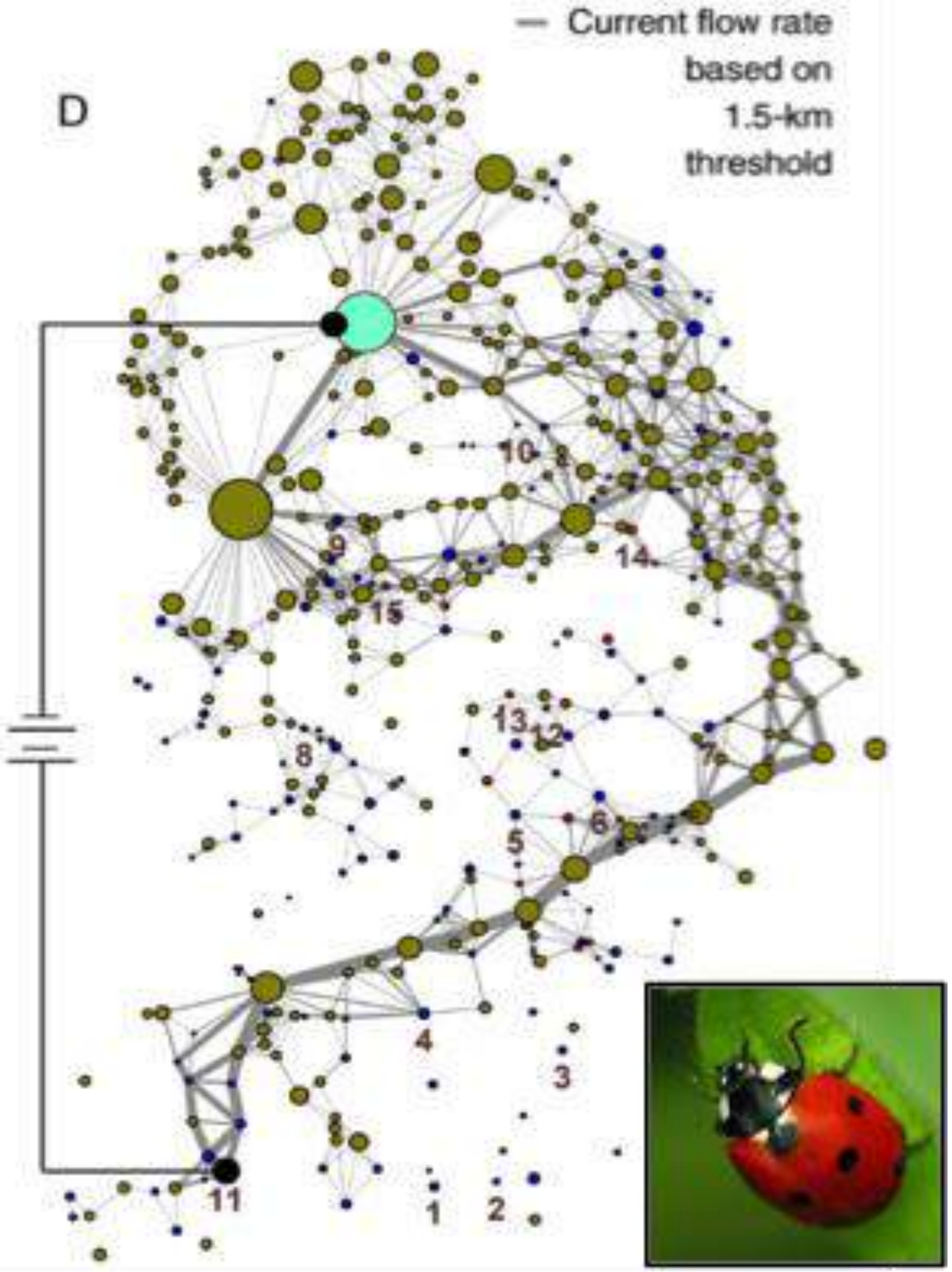
Yellow areas are connectivity pinch points that can be targeted for placement of fuel breaks.

NDVI from spring Landsat imagery was used to identify cheatgrass (tan).



Drake et al. (2015) combined Circuitscape with least-cost paths to evaluate how to site new artificial water sources for mule deer (economically important) in the Sonoran Desert in places **that would not promote spread of invasive bullfrogs** under current & future climate scenarios.

