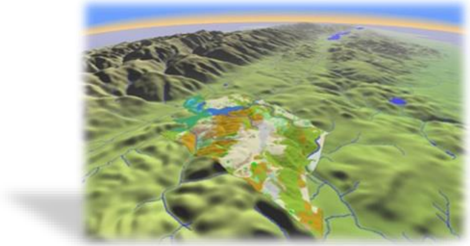
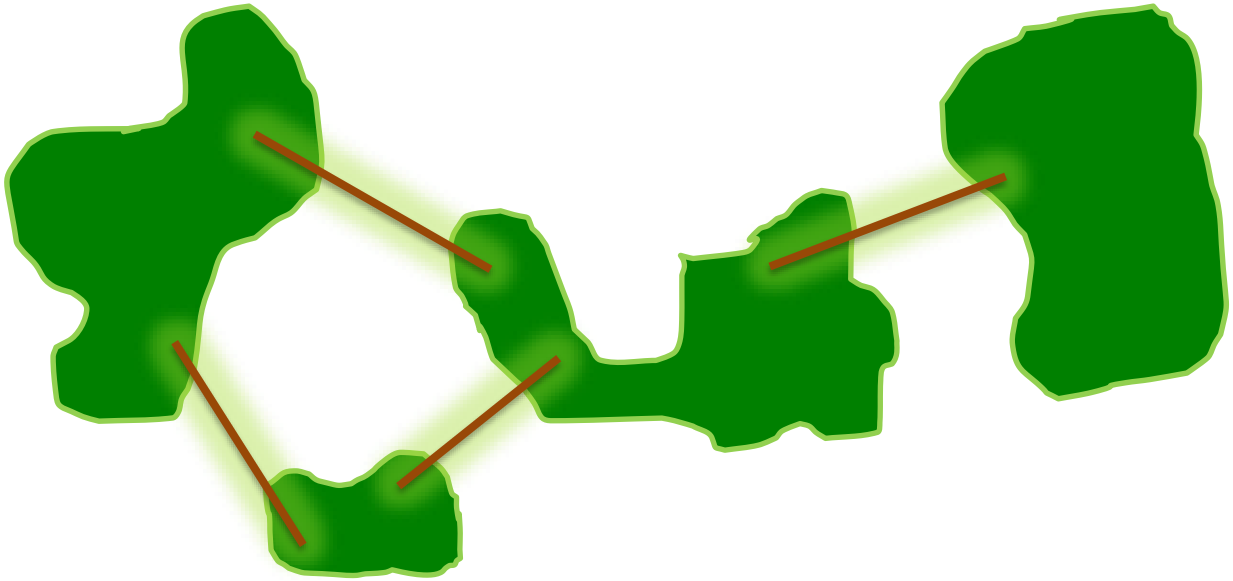
NICHOLAS SCHOOL OF THE
ENVIRONMENT AND EARTH SCIENCES
DUKE UNIVERSITY



ENVIRON 761: Connectivity

Instructor: John Fay

What is connectivity?



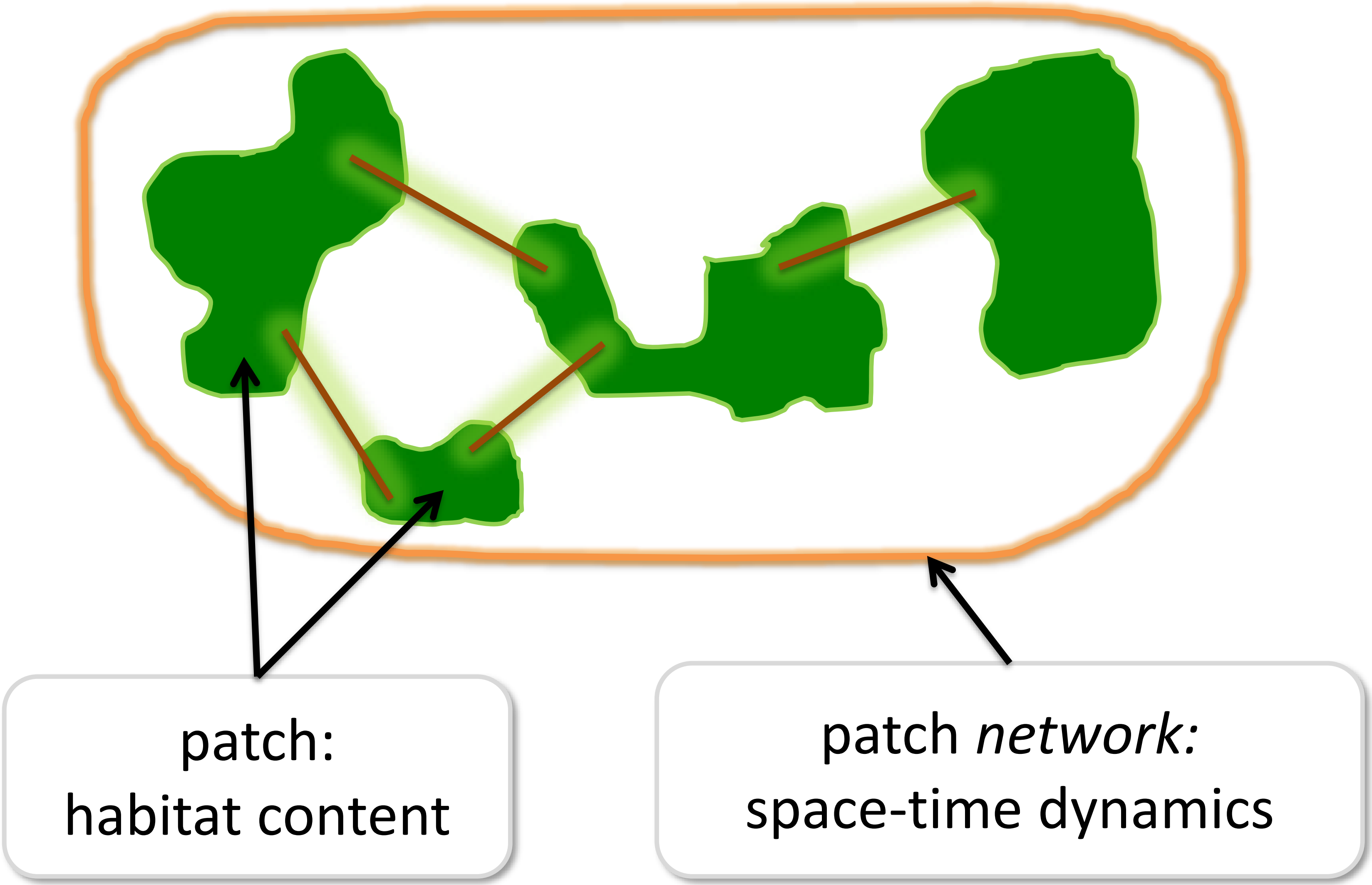
It's the linking of two or more areas so that individual critters can successfully move among these areas

It's the opposite of fragmentation

Connectivity

- We have been talking about connectivity for a few decades
- It remains surprisingly hard to quantify
- Its importance remains as much a working hypothesis as established truth
- Here we will:
  - explore new methods for measuring connectivity
  - discuss ways to verify its importance

Why look at connectivity?



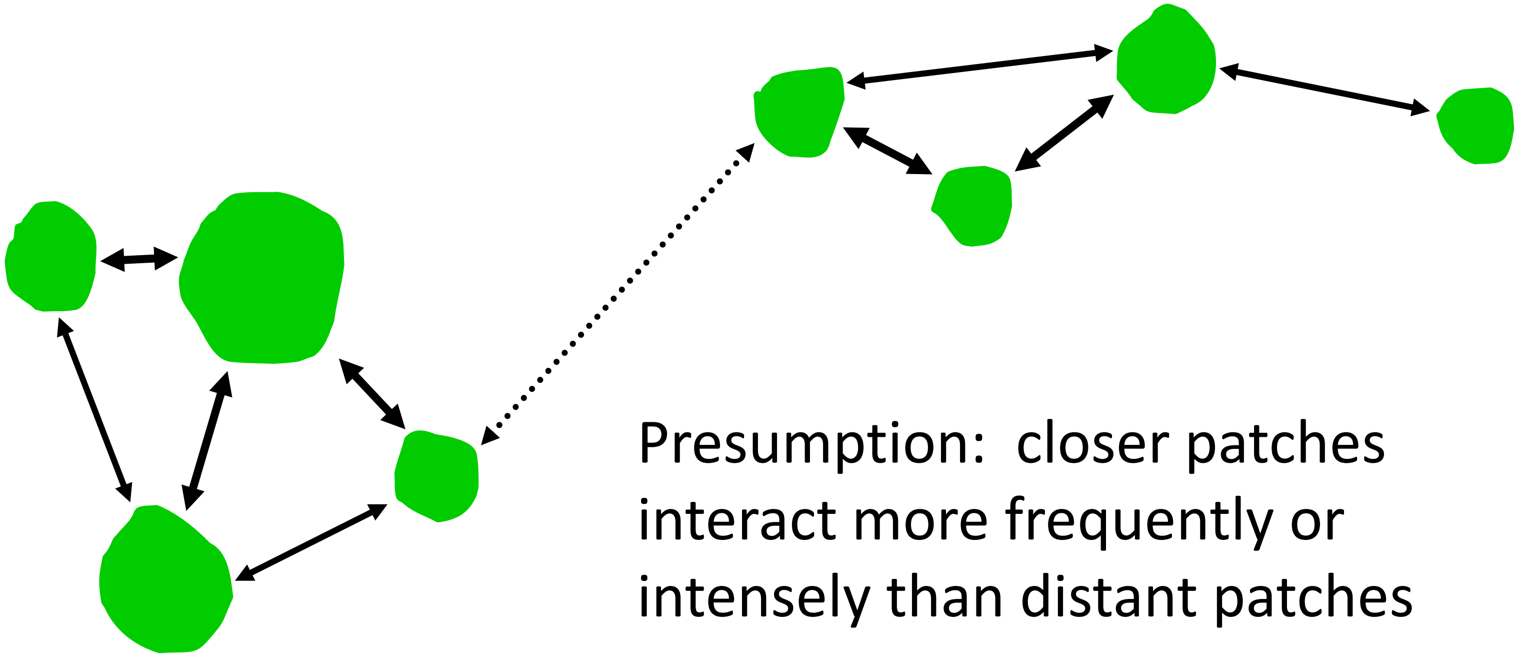
patch:
habitat content

patch *network:*
space-time dynamics

Noss and Harris 1986

Connectivity & metapopulations

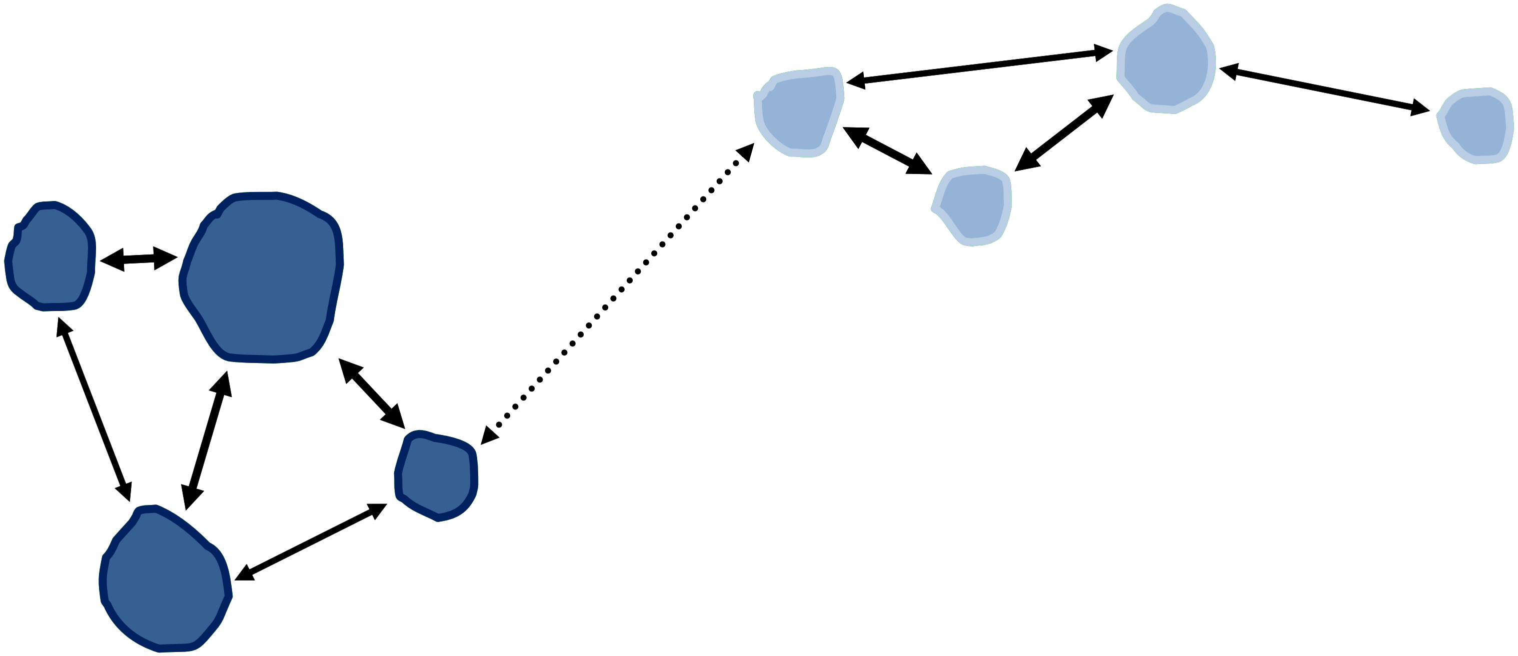
Metapopulation → population of populations



Presumption: closer patches interact more frequently or intensely than distant patches