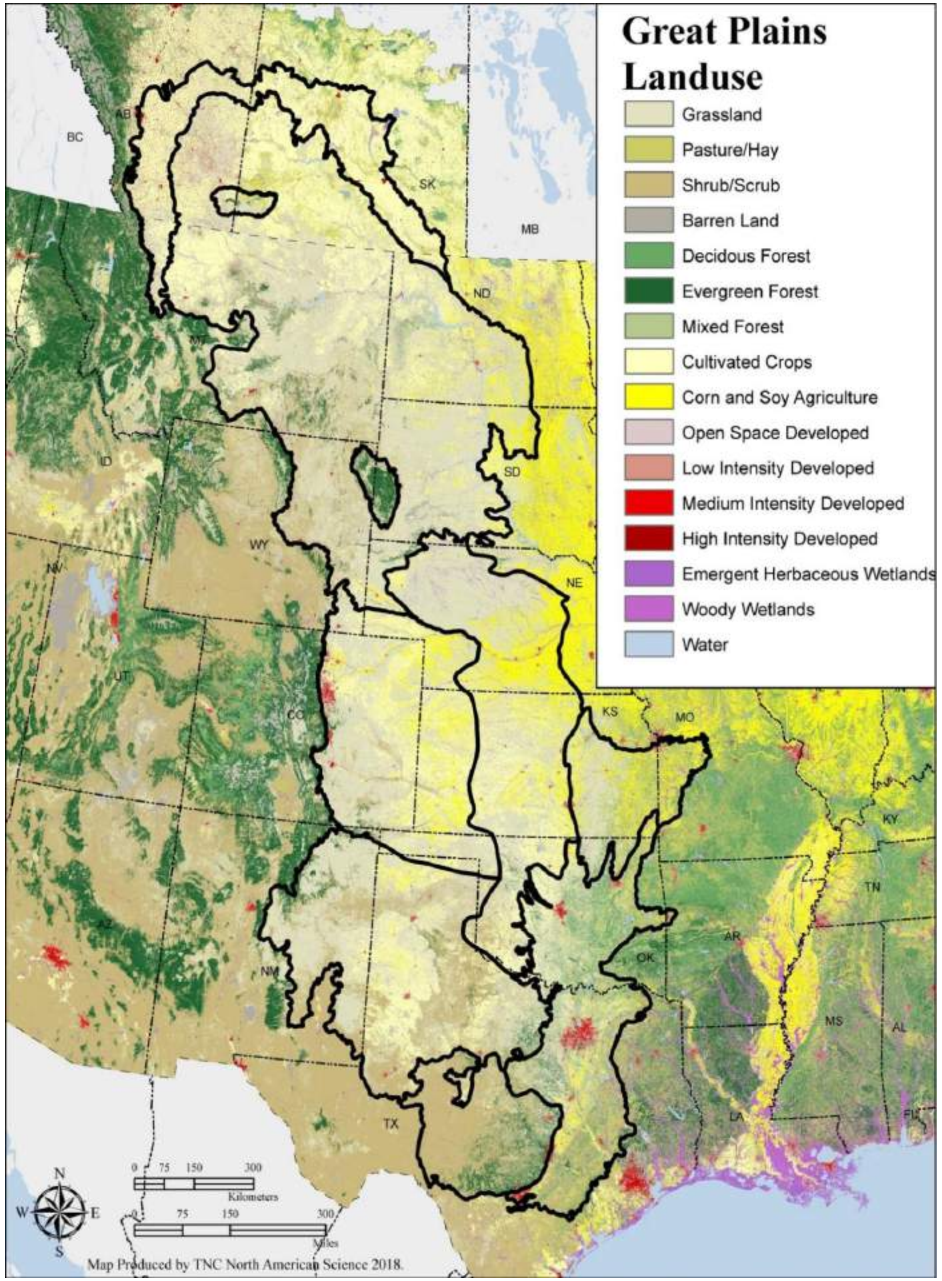
Runs required 4-8 weeks on a *Janus* supercomputer at Texas Tech; coarsened data to improve speed