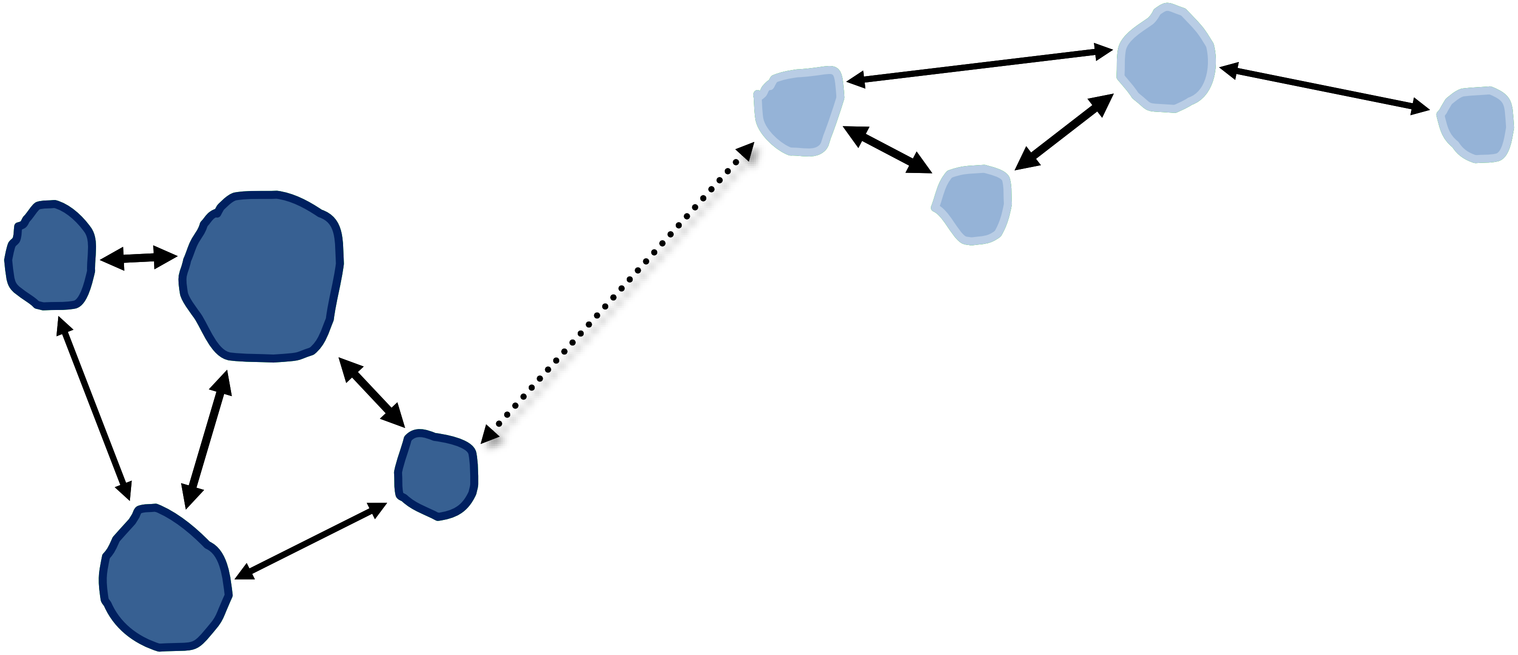
Metapopulations & scale

- Local scale — individuals interact with each other during normal living



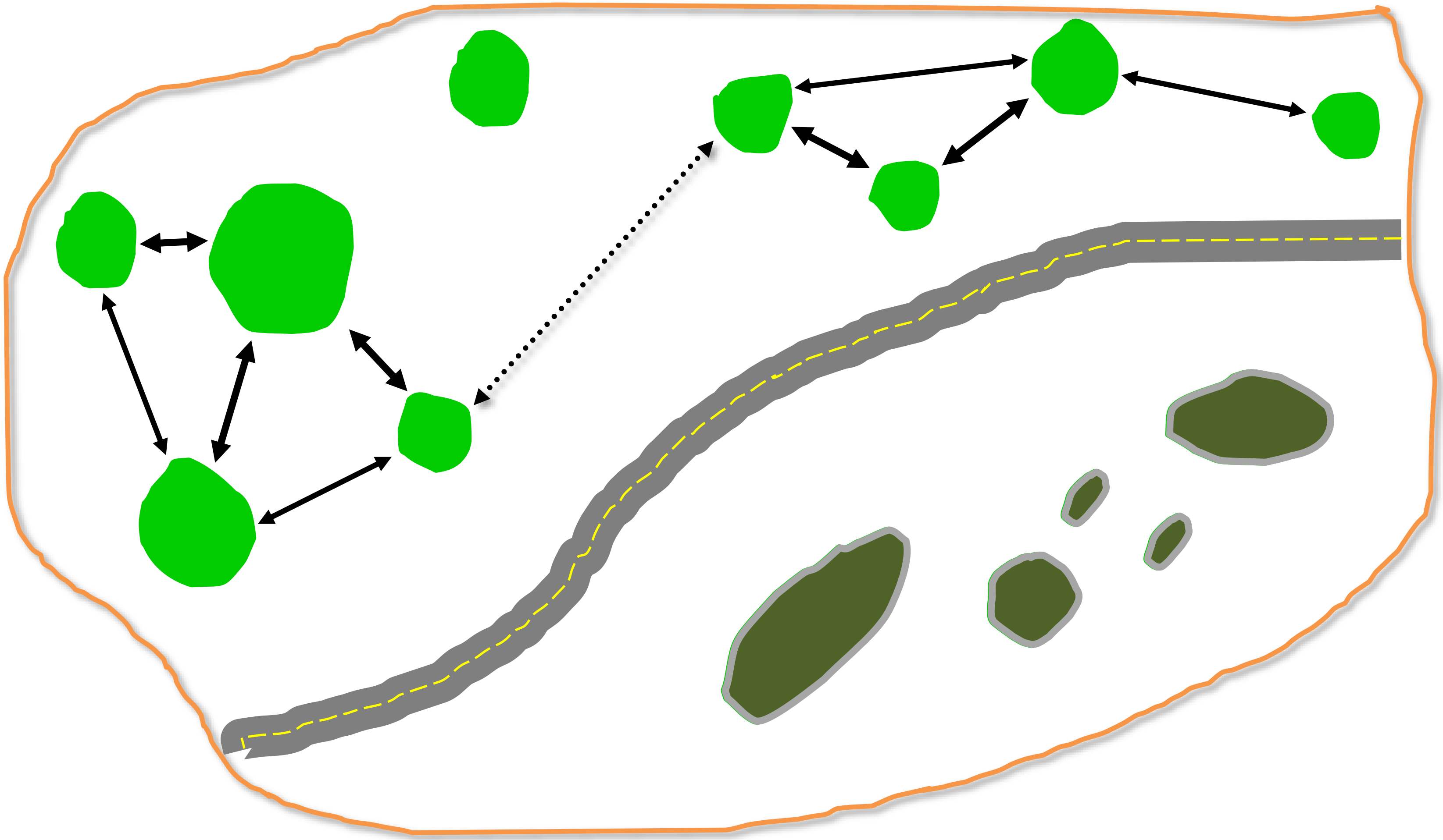
Metapopulations & scale

- Metapopulation — a set of populations linked by dispersal (perhaps “once in a lifetime” experience)



Metapopulations & scale

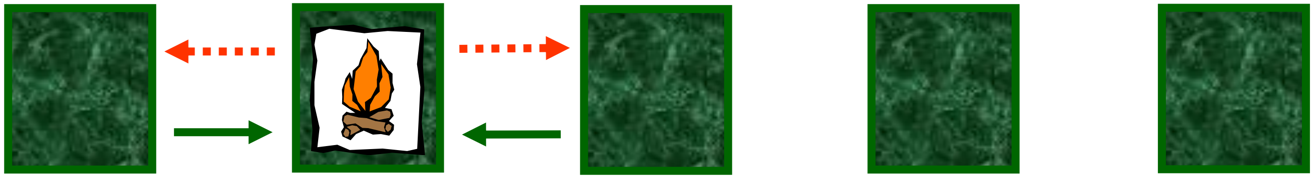
- Geographic range — perhaps a set of metapopulations; an individual does not experience much of its range



Connectivity and ecology

- Maintenance of demographic flows (rescue effect)

distributing a population among patches buffers it from local catastrophes while permitting recolonization from afar *Den Boer 1968*



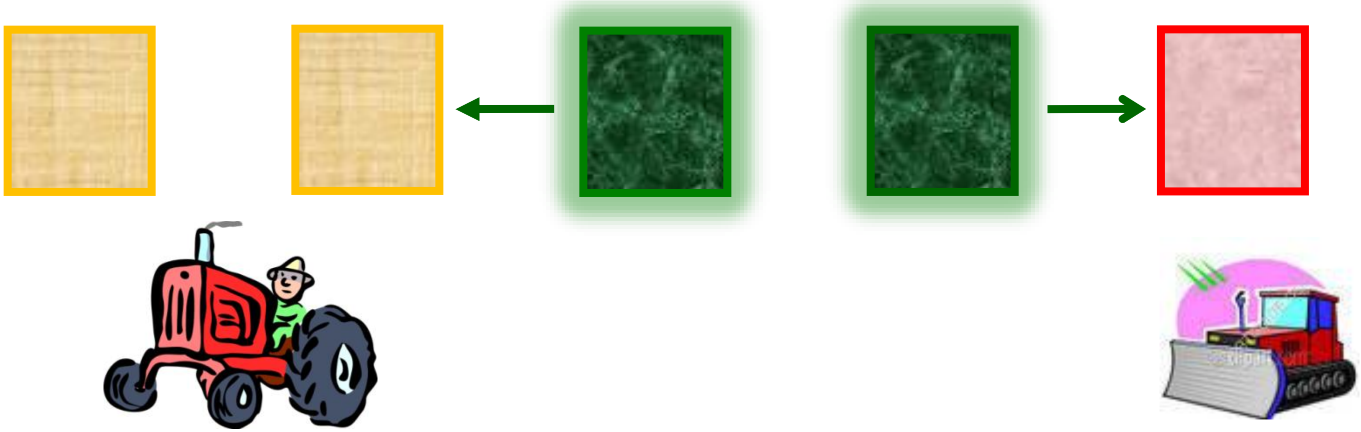
Connectivity and ecology

- Maintenance of demographic flows (rescue effect)
- Maintenance of genetic flows
  - avoid inbreeding depression
  - long term maintenance of genetic adaptability
  - diversification of evolutionary lineages via dispersal

Young & Clarke 2000

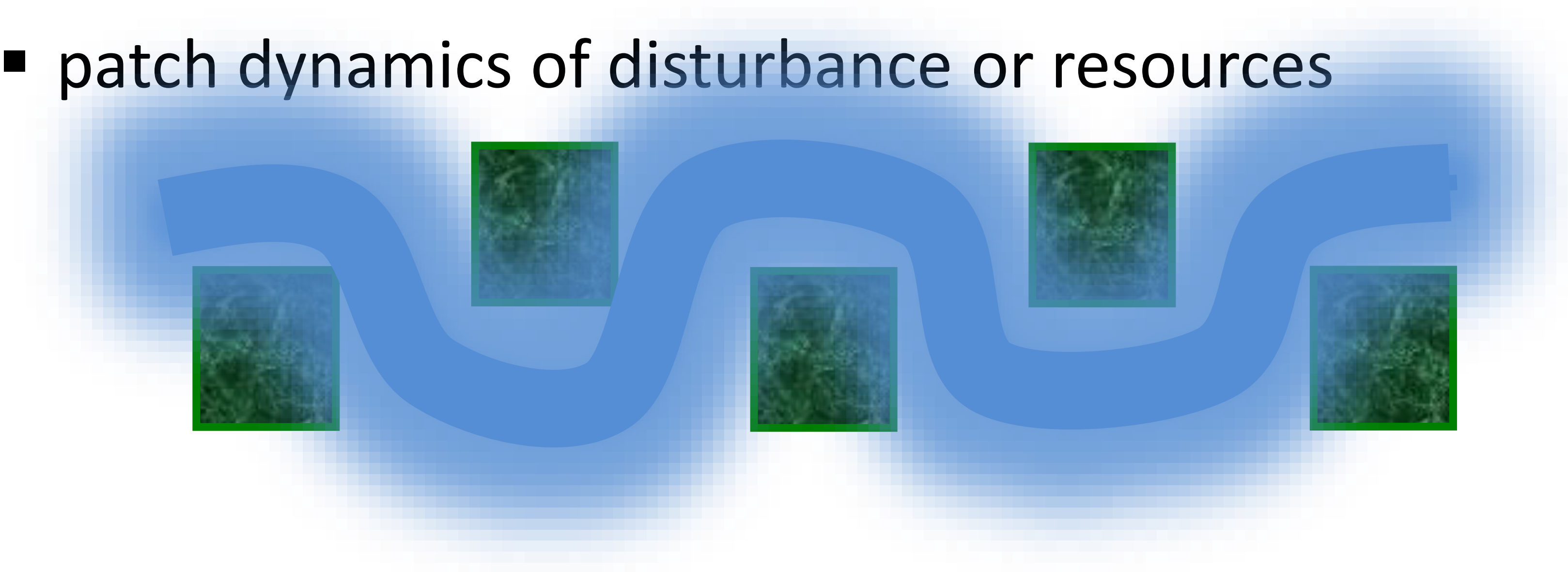
Connectivity and ecology

- Maintenance of demographic flows (rescue effect)
- Maintenance of genetic flows
- Resilience of populations…
  - to conversion by agriculture, forestry, development,…
  - to climate change



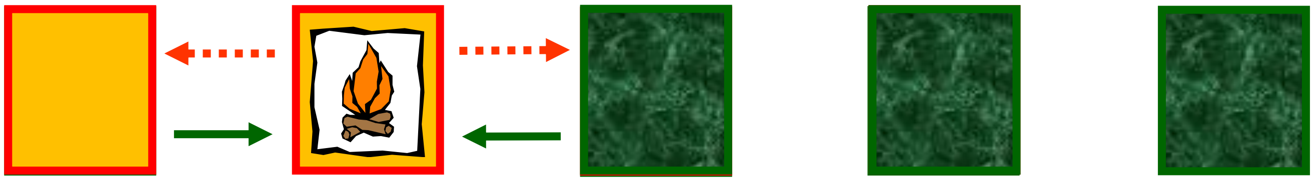
Connectivity and ecology

- Maintenance of demographic flows (rescue effect)
- Maintenance of genetic flows
- Resilience of populations…
- Maintenance of ecological processes
  - nutrient/hydraulic flows in freshwater systems
  - patch dynamics of disturbance or resources



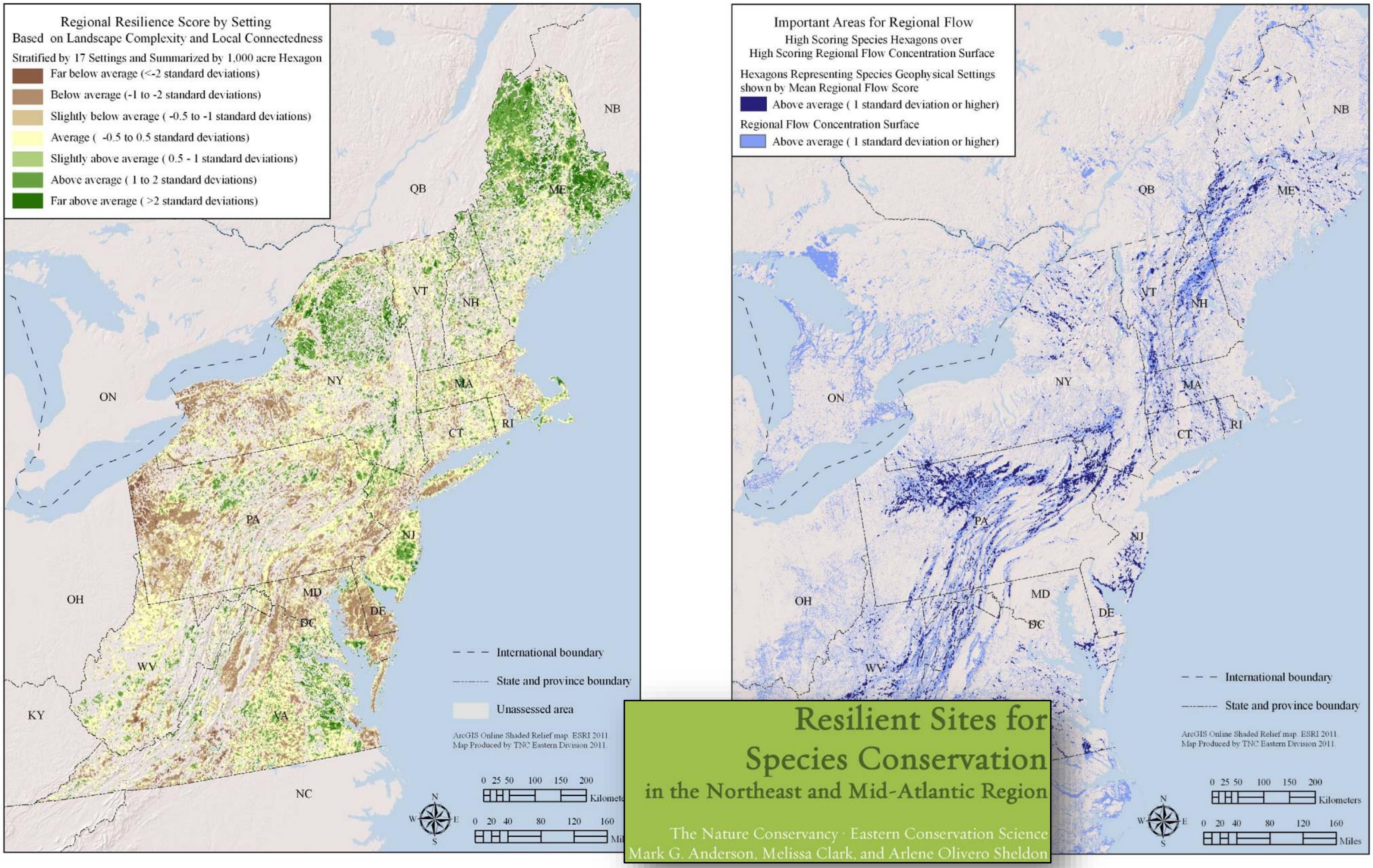
Connectivity - risks

Connectivity can allow threats to propagate just as it allows species to propagate…



- Optimal balance in connectivity:
  not enough to propagate bad things (disturbance, pathogens, pests), but enough to allow recolonization (rescue) after a local extinction

Connectivity – Climate Resilience



Resilient Sites for
Species Conservation
in the Northeast and Mid-Atlantic Region

The Nature Conservancy · Eastern Conservation Science
Mark G. Anderson, Melissa Clark, and Arlene Olivero Sheldon

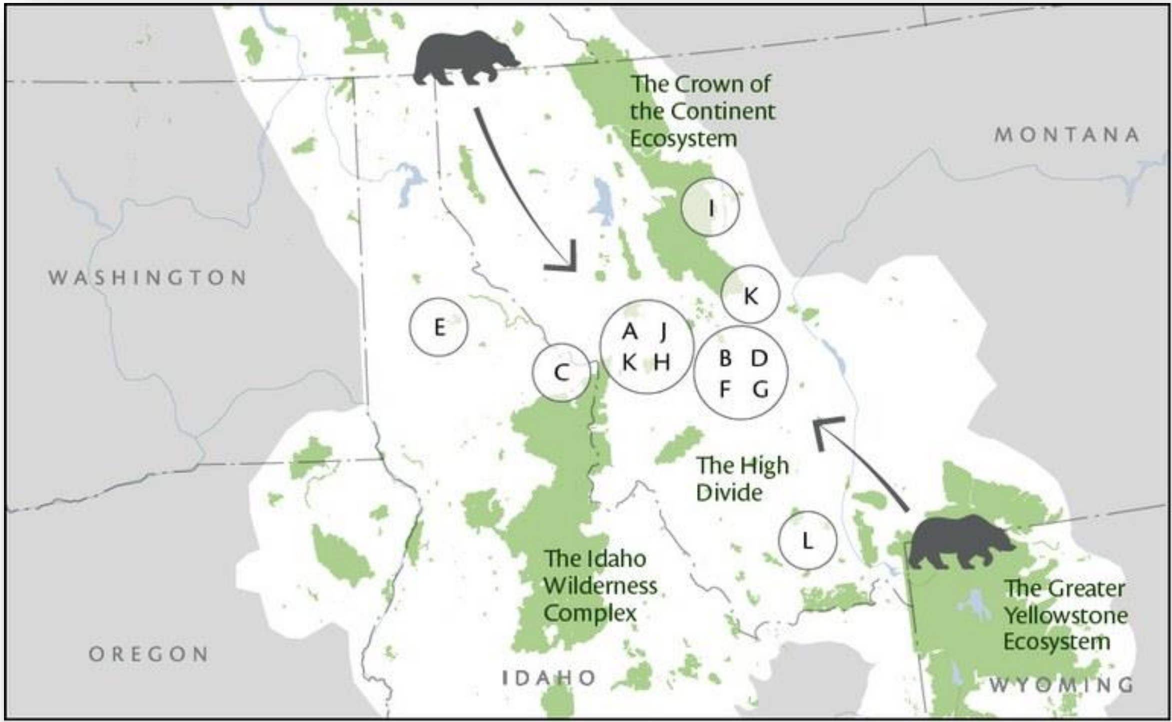
Studying connectivity

- *What is the question to be addressed?*

conservationcorridor.org

"Where along this 15-mile stretch of highway should crossing structures lynx be located?"

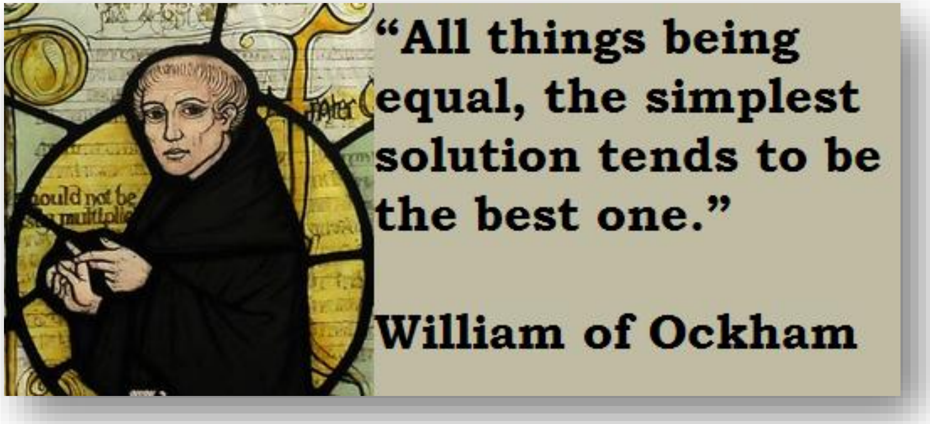
"Which areas between Yellowstone NP and the Yukon are least impacted by human activities & how are they connected?



https://y2y.net

Studying connectivity

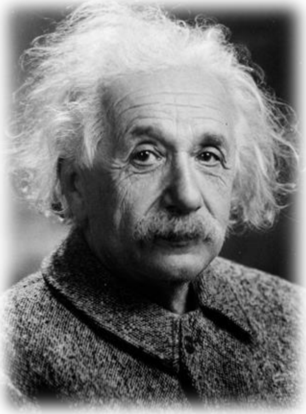
- *What is the simplest approach to provide the needed information?*



"All things being equal, the simplest solution tends to be the best one."

William of Ockham

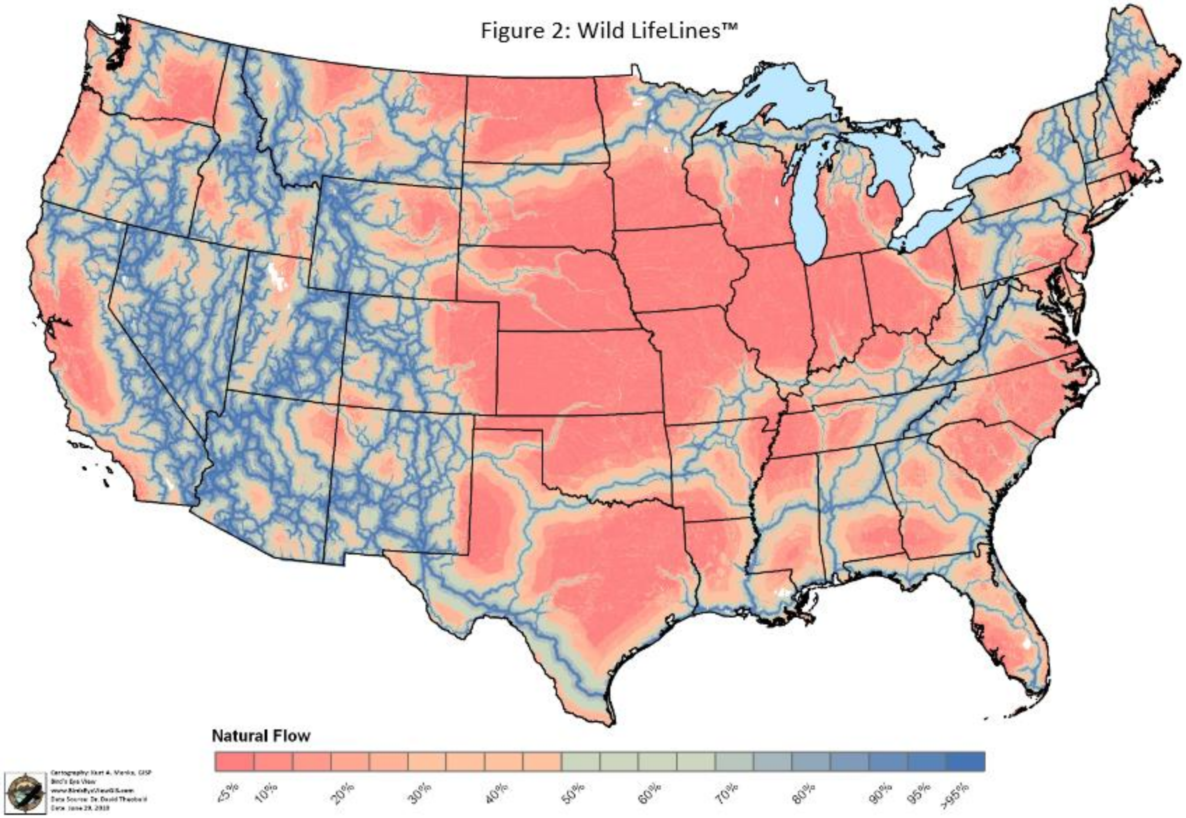
- Errors multiply as datasets are combined…
- Use the fewest GIS layers with the fewest classes that adequately address the question



"Make everything as simple as possible, but not simpler."

Studying connectivity

- *What is the scale of the question?*



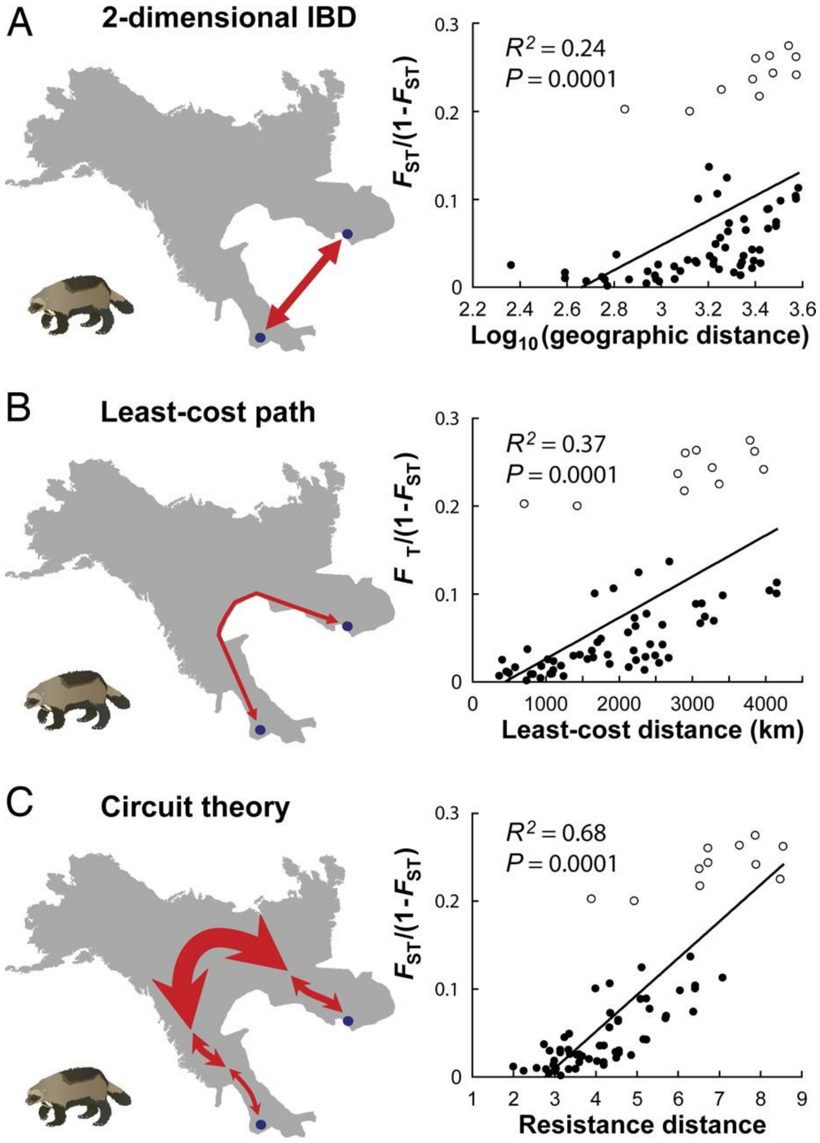
http://www.wildlandsnetwork.org/sites/default/files/Wild%20LifeLines%20White%20Paper.pdf

http://www.savingspecies.org

Studying connectivity

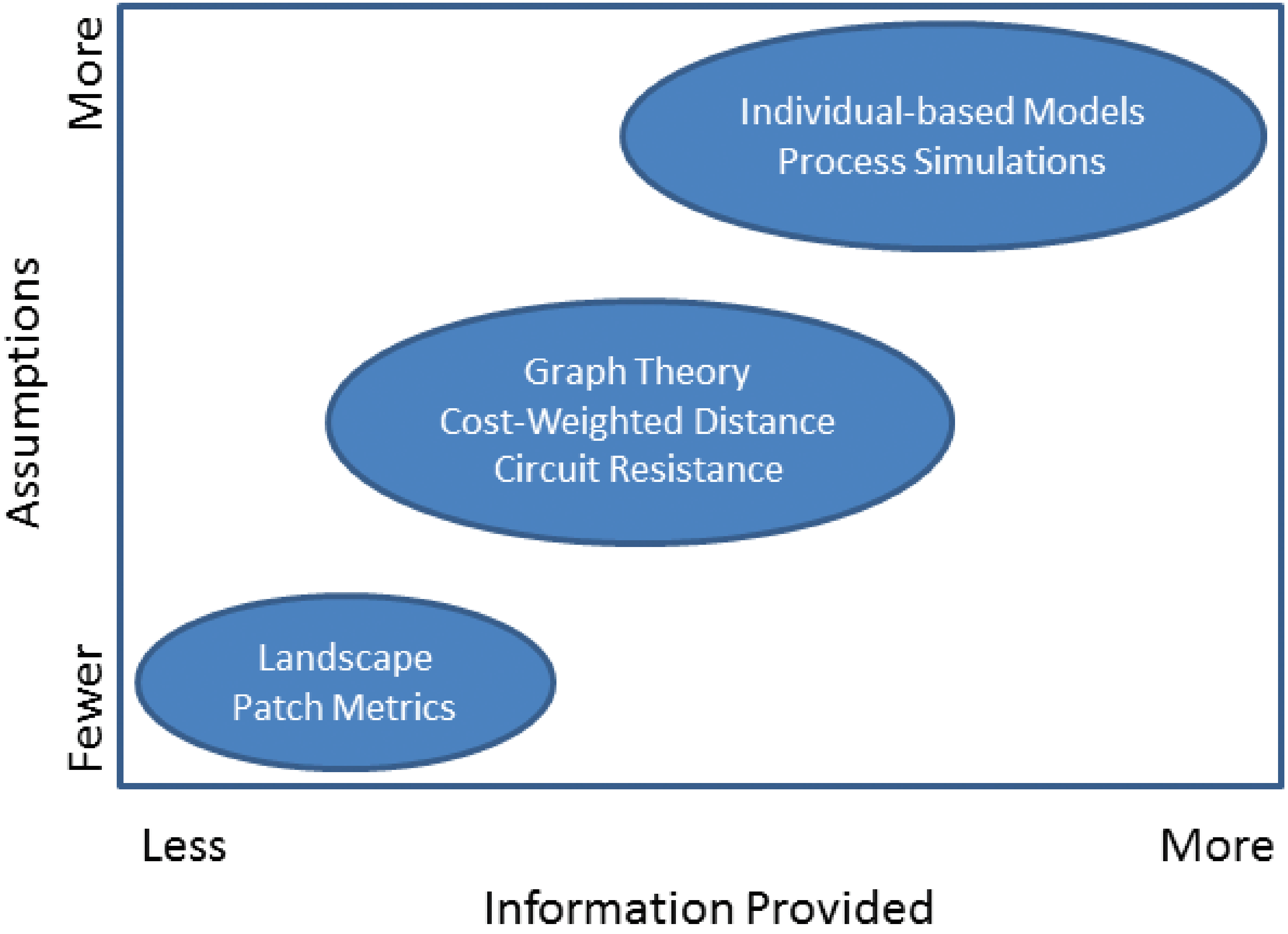
- *Is the model testable?*

Circuit theory outperforms standard models of genetic differentiation among wolverine populations. Range maps illustrate how pairwise isolation is measured under the competing models between two example wolverine populations (Idaho and Manitoba). Models compared are two-dimensional IBD (A), the better justified IBD model (see IBD Predictions under Methods), LCP (B), and IBR (C). Open circles indicate pairwise comparisons including Idaho. Linear regression lines include all populations.



Brad H. McRae, and Paul Beier PNAS 2007;104:19885-19890

Modeling connectivity



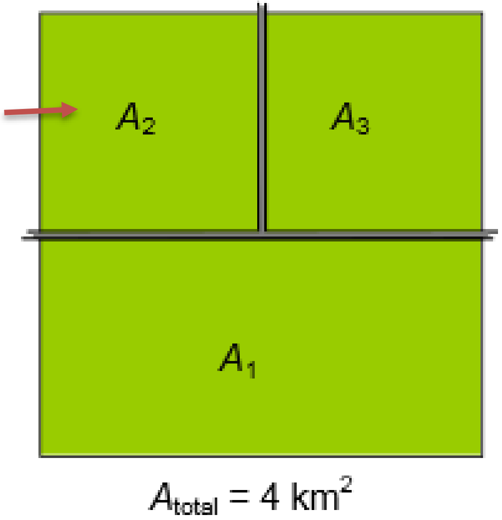
Landscape metrics (e.g., Fragstats)

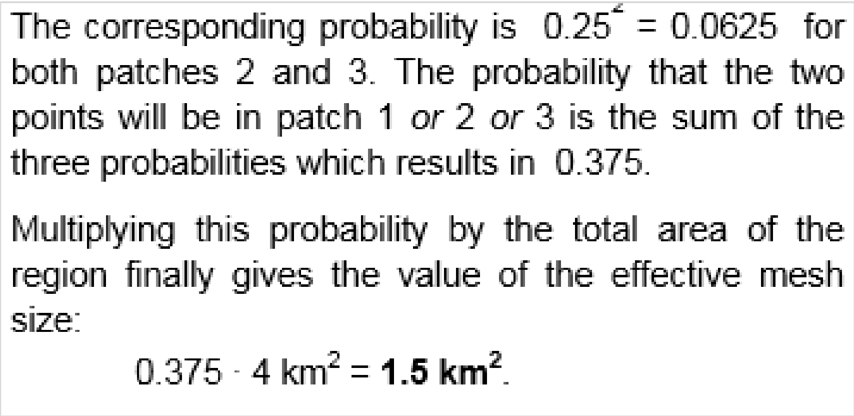
Effective mesh size…

- The probability that two random points are connected…
- Inversely related to # of barriers

$$m_{\text{eff}} = \frac{1}{A_{\text{total}}}\left(A_1^2 + A_2^2 + \ldots + A_i^2 + \ldots + A_n^2\right)$$

$$\left(\frac{A_1}{A_{\text{total}}}\right)^2 = 0.5 \cdot 0.5 = 0.25.$$



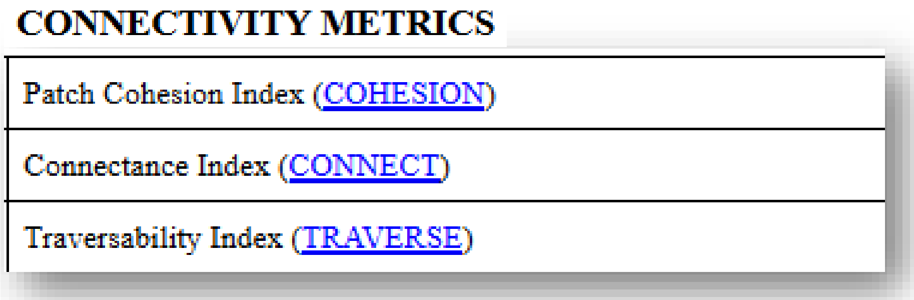

The corresponding probability is $0.25^2 = 0.0625$ for both patches 2 and 3. The probability that the two points will be in patch 1 *or* 2 *or* 3 is the sum of the three probabilities which results in 0.375.