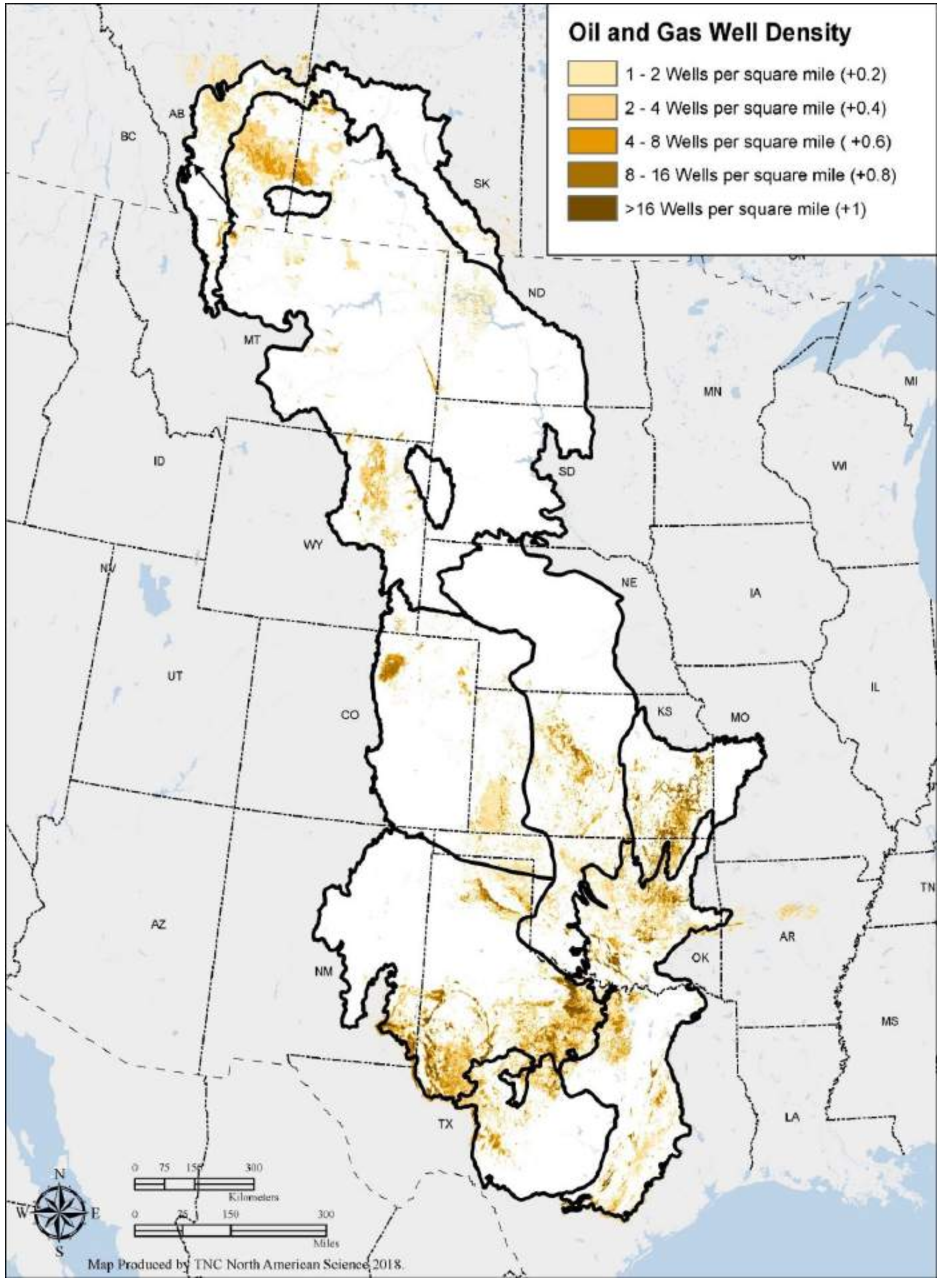


Ecosystem services: Biocontrol

Koh et al. 2013 predicted the abundance of native insects that predate on agricultural pests in northwestern Indiana using graph & circuit-theory metrics.

Native tallgrass prairie, restored prairie, and semi-natural areas are the nodes – they were found to facilitate the movement of native predators.

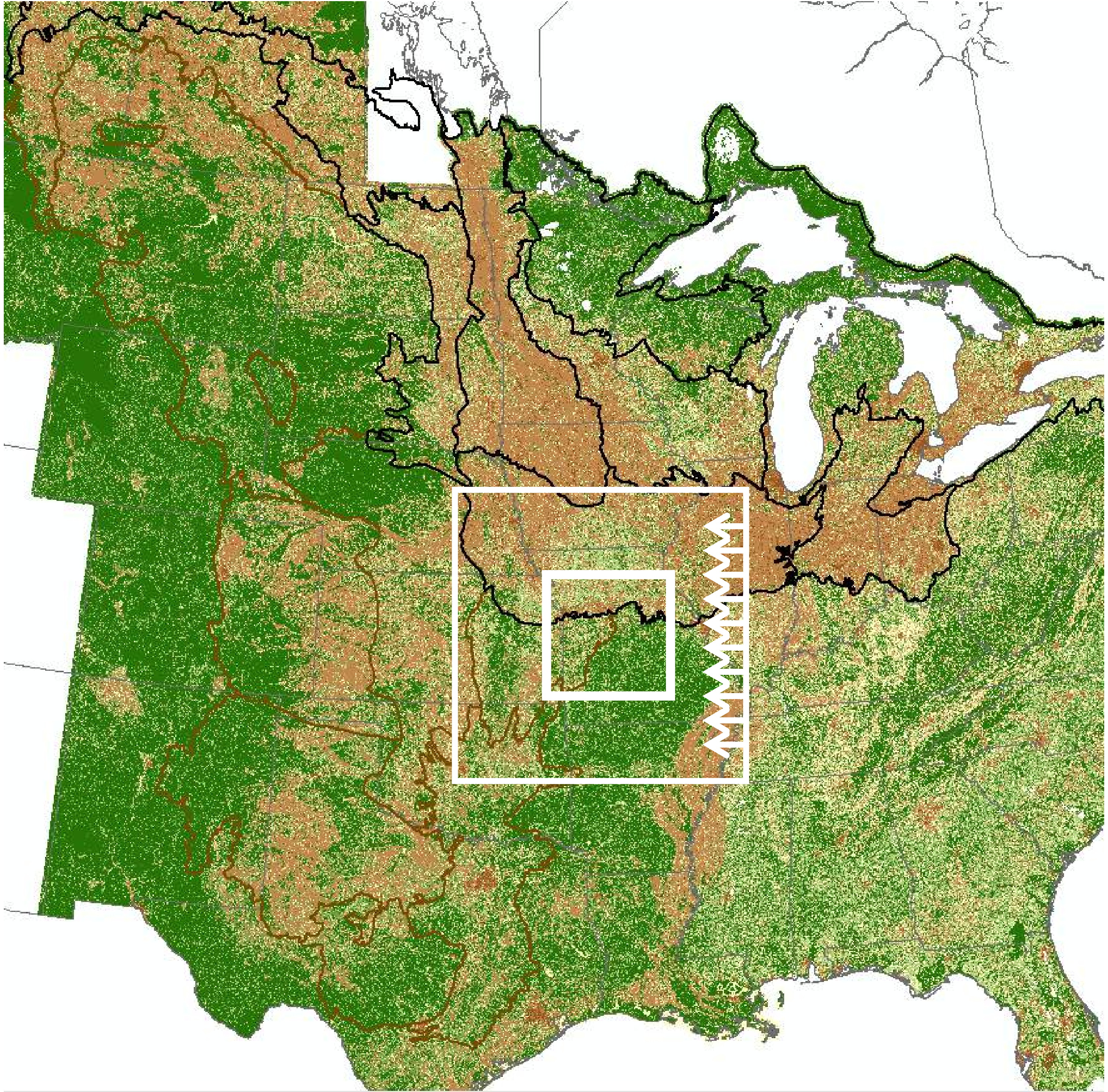




Inputs to resistance grid for landscape structural connectivity

Roads, railroads
Wind turbines
Large water bodies....