Multiplying this probability by the total area of the region finally gives the value of the effective mesh size:

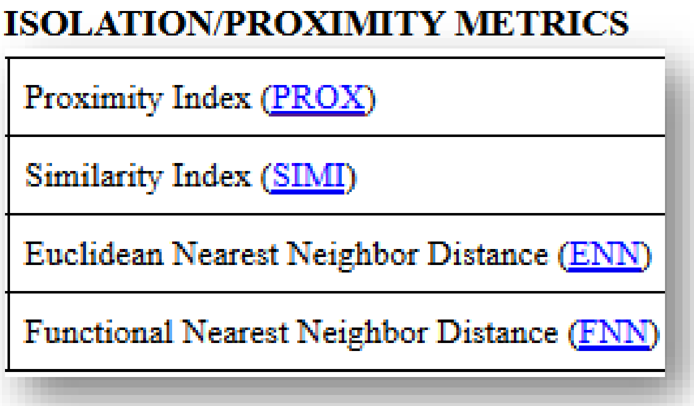
$$0.375 \cdot 4\ \text{km}^2 = \mathbf{1.5\ km^2}.$$

http://www.concordia.ca/content/dam/artsci/geography-planning-environment/docs/jaeger/publications/more2a-faltblatt_engl.pdf

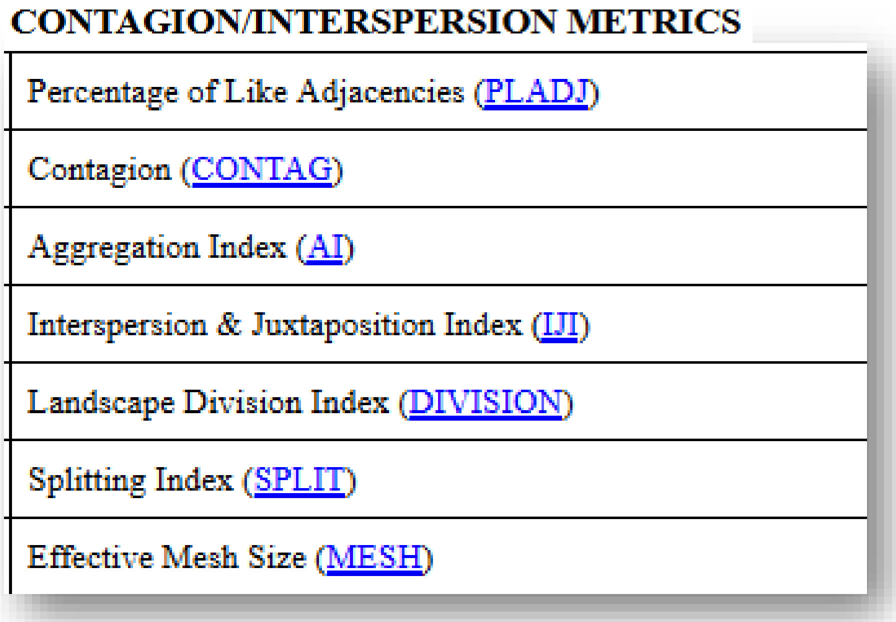
Landscape metrics (e.g., Fragstats)



CONNECTIVITY METRICS
Patch Cohesion Index (COHESION)
Connectance Index (CONNECT)
Traversability Index (TRAVERSE)



ISOLATION/PROXIMITY METRICS
Proximity Index (PROX)
Similarity Index (SIMI)
Euclidean Nearest Neighbor Distance (ENN)
Functional Nearest Neighbor Distance (FNN)



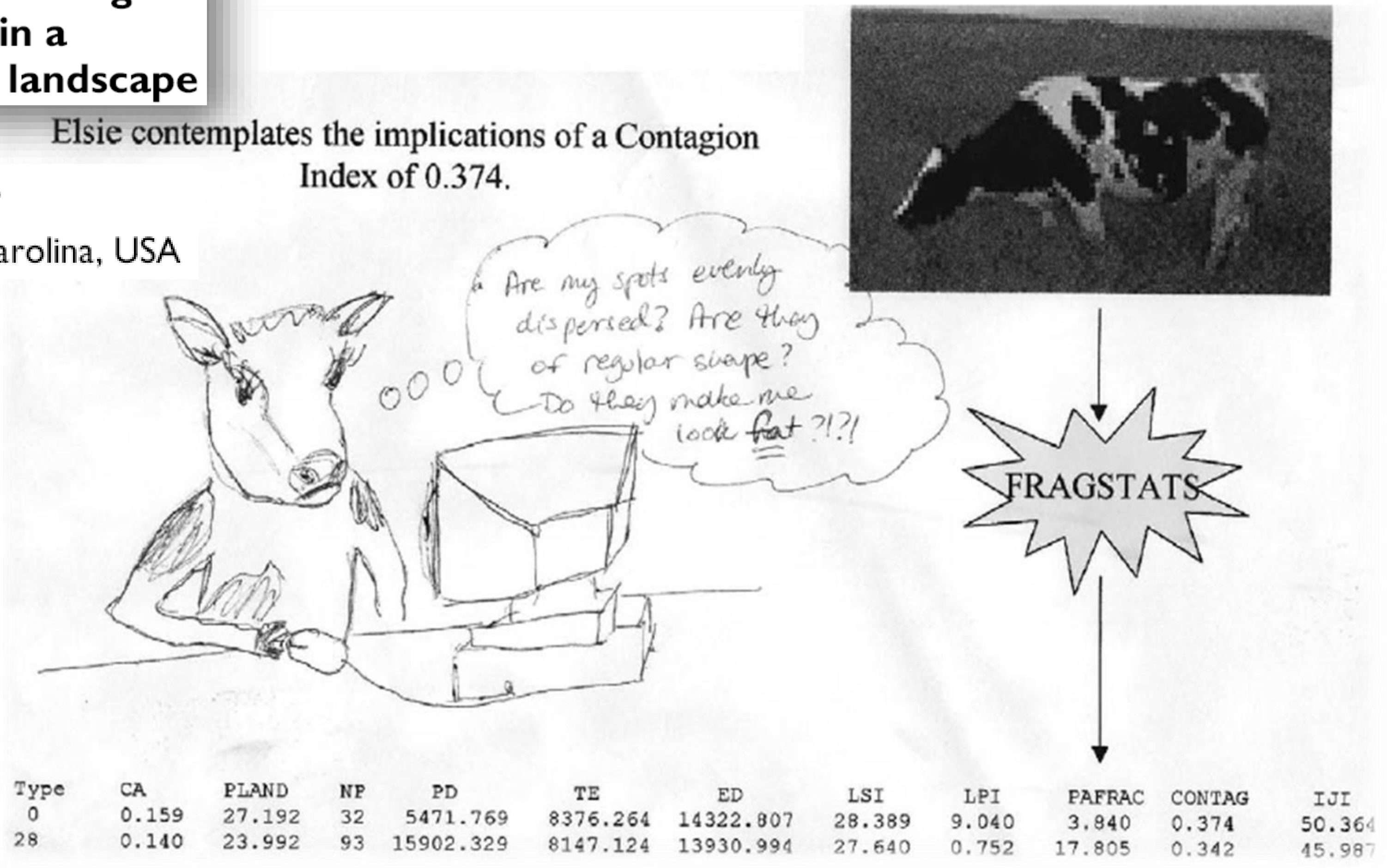
CONTAGION/INTERSPERSION METRICS
Percentage of Like Adjacencies (PLADJ)
Contagion (CONTAG)
Aggregation Index (AI)
Interspersion & Juxtaposition Index (IJI)
Landscape Division Index (DIVISION)
Splitting Index (SPLIT)
Effective Mesh Size (MESH)

All of these measure *structural* connectivity…

Landscape metrics

Landscape ecology and biogeography: Rethinking landscape metrics in a post-FRAGSTATS landscape

John A. Kupfer
University of South Carolina, USA



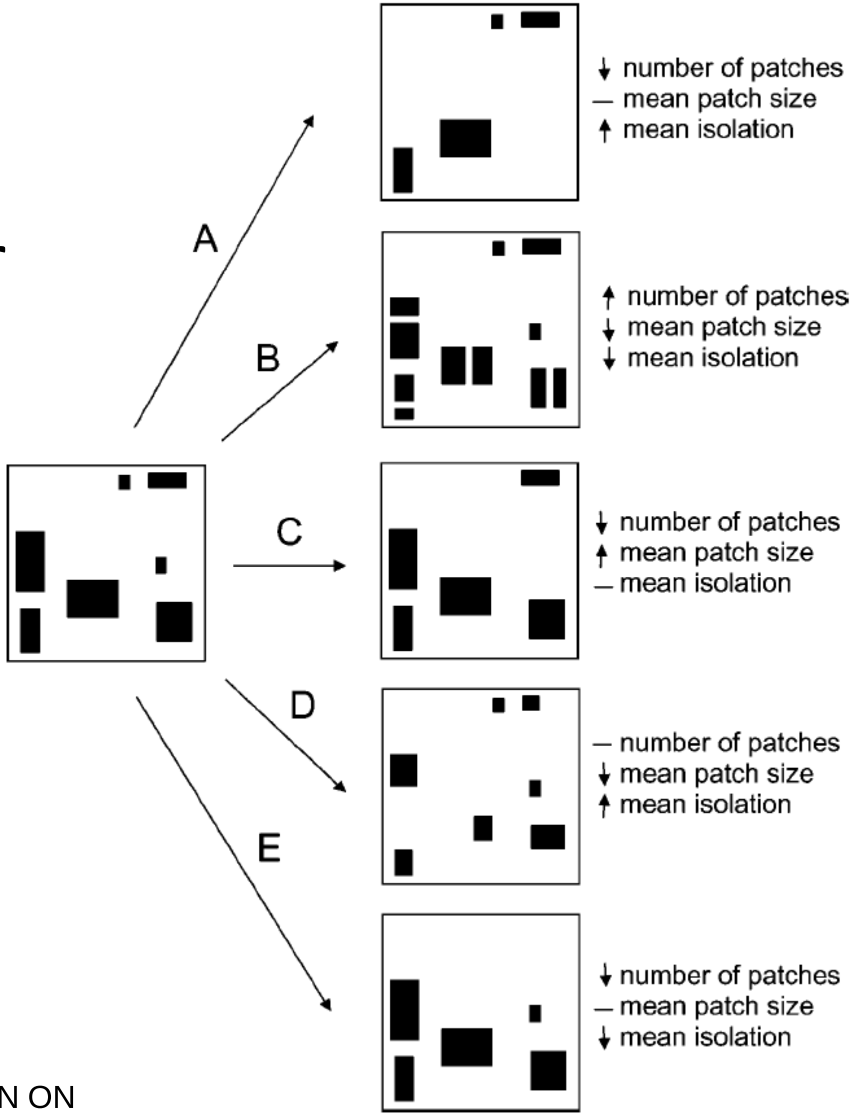
```
Type     CA      PLAND    NP     PD         TE        ED         LSI      LPI     PAFRAC   CONTAG     IJI
 0      0.159   27.192    32   5471.769   8376.264  14322.807   28.389   9.040    3.840   0.374     50.364
28      0.140   23.992    93  15902.329   8147.124  13930.994   27.640   0.752   17.805   0.342     45.987
```

Figure 1. Technological advances have facilitated the generation of dozens of measures of landscape structure, but the amount of information produced has often outpaced our understanding of how such measures relate to ecological processes.

Ecological & Theoretical background

- *Structural connectivity*:

  The spatial arrangement of different types of habitat or other elements in the landscape.



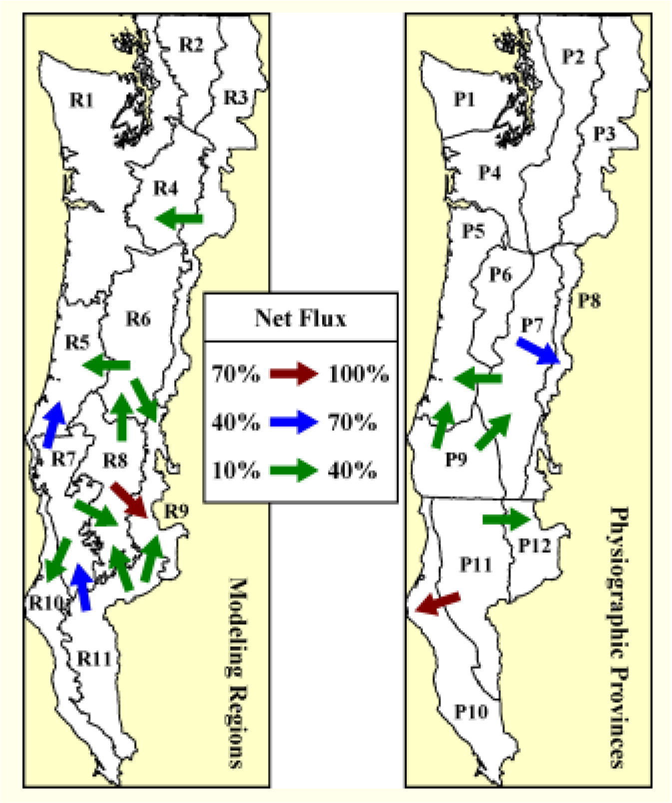
Fahrig, L. 2003. EFFECTS OF HABITAT FRAGMENTATION ON BIODIVERSITY Annu. Rev. Ecol. Evol. Syst. 34:487–515

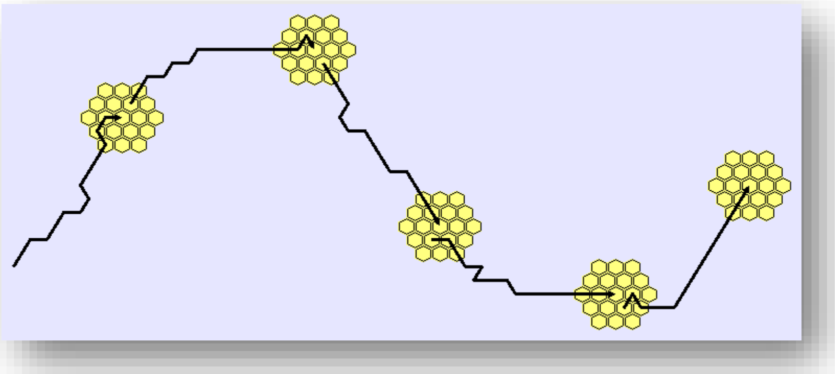
Ecological & Theoretical background

- *Functional Connectivity:*

  The behavioral response of individuals, species, or ecological processes to the physical structure of the landscape.

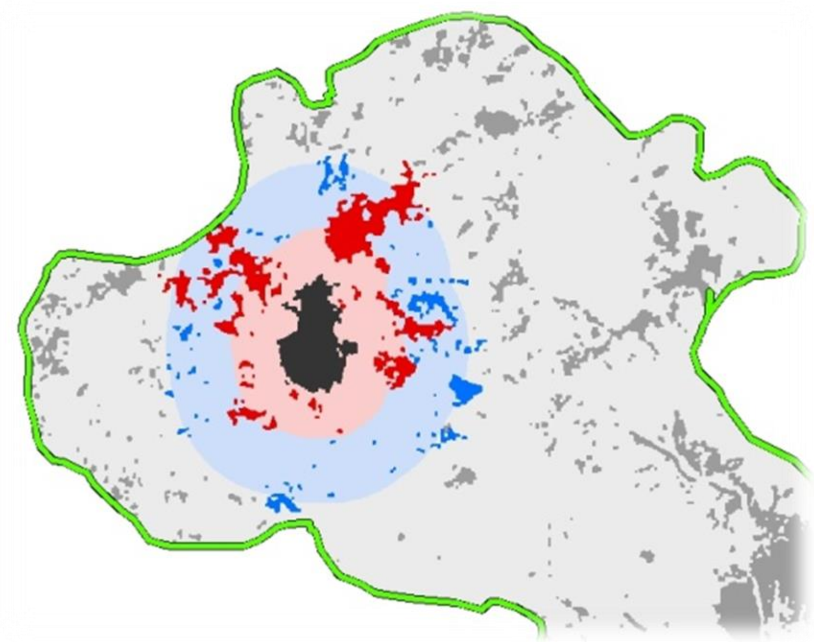
  - Potential Connectivity (simulation)
  - Actual Connectivity





Distance-based connectivity modeling

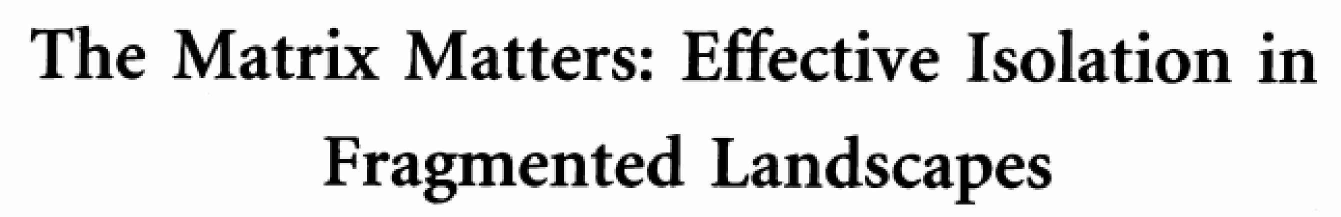
- Closer is better: *Euclidean distance*



But - is the all the area between patches equal?

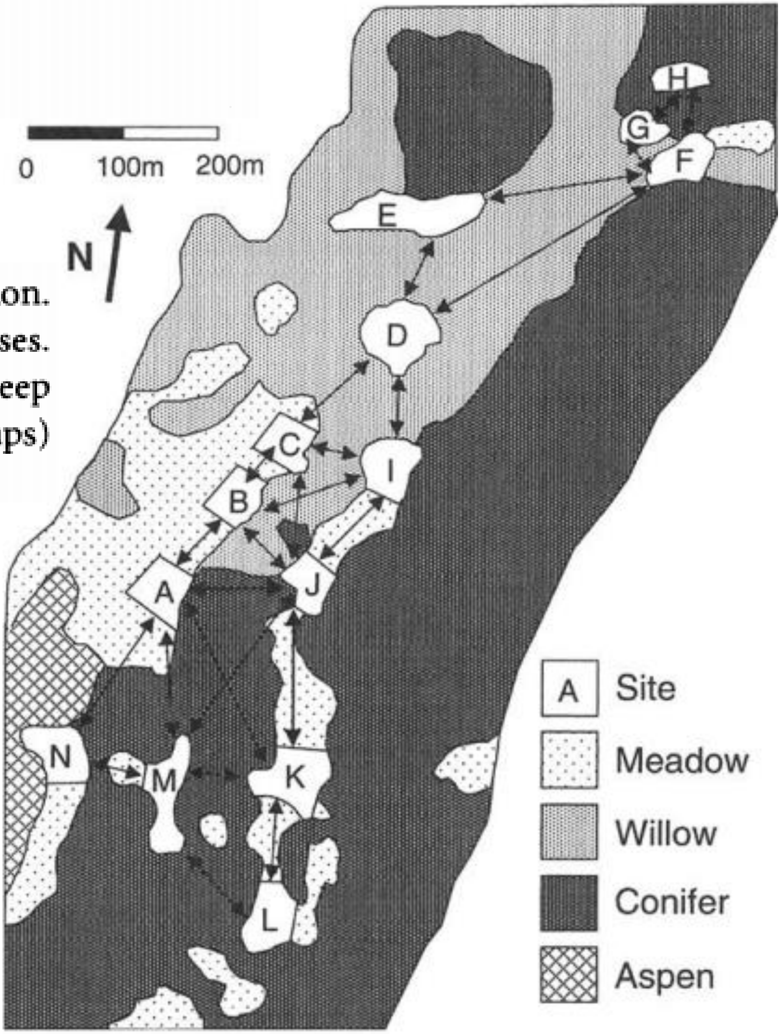
In other words: *Does the matrix matter??*

Distance-based connectivity modeling



The Matrix Matters: Effective Isolation in Fragmented Landscapes

Ricketts 2001



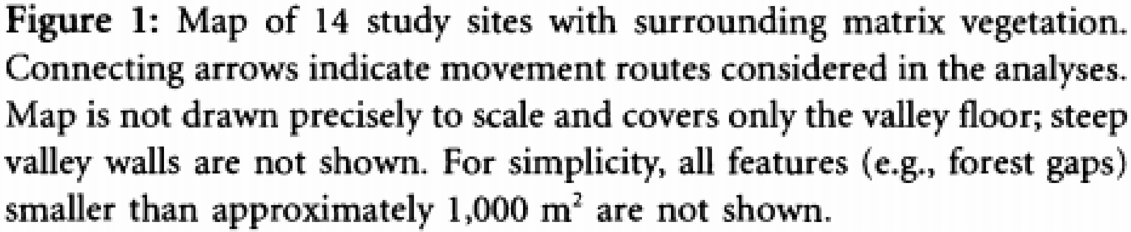
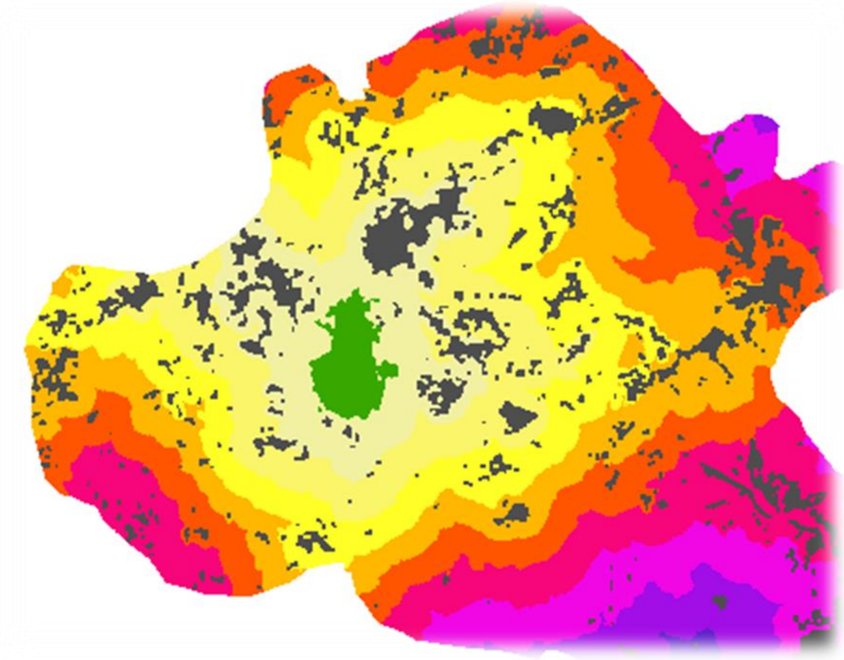


Figure 1: Map of 14 study sites with surrounding matrix vegetation. Connecting arrows indicate movement routes considered in the analyses. Map is not drawn precisely to scale and covers only the valley floor; steep valley walls are not shown. For simplicity, all features (e.g., forest gaps) smaller than approximately 1,000 m² are not shown.

Distance-based connectivity modeling

- The matrix matters: *Cost distance**



* But – how do we determine the cost?

Distance-based connectivity modeling

Resistance/Cost:

Impedance from crossing a particular environment

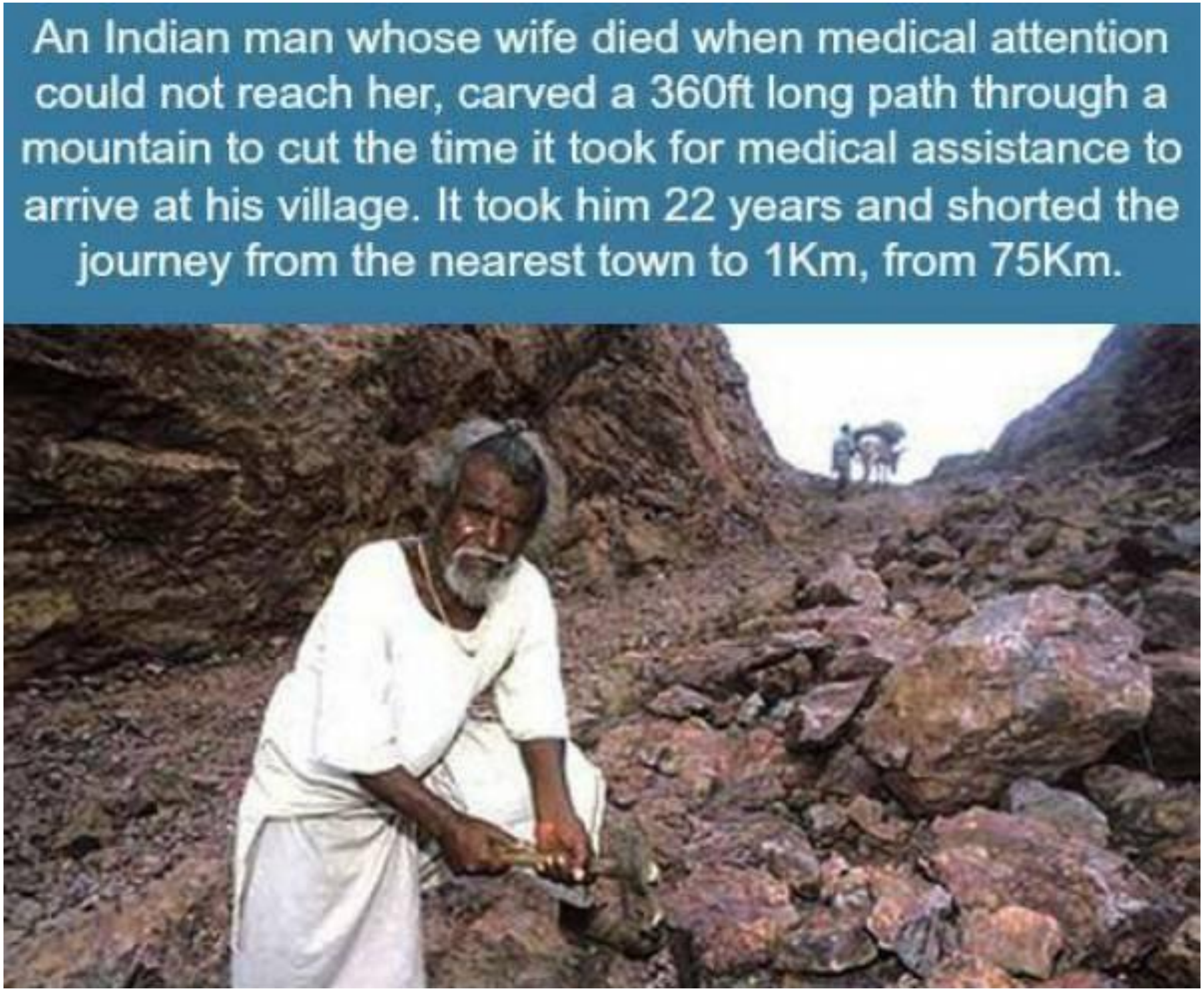
Physiological cost

Mortality risk

Permeability/Conductivity: *(Inverse of resistance…)*

Facility of moving through an environment

Distance-based connectivity modeling



An Indian man whose wife died when medical attention could not reach her, carved a 360ft long path through a mountain to cut the time it took for medical assistance to arrive at his village. It took him 22 years and shorted the journey from the nearest town to 1Km, from 75Km.

Determining cost

Landscape Ecol (2012) 27:777–797
DOI 10.1007/s10980-012-9737-0

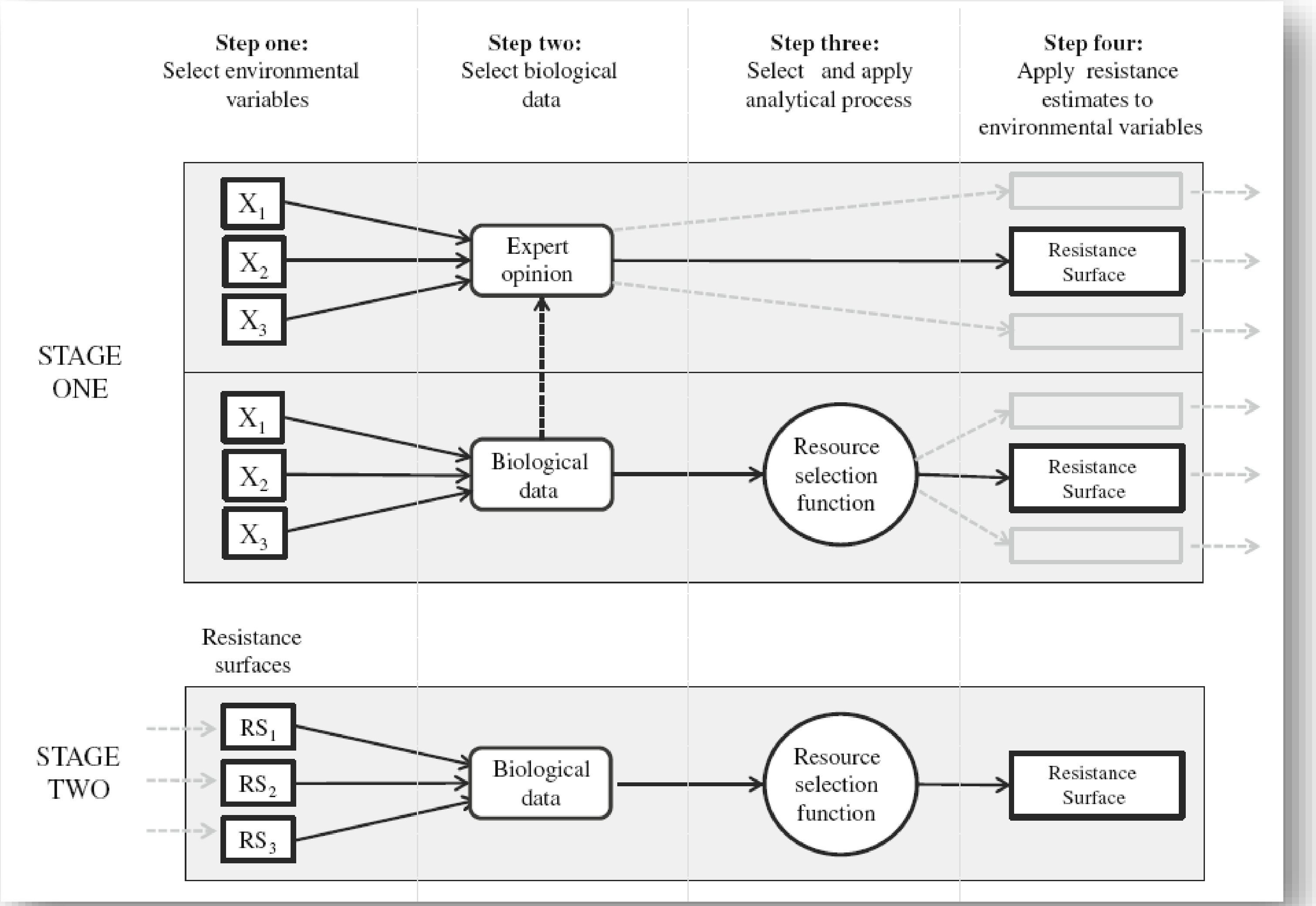
LANDSCAPE ECOLOGY IN REVIEW

Estimating landscape resistance to movement: a review

**Katherine A. Zeller · Kevin McGarigal ·
Andrew R. Whiteley**

- 5 Types of biological input data
  - Expert opinion
  - Detection data (element occurrence data)
  - Relocation data (mark – recapture)
  - Pathway data (tracking)
  - Genetic data (movement of genes)

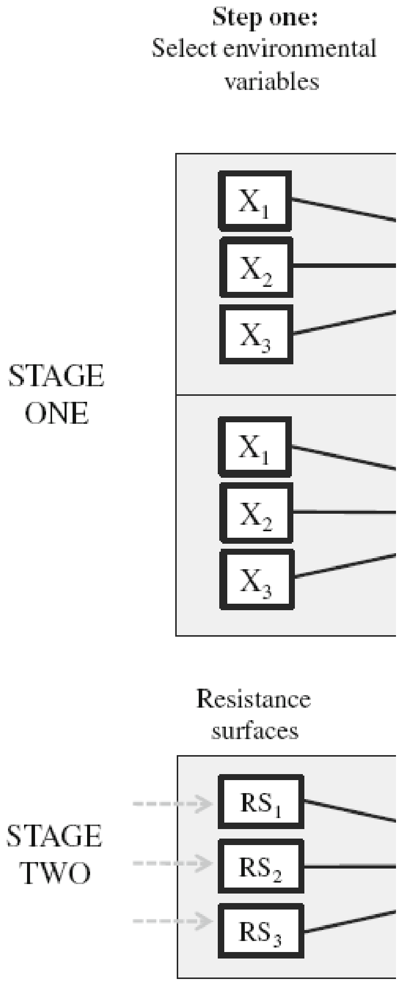
Determining cost



Estimating landscape resistance to movement: a review

Katherine A. Zeller · Kevin McGarigal ·
Andrew R. Whiteley

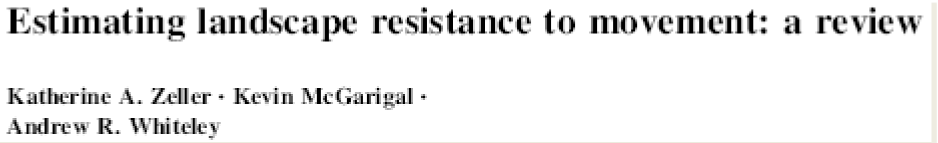
Determining cost



Typical environmental layers…

- Land cover
- Roads
- Elevation
- Hydrology
- Slope

- ➢ Which to use?
- ➢ Are these proxies?
- ➢ Are they accurate?