Many tiers of scoring



Wall to Wall Circuitscape

Break the area into square tiles that incorporate a 50% buffer

Run Circuitscape from “wall to wall”

Change direction – do all four

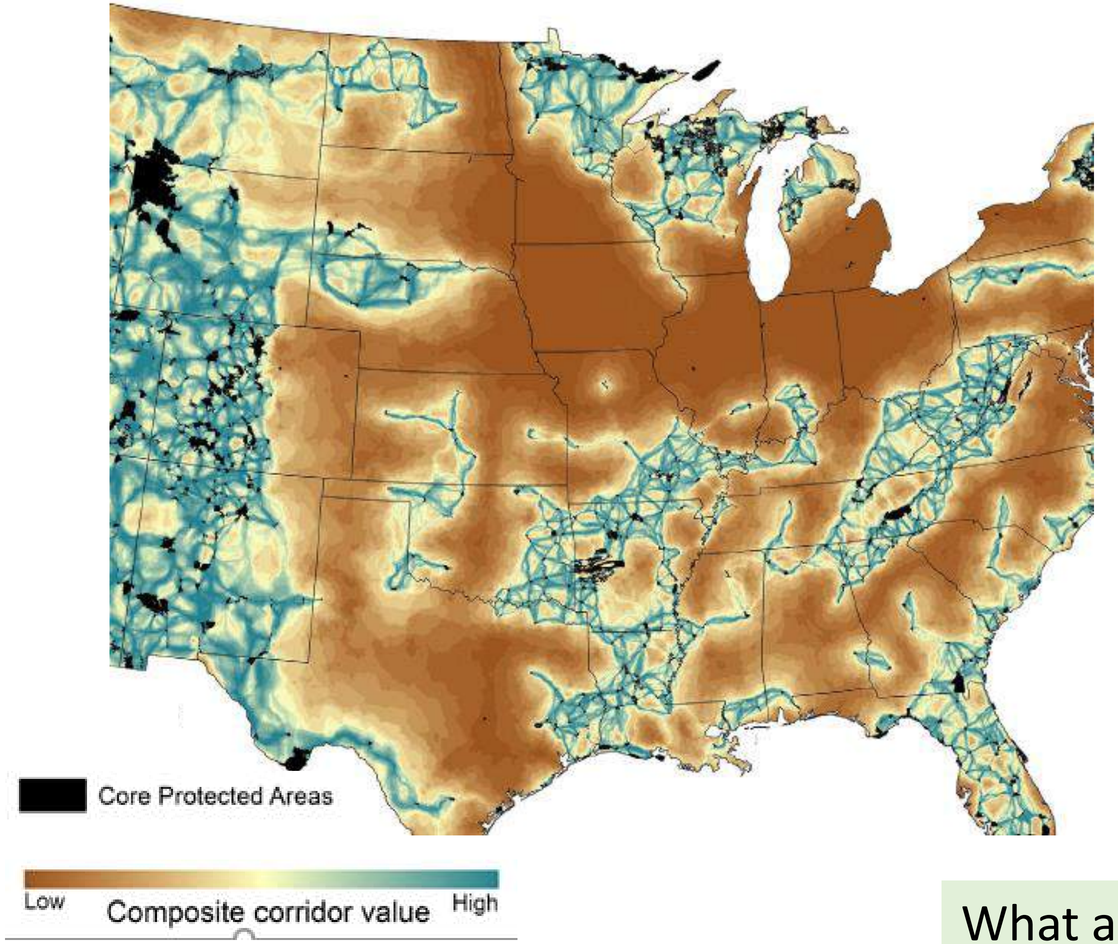
Sum results

Do next tile

Re-assemble and edge match

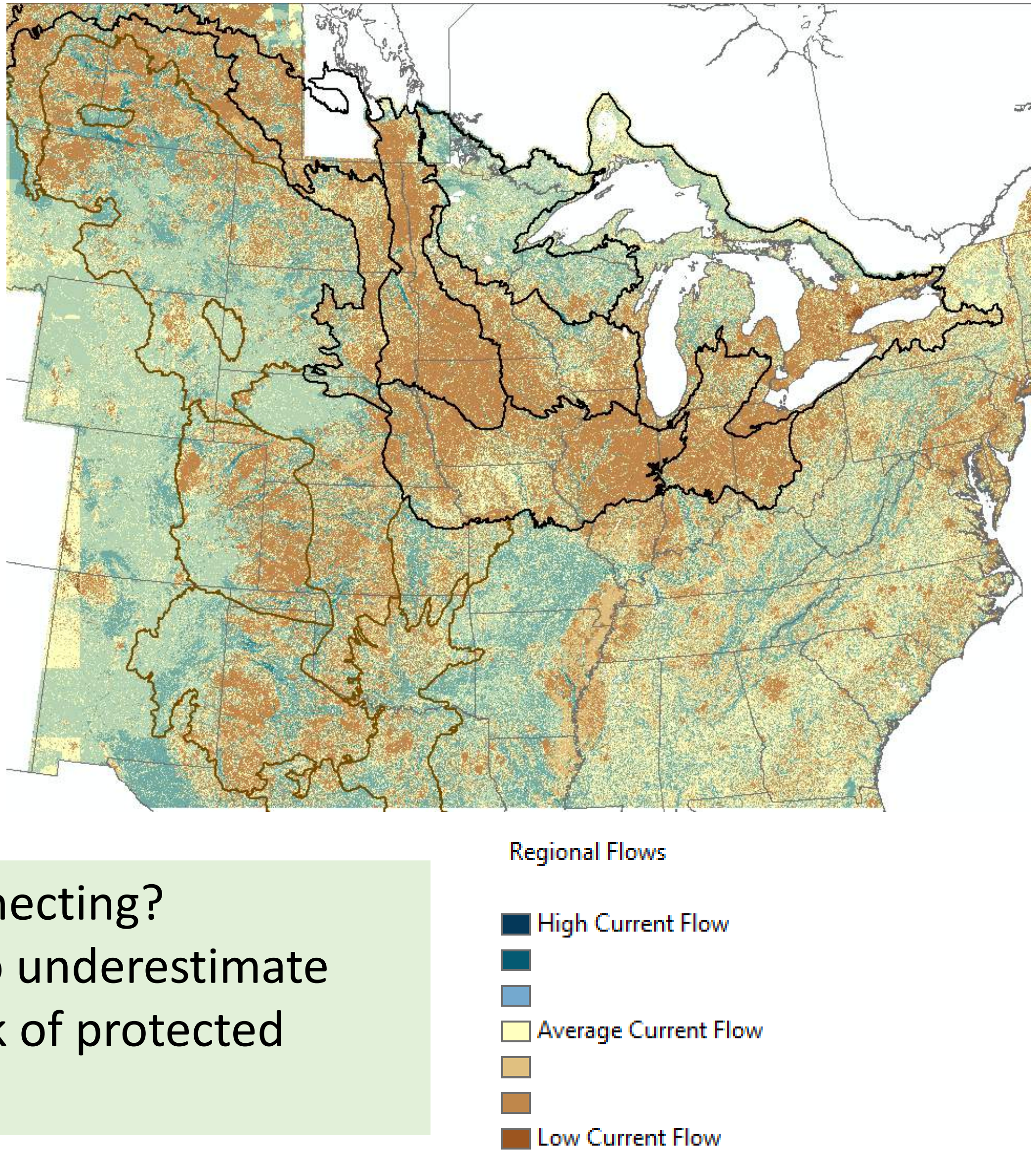
How are these maps different from corridors/least cost path?