Estimating landscape resistance to movement: a review

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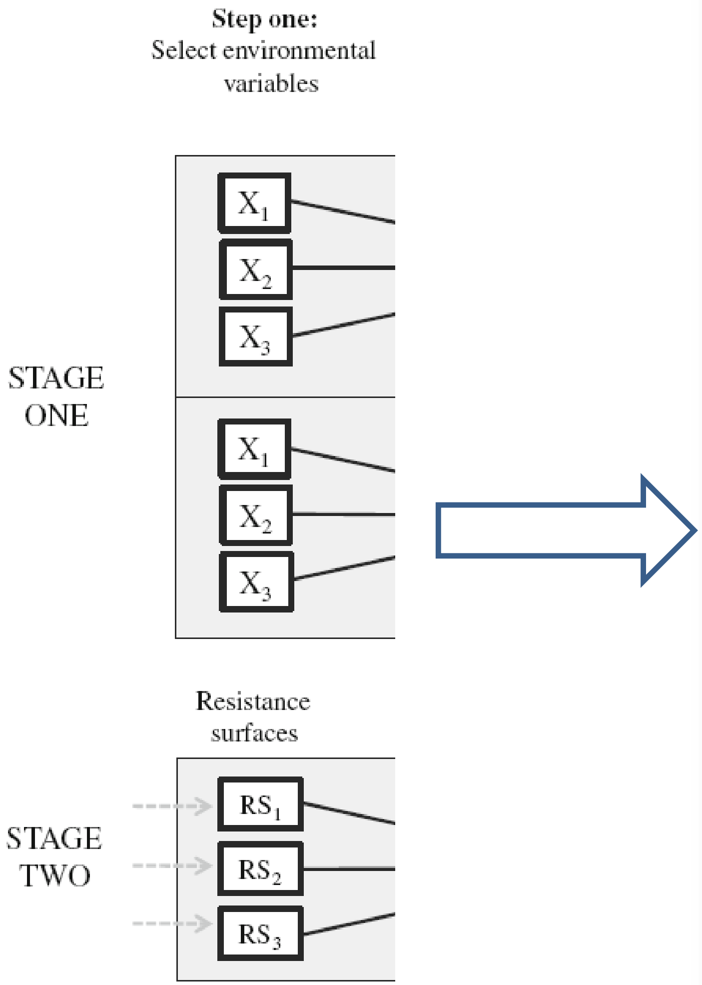
Determining cost



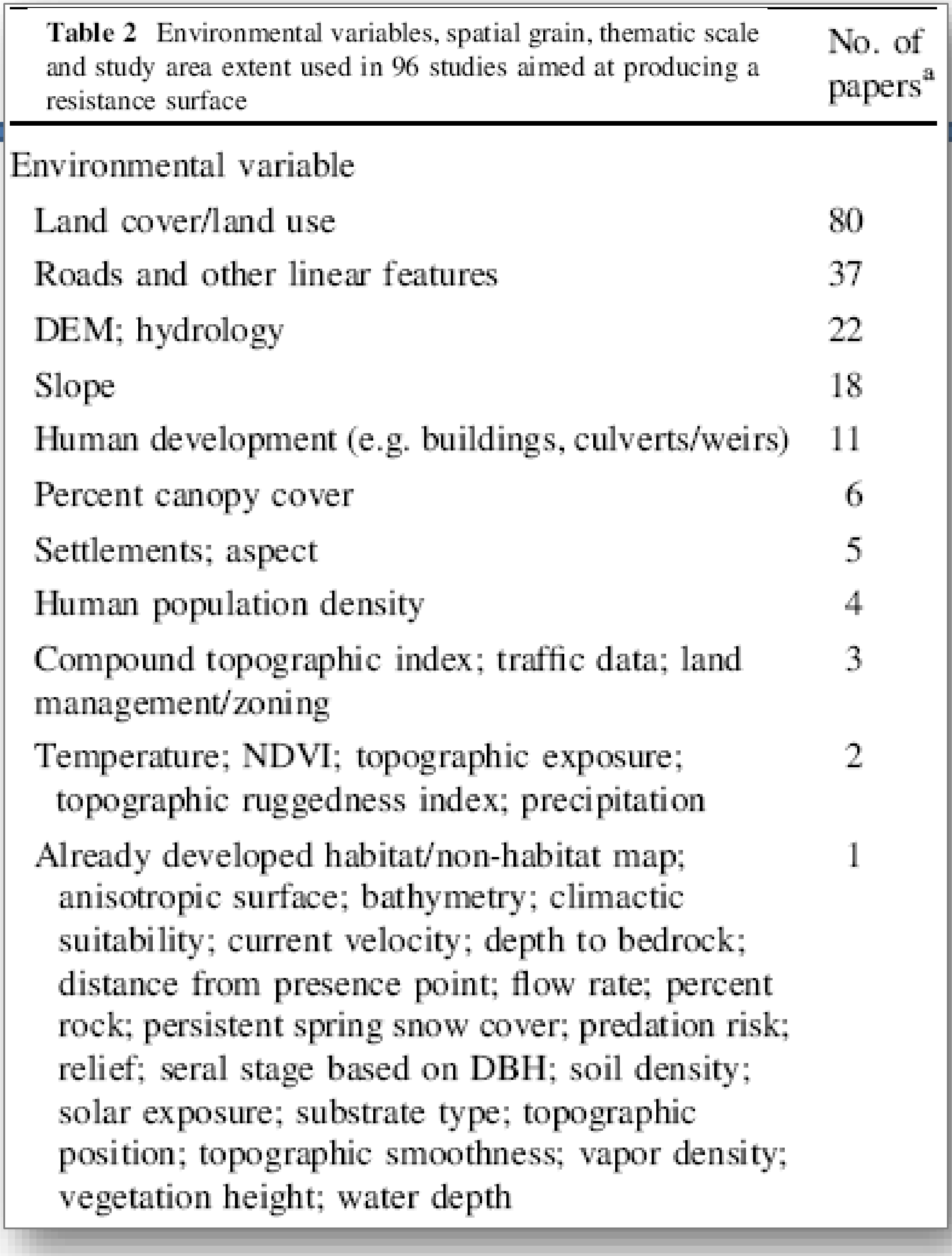


Table 2 Environmental variables, spatial grain, thematic scale and study area extent used in 96 studies aimed at producing a resistance surface

	No. of papers[a]
Environmental variable	
Land cover/land use	80
Roads and other linear features	37
DEM; hydrology	22
Slope	18
Human development (e.g. buildings, culverts/weirs)	11
Percent canopy cover	6
Settlements; aspect	5
Human population density	4
Compound topographic index; traffic data; land management/zoning	3
Temperature; NDVI; topographic exposure; topographic ruggedness index; precipitation	2
Already developed habitat/non-habitat map; anisotropic surface; bathymetry; climactic suitability; current velocity; depth to bedrock; distance from presence point; flow rate; percent rock; persistent spring snow cover; predation risk; relief; seral stage based on DBH; soil density; solar exposure; substrate type; topographic position; topographic smoothness; vapor density; vegetation height; water depth	1

Zeller, et al (2012)

Determining cost

Connecting natural landscapes using a landscape permeability model to prioritize conservation activities in the United States

David M. Theobald[1], Sarah E. Reed[1,2], Kenyon Fields[3], & Michael Soulé[3]

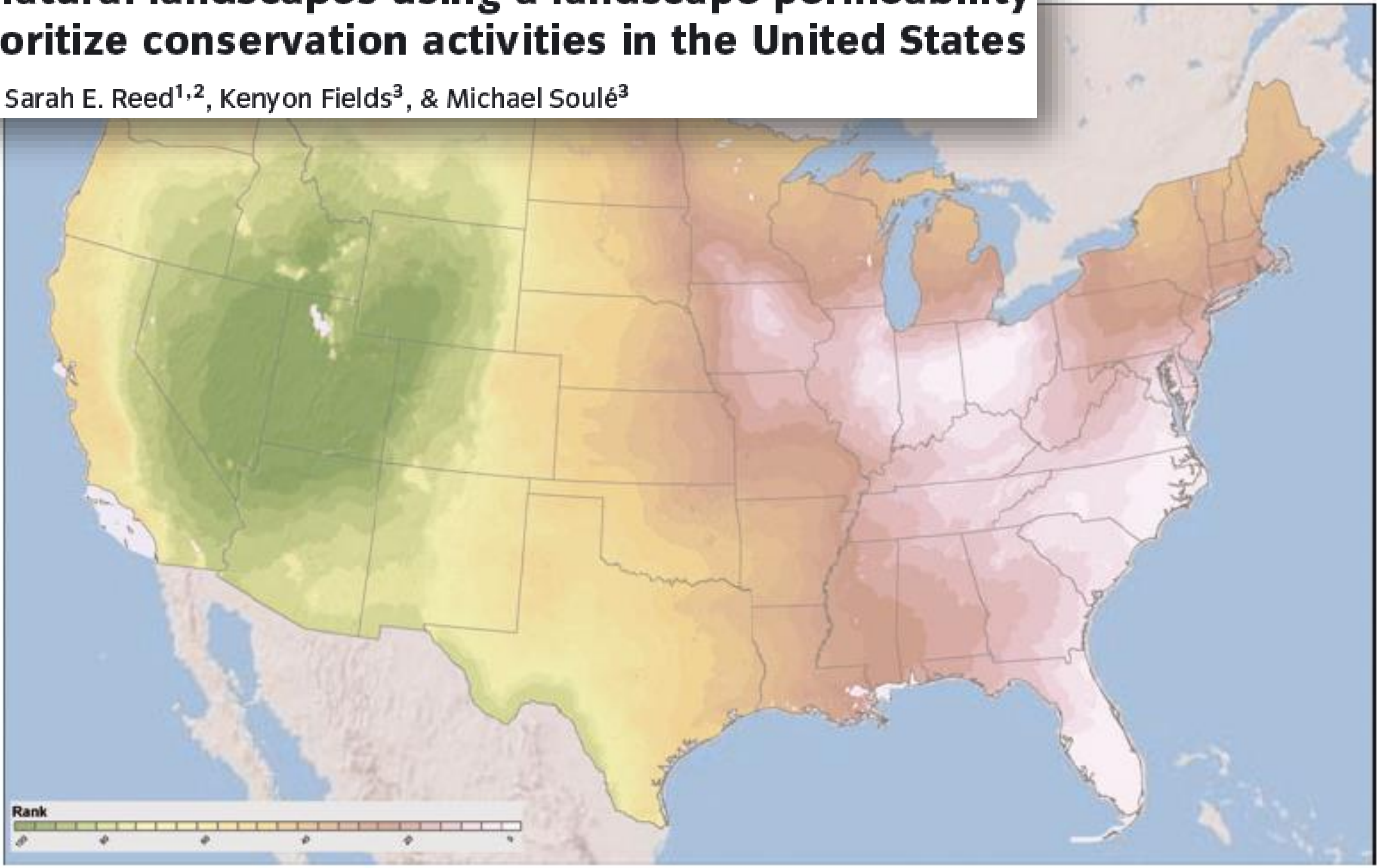
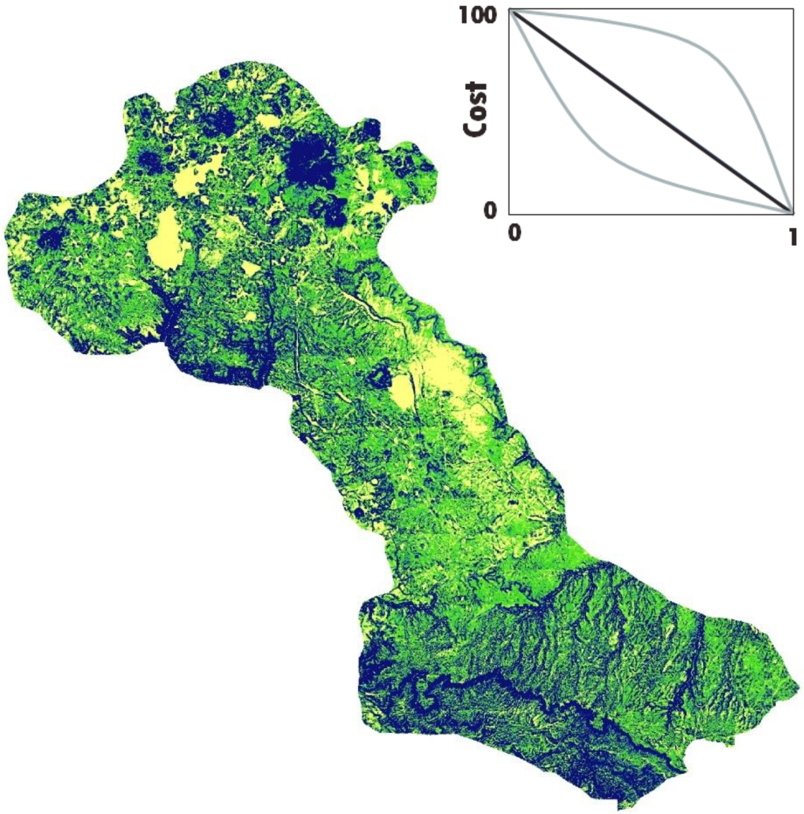


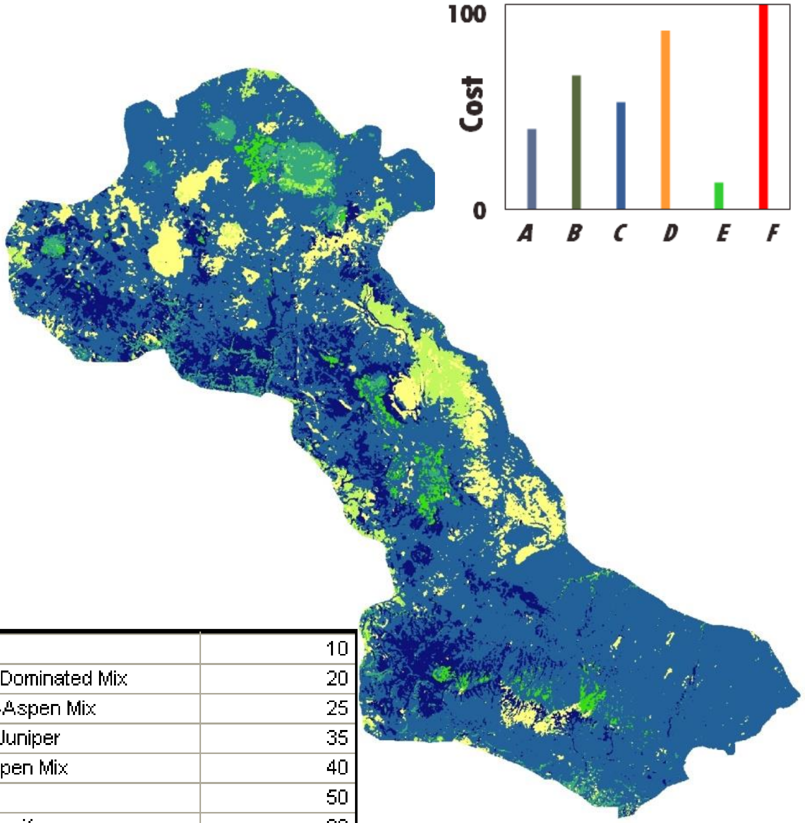
Figure 2 U.S. natural permeability of natural landscapes. This map of connected landscapes shows the natural landscape connectivity as a surface (or gradient) representing each cell's value as a percentile distribution normalized to the United States. Colors represent the amount of connected, natural lands (green = high; yellow = medium; purple/white = low).

Connectivity cost surfaces



*100 * (1.0 - Pronghorn Habitat Suitability)*

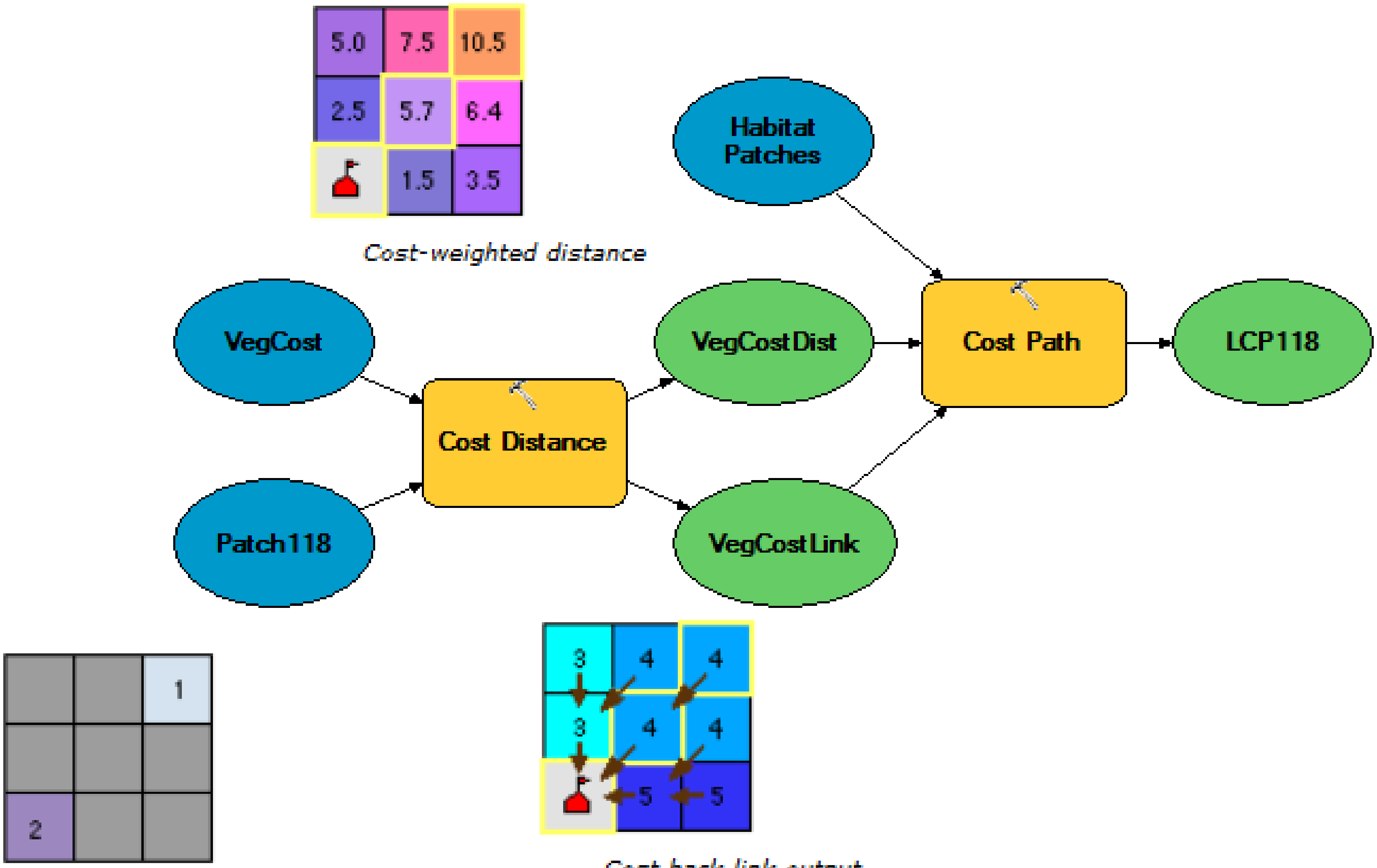
Habitat Suitability Based



Open	10
Juniper Dominated Mix	20
Conifer-Aspen Mix	25
Pinyon-Juniper	35
Pine-Aspen Mix	40
Aspen	50
Mixed Conifer	60
Ponderosa Pine	80
Pine-Oak Mix	100

Classification Based
(Vegetation Overstory)

Least cost paths (LCPs)