Connecting discrete patches

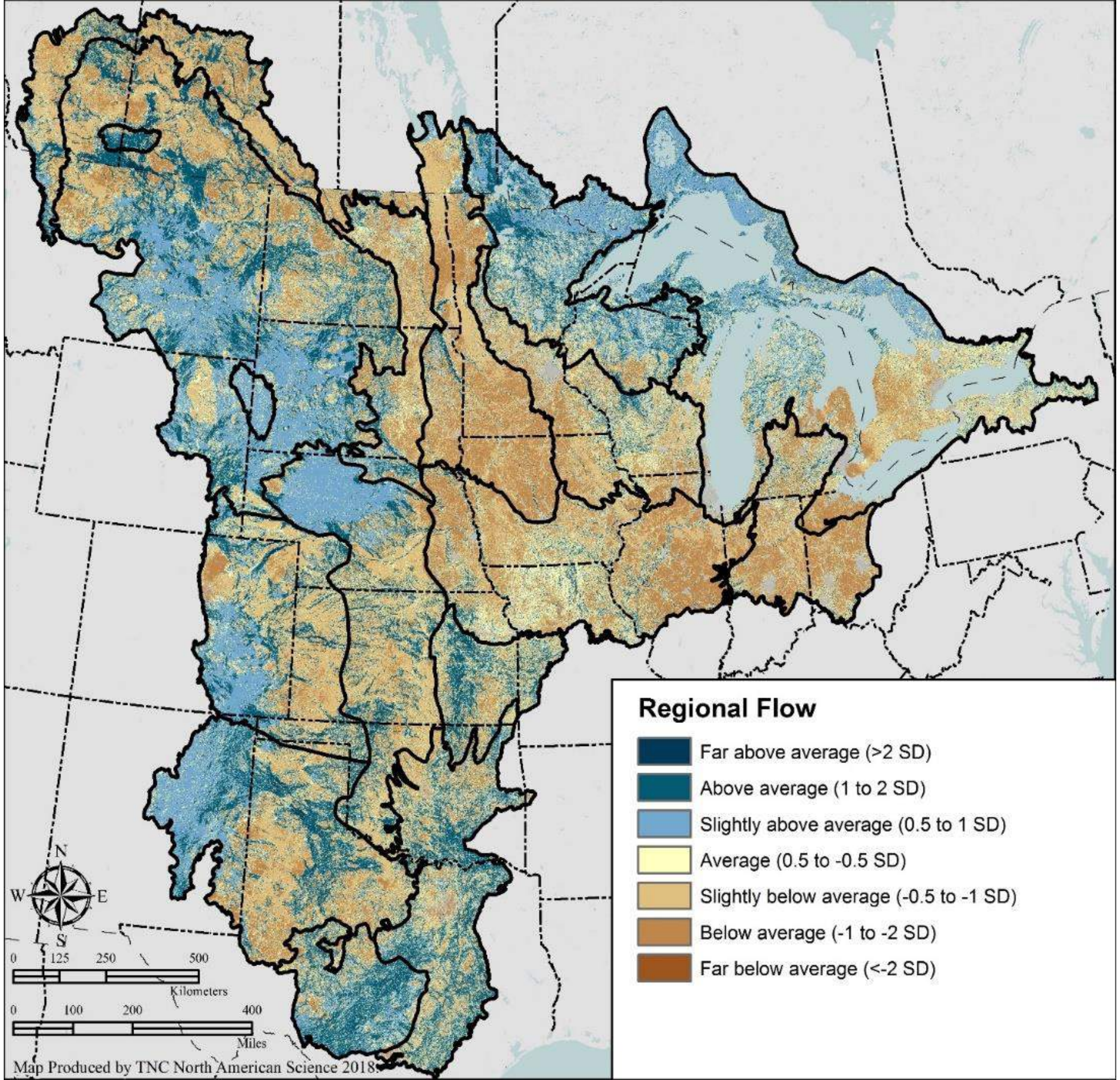


Identifying Corridors among Large Protected Areas in the United States
Belote et al. 2016. Plos1

Continuous flow (wall to wall)

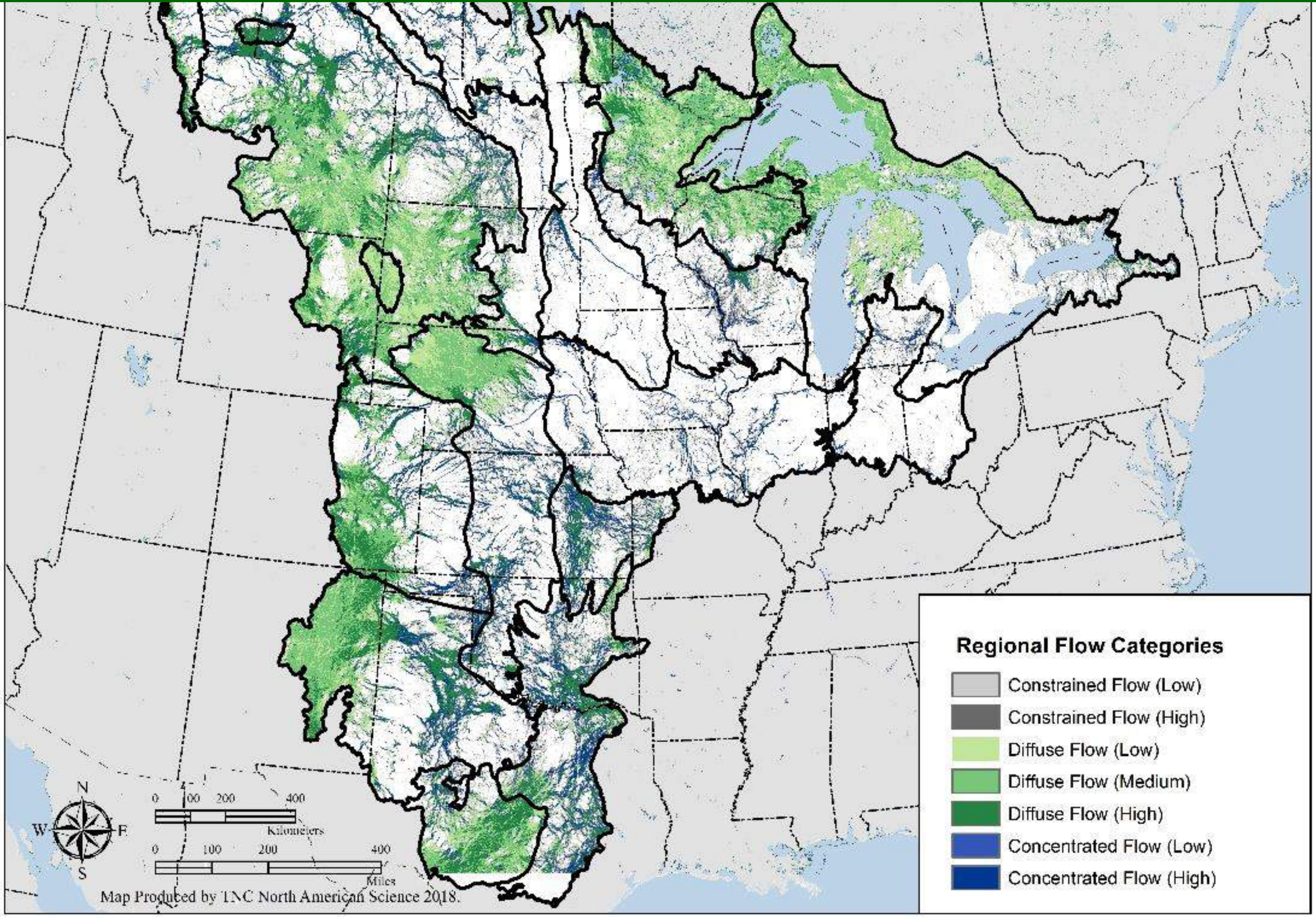


What are you connecting?
In this case easy to underestimate "value" due to lack of protected areas to connect