5.0	7.5	10.5
2.5	5.7	6.4
🚩	1.5	3.5

Cost-weighted distance

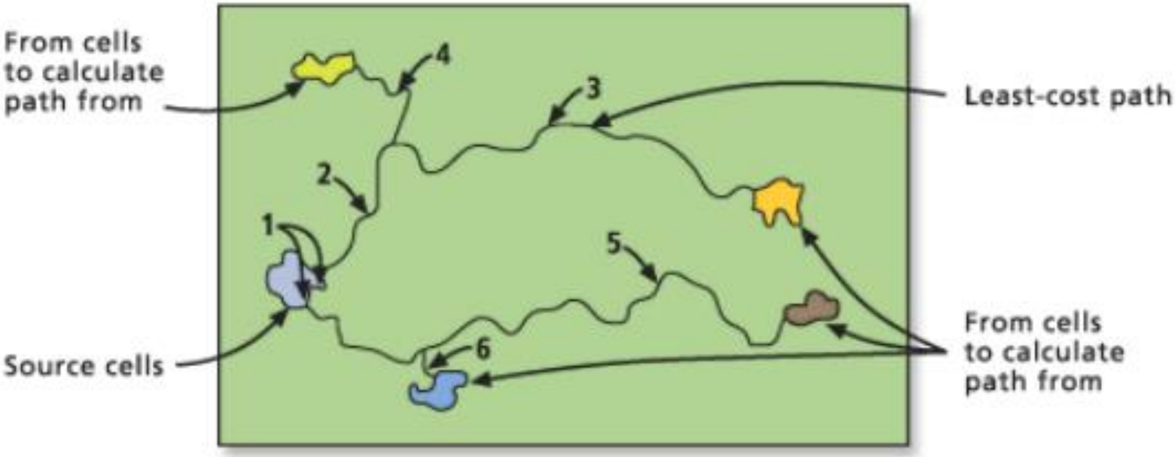
3	4	4
3	4	4
🚩	5	5

Cost back link output

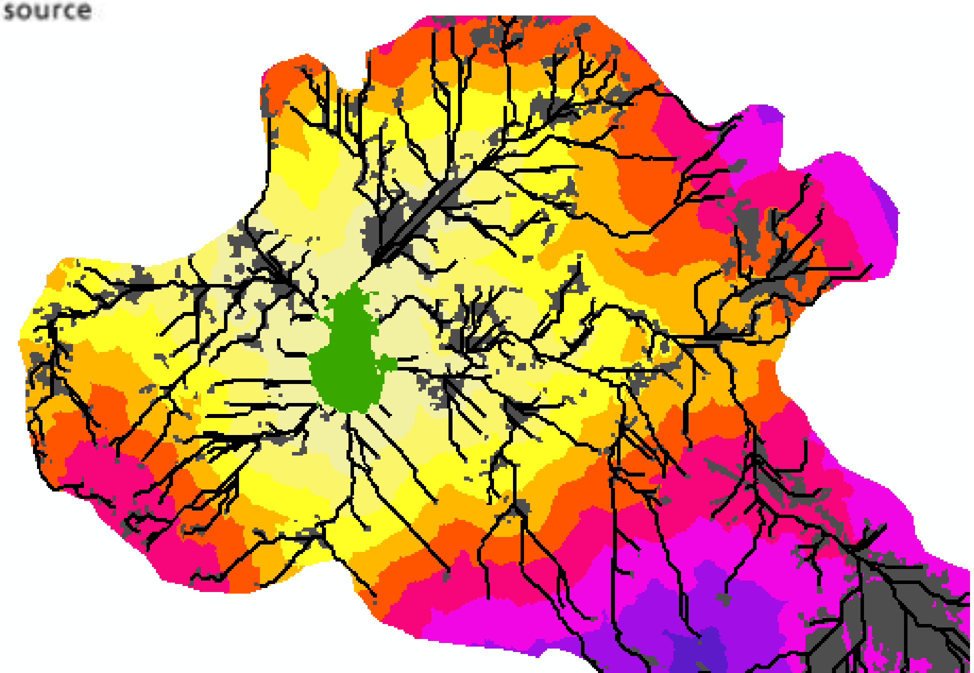
		1
2		

Input source locations

Least cost paths



COSTPATH using the BYZONE keyword
from multiple cell locations to a single source



Least cost paths: how useful are they?

Although LCPs are easy to calculate, are they really a wise choice for modeling connectivity?

- How "optimal" is it vs. sub-optimal paths?
- Paths are a single pixel wide…
- How likely are animals to find and use LCPs?
    - Will they find the optimal exit point from a patch?
    - Are they able to discern costs along path?

Alternatives to least cost paths…

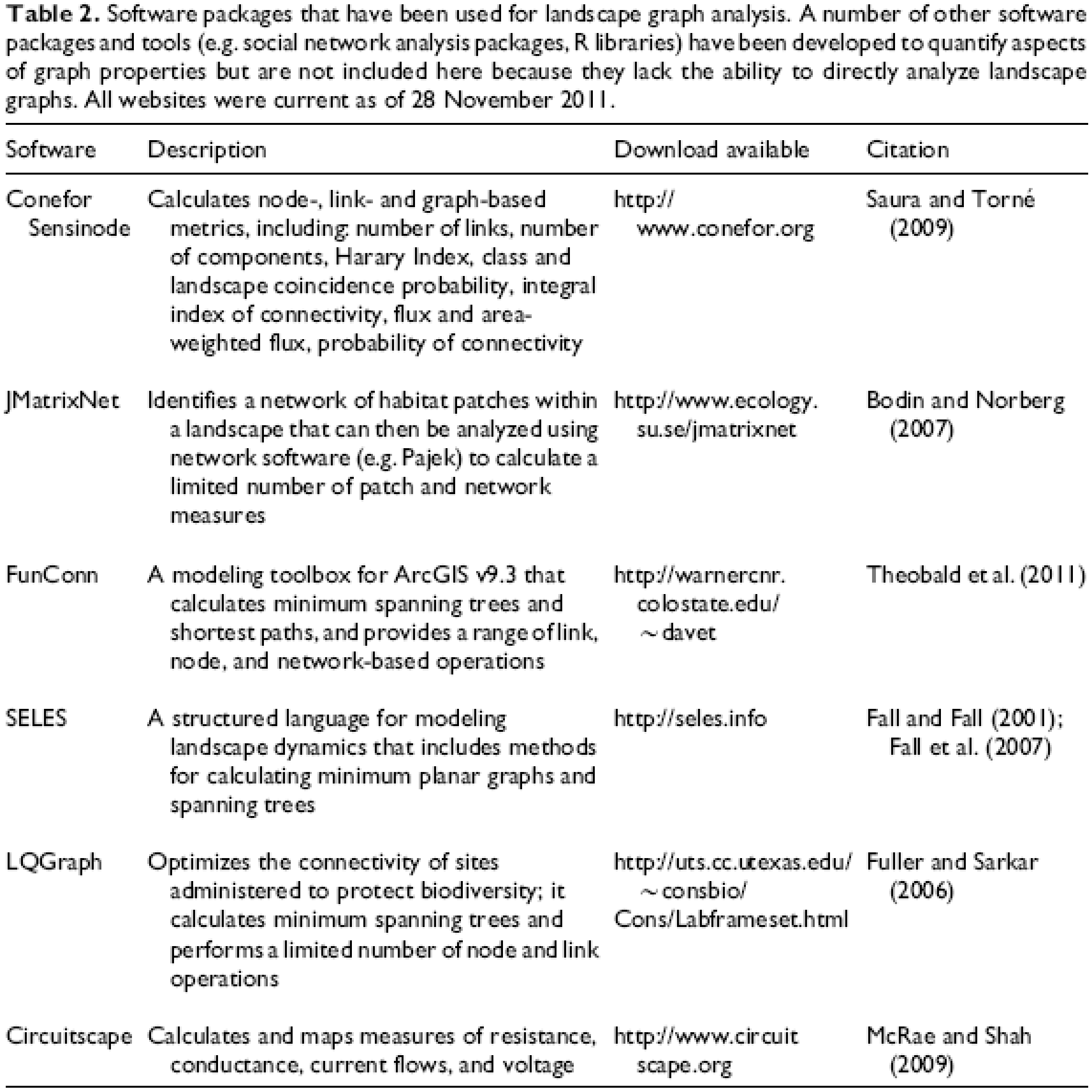


Table 2. Software packages that have been used for landscape graph analysis. A number of other software packages and tools (e.g. social network analysis packages, R libraries) have been developed to quantify aspects of graph properties but are not included here because they lack the ability to directly analyze landscape graphs. All websites were current as of 28 November 2011.

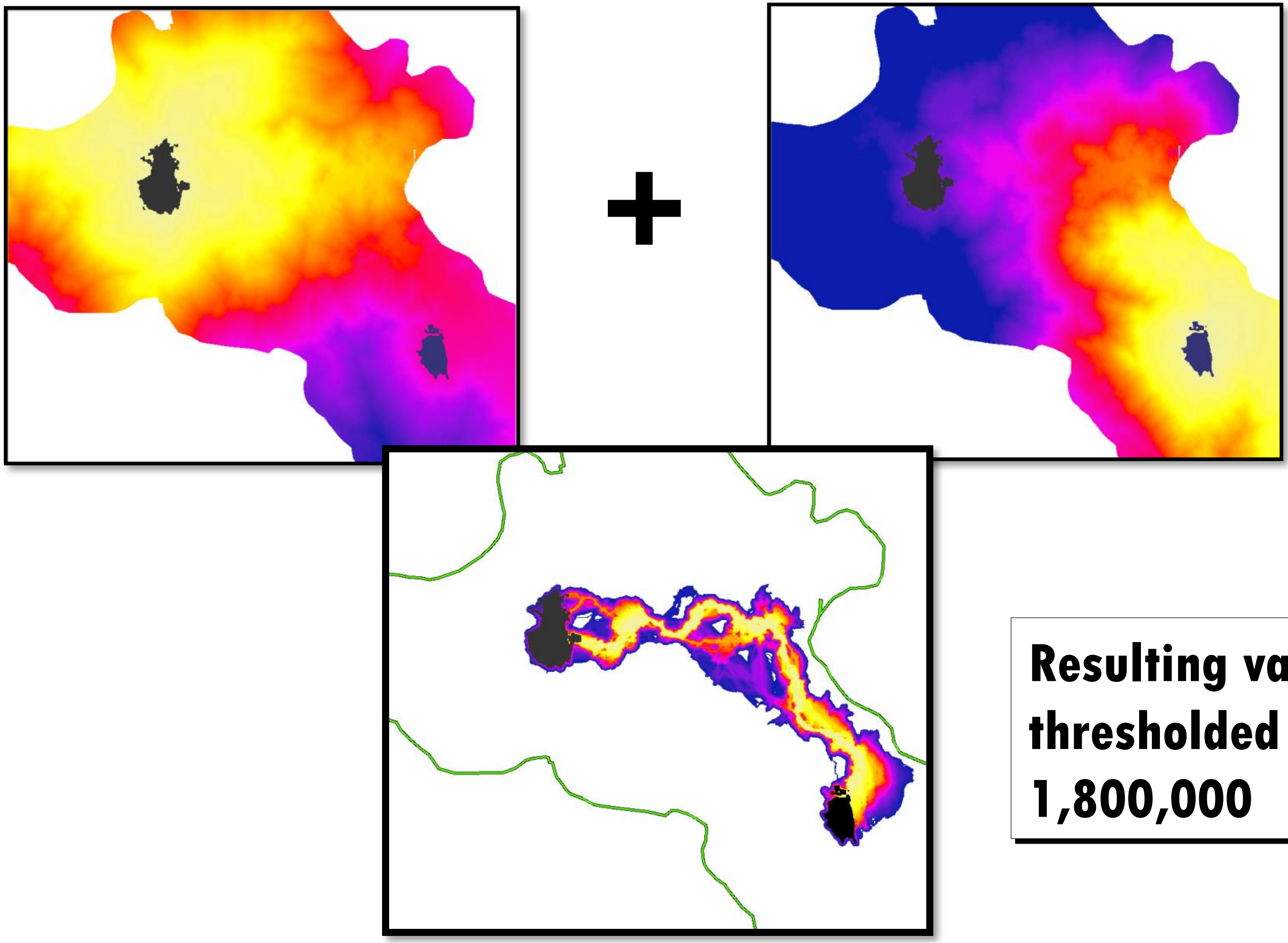
Software	Description	Download available	Citation
Conefor Sensinode	Calculates node-, link- and graph-based metrics, including: number of links, number of components, Harary Index, class and landscape coincidence probability, integral index of connectivity, flux and area-weighted flux, probability of connectivity	http://www.conefor.org	Saura and Torné (2009)
JMatrixNet	Identifies a network of habitat patches within a landscape that can then be analyzed using network software (e.g. Pajek) to calculate a limited number of patch and network measures	http://www.ecology.su.se/jmatrixnet	Bodin and Norberg (2007)
FunConn	A modeling toolbox for ArcGIS v9.3 that calculates minimum spanning trees and shortest paths, and provides a range of link, node, and network-based operations	http://warnercnr.colostate.edu/~davet	Theobald et al. (2011)
SELES	A structured language for modeling landscape dynamics that includes methods for calculating minimum planar graphs and spanning trees	http://seles.info	Fall and Fall (2001); Fall et al. (2007)
LQGraph	Optimizes the connectivity of sites administered to protect biodiversity; it calculates minimum spanning trees and performs a limited number of node and link operations	http://uts.cc.utexas.edu/~consbio/Cons/Labframeset.html	Fuller and Sarkar (2006)
Circuitscape	Calculates and maps measures of resistance, conductance, current flows, and voltage	http://www.circuitscape.org	McRae and Shah (2009)

Kupfer 2012

Alternatives to least cost paths…

- Corridors
- Graph theory
    - Centrality analysis
- Circuit theory
- Agent-based analysis
- Barrier mapping

Least cost path alternative: Corridors



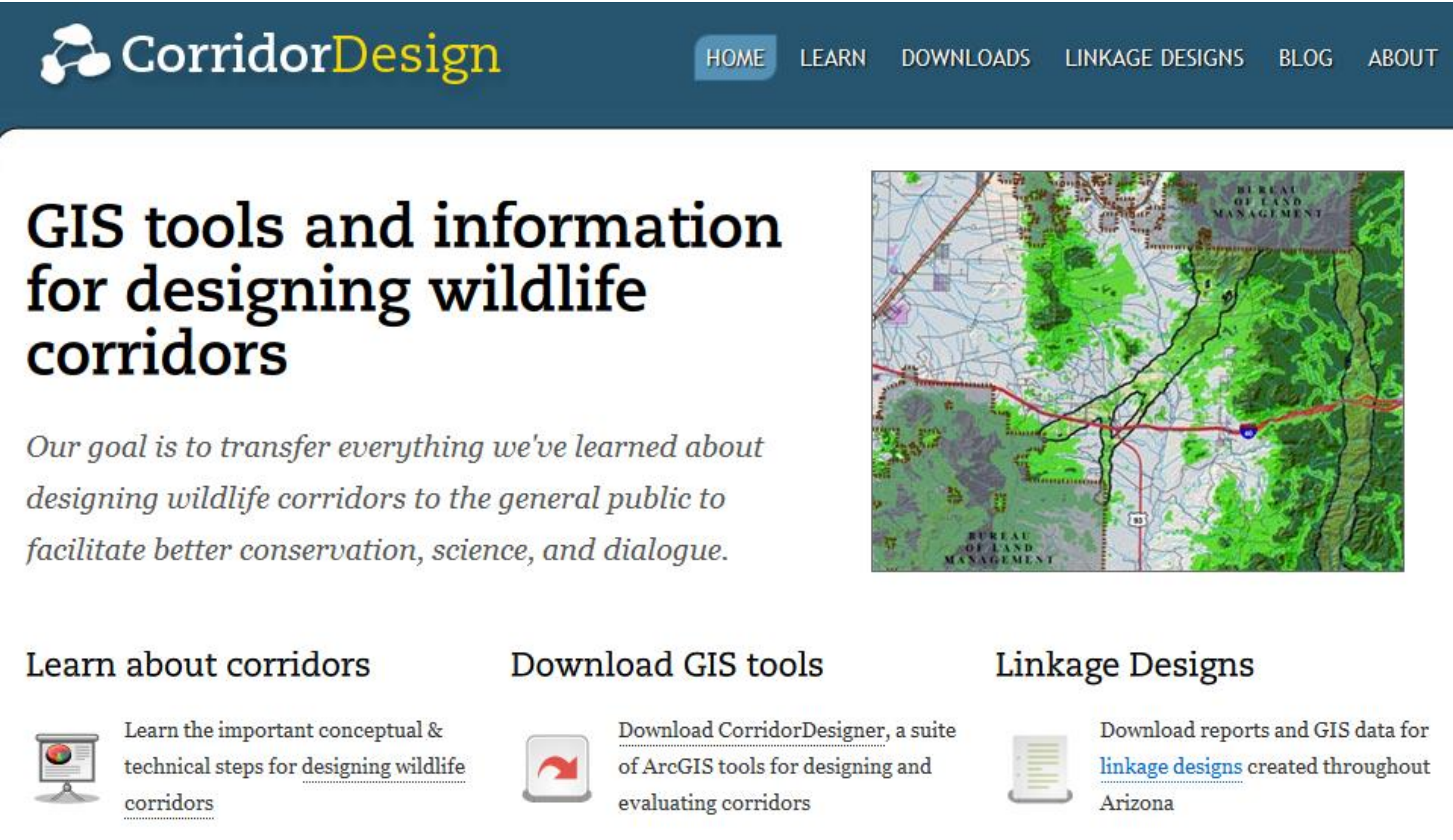
Cost distance to patch 118

Cost distance to patch 358

Resulting values, thresholded at e.g. 1,800,000

Corridor design

http://corridordesign.org/



GIS tools and information for designing wildlife corridors

Our goal is to transfer everything we've learned about designing wildlife corridors to the general public to facilitate better conservation, science, and dialogue.