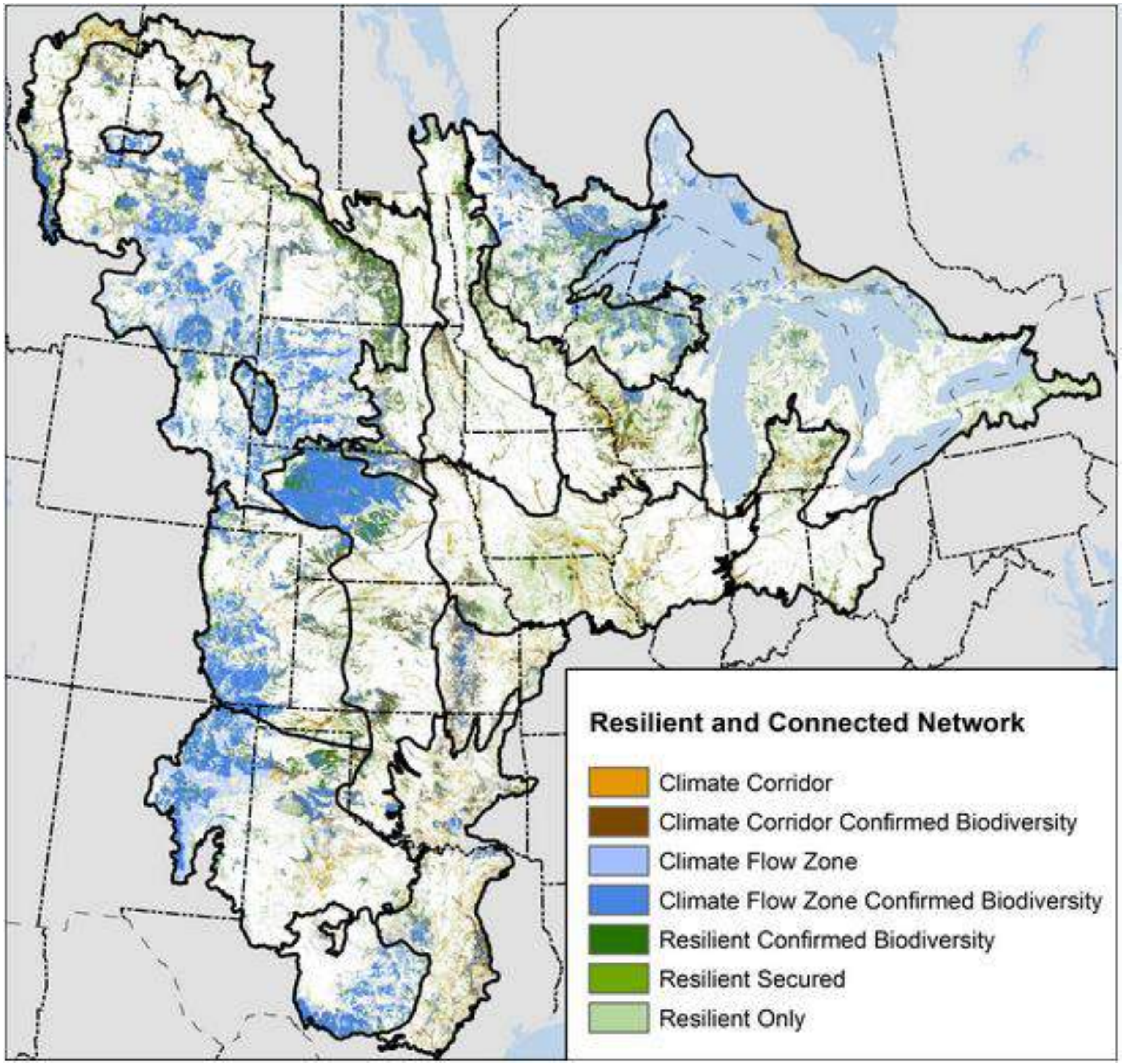
Regional Flow
Far above average (>2 SD)
Above average (1 to 2 SD)
Slightly above average (0.5 to 1 SD)
Average (0.5 to -0.5 SD)
Slightly below average (-0.5 to -1 SD)
Below average (-1 to -2 SD)
Far below average (<-2 SD)
N
W
E
S
0 125 250 500
Kilometers
0 100 200 400
Miles
Map Produced by TNC North American Science 2018

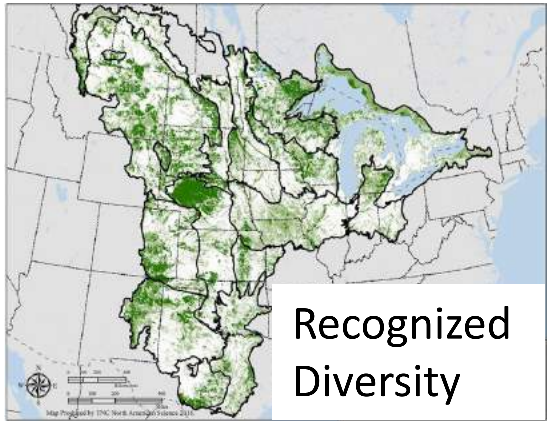
Climate Flow Maps: Translating "current" to categories

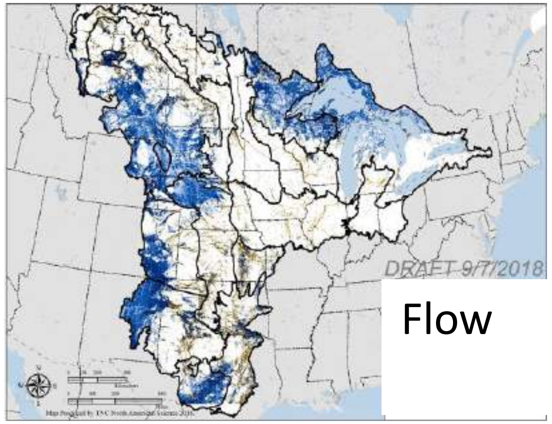


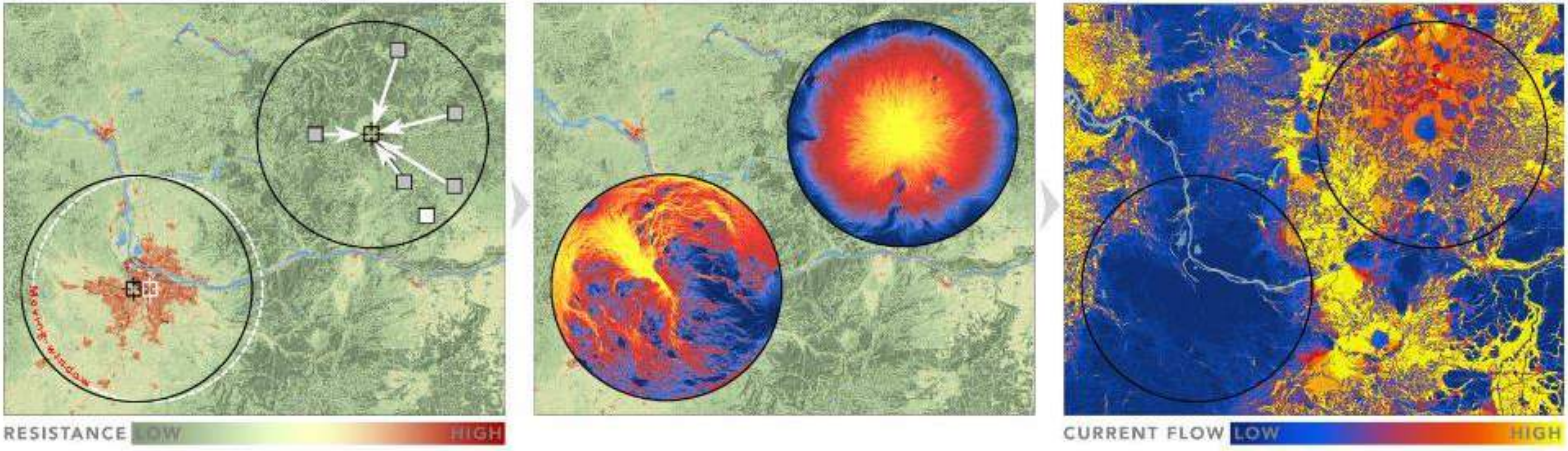
Resilient and Connected Landscapes – a resource for conservation planning

The network covers 23% of the region (shown here) and 75% of the resilient sites.









Omniscape – moving window version Circutscape (pixel by pixel), which allows source strength surfaces as well as resistance surfaces.

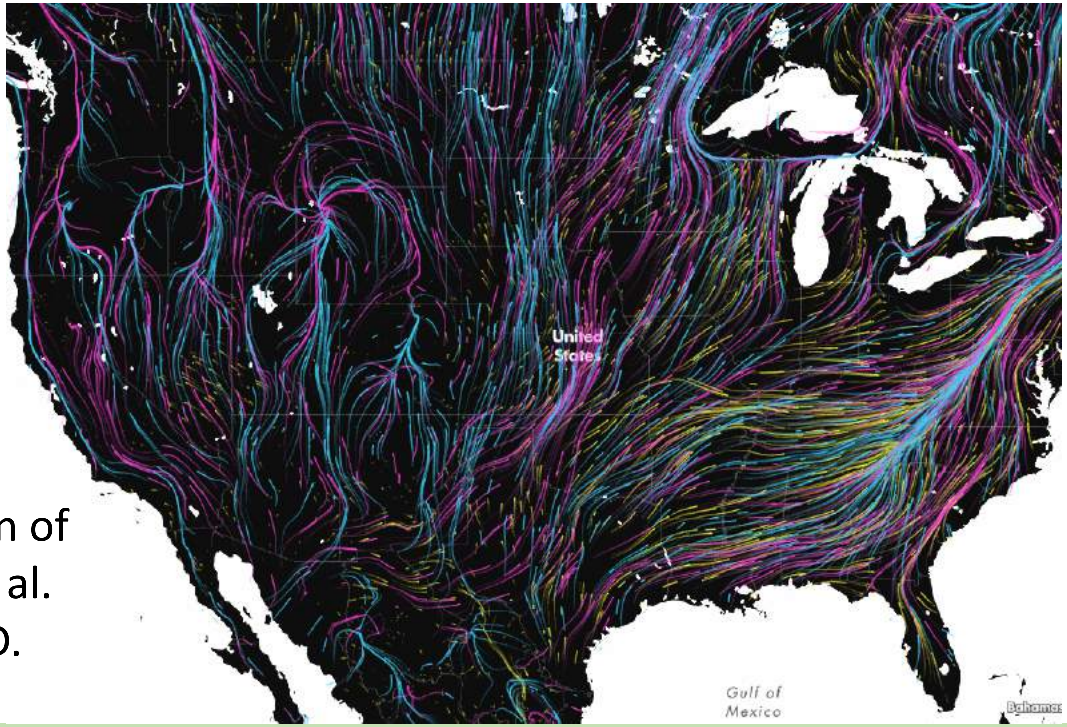
McRae et al. 2016, cartography by Aaron Jones

Brad McRae & Charlie

Credit: T. N. McRae

New ideas for functions, inputs & collaborations?

- Forest structure
- Phenology
- AI applications with Azure (credits to share!)



Animation of Lawler et al. 2015 by D. Majka

Brad McRae Fellowship for Innovation in Conservation Fund

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Connect to part 2 --- Ranjan’s slides