Learn about corridors

Learn the important conceptual & technical steps for designing wildlife corridors

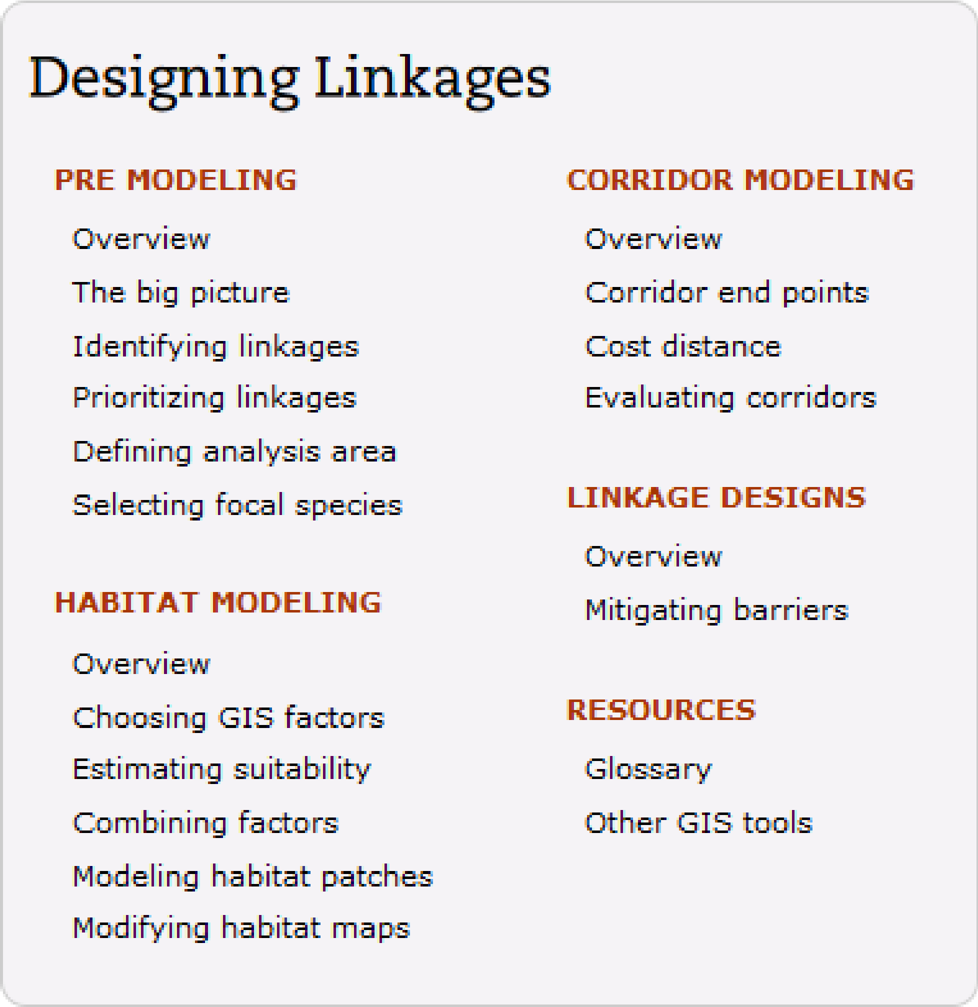
Download GIS tools

Download CorridorDesigner, a suite of ArcGIS tools for designing and evaluating corridors

Linkage Designs

Download reports and GIS data for linkage designs created throughout Arizona

CorridorDesign



Designing Linkages

PRE MODELING

- Overview
- The big picture
- Identifying linkages
- Prioritizing linkages
- Defining analysis area
- Selecting focal species

HABITAT MODELING

- Overview
- Choosing GIS factors
- Estimating suitability
- Combining factors
- Modeling habitat patches
- Modifying habitat maps

CORRIDOR MODELING

- Overview
- Corridor end points
- Cost distance
- Evaluating corridors

LINKAGE DESIGNS

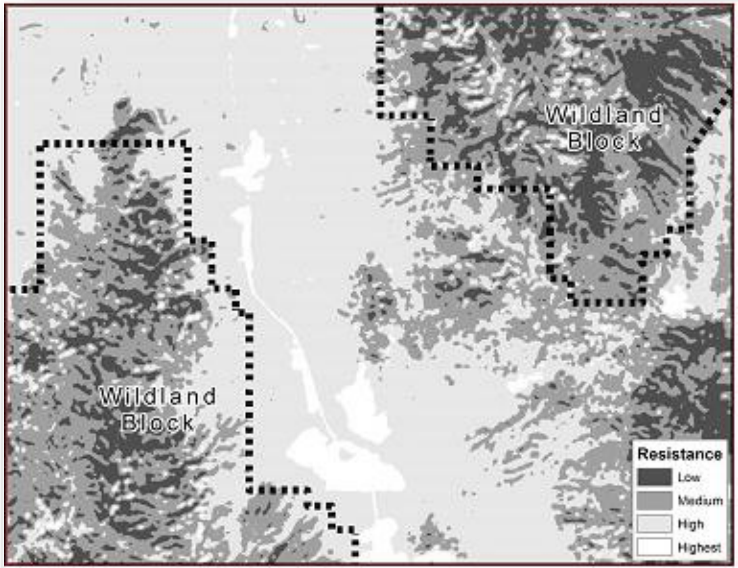
- Overview
- Mitigating barriers

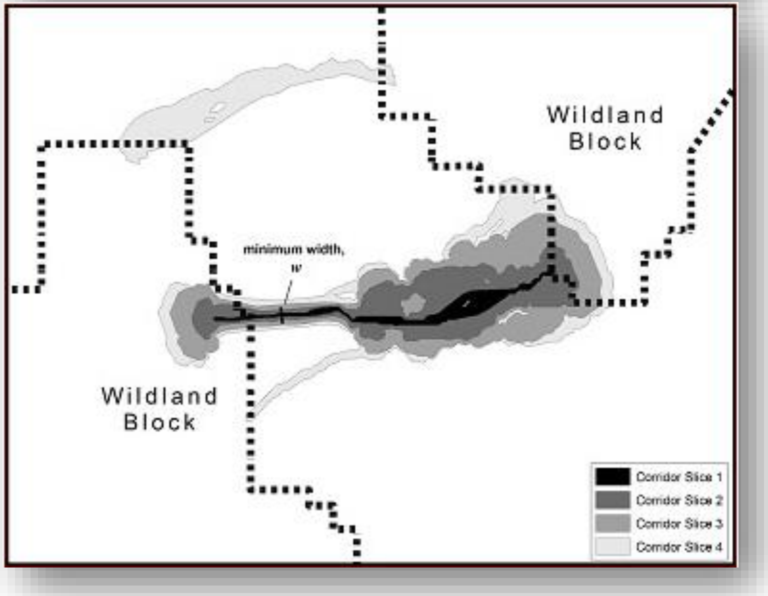
RESOURCES

- Glossary
- Other GIS tools

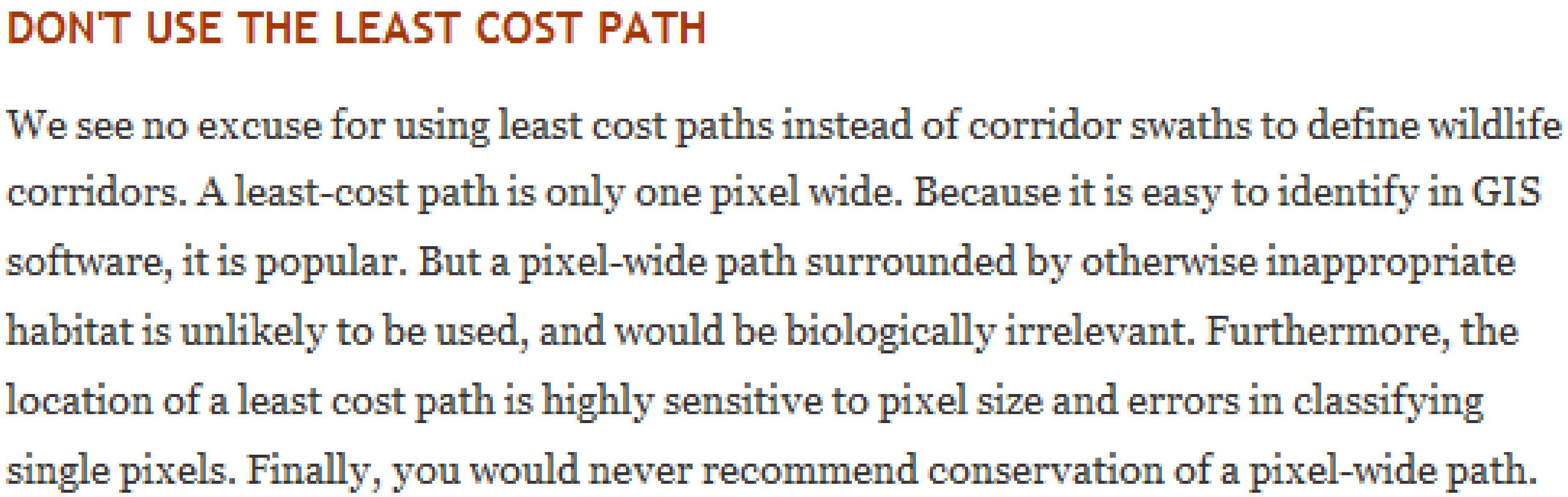
- Why do you need to maintain connectivity in your analysis area?
- What are you trying to connect?
- What are the land ownership/stewardship patterns in the area?
- What are the threats?
- What does the land cover look like?
- What types of species occur in your analysis area?
- Who are the major stakeholders who you should work with in your study?

1. Use the inverse of the habitat suitability map as a resistance map
2. Select terminals within each *wildland block* as start and end points for modeling the corridor
3. Calculate cost-distance for each pixel, and select an appropriate slice of the cost-distance map as the modeled corridor





CorridorDesign



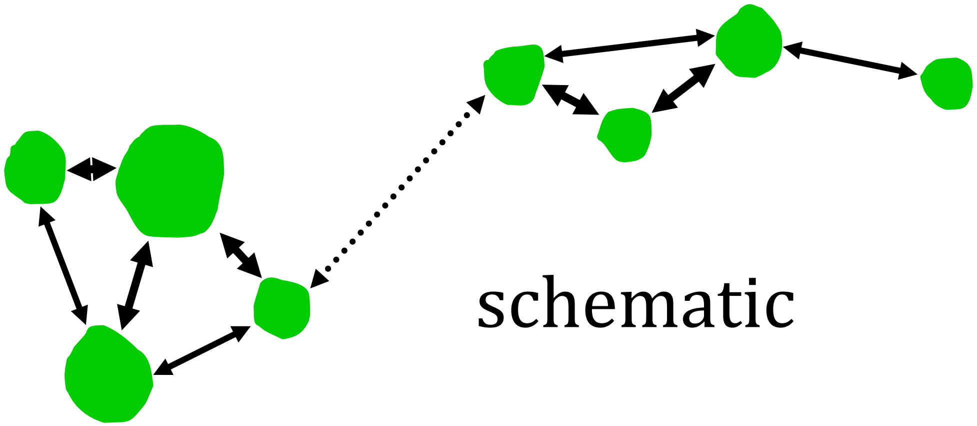
DON'T USE THE LEAST COST PATH

We see no excuse for using least cost paths instead of corridor swaths to define wildlife corridors. A least-cost path is only one pixel wide. Because it is easy to identify in GIS software, it is popular. But a pixel-wide path surrounded by otherwise inappropriate habitat is unlikely to be used, and would be biologically irrelevant. Furthermore, the location of a least cost path is highly sensitive to pixel size and errors in classifying single pixels. Finally, you would never recommend conservation of a pixel-wide path.

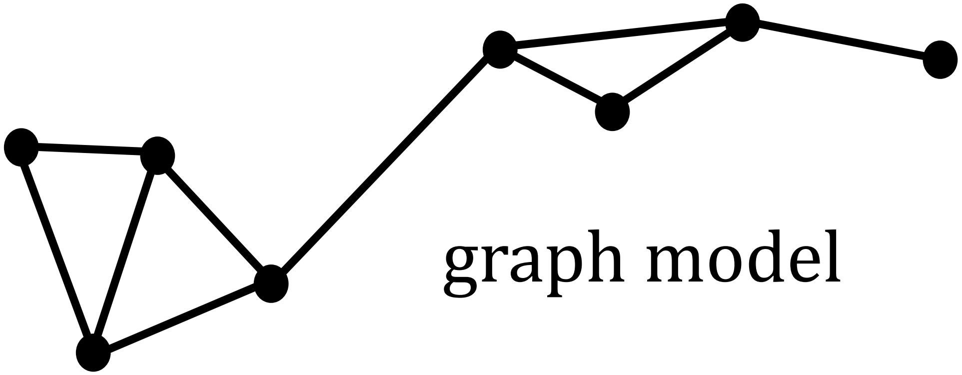
Summary:

- Provides a good overview of conservation planning process with an emphasis on corridor design
- Tips and advice derived from numerous design workshops
- CorridorDesign tool does not do much that's different from what we do in our lab…

Graph analysis



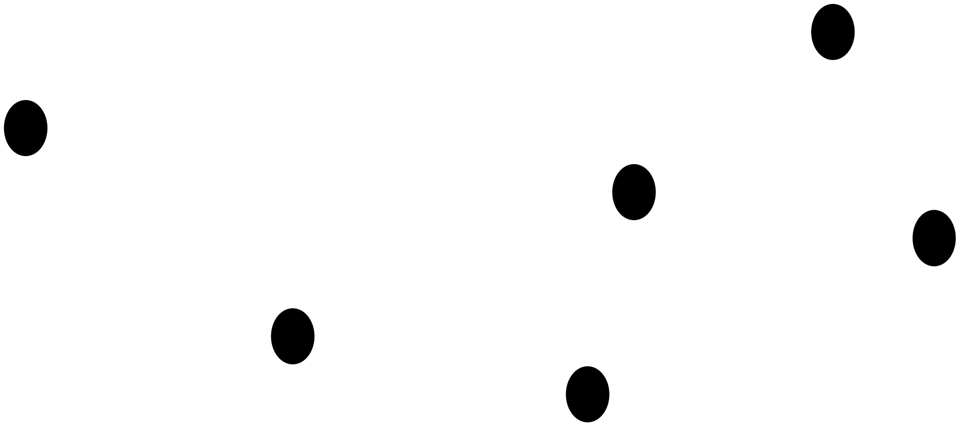
schematic



graph model

Graph analysis

A *graph* is a set of *nodes*…

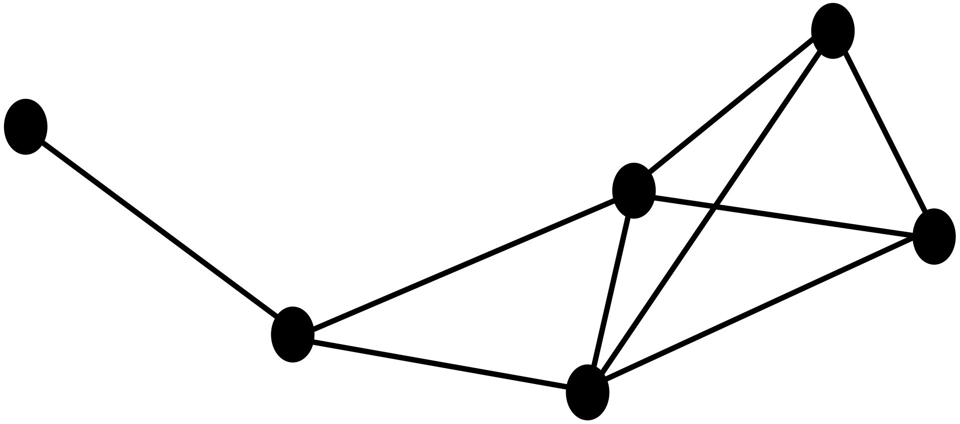


Nodes are habitat patches

After Dykstra 1969

Graph analysis

A *graph* is a set of *nodes* and *edges*

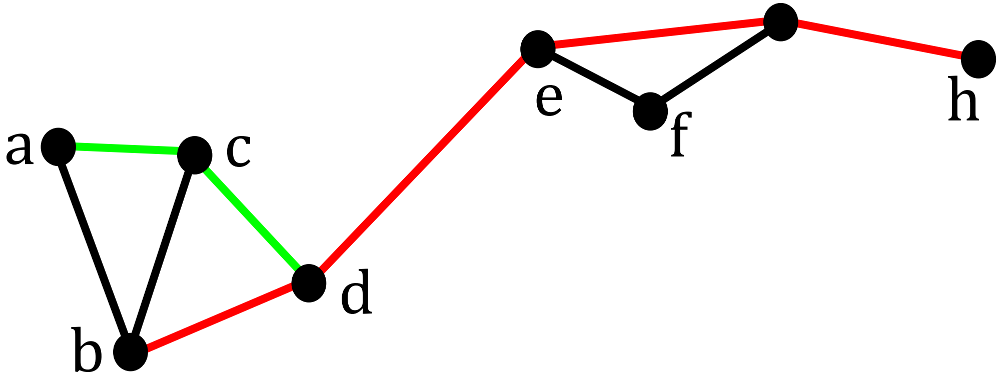


- **Nodes** are habitat patches
- **Edges** are drawn if the two patches are connected by dispersal

After Dykstra 1969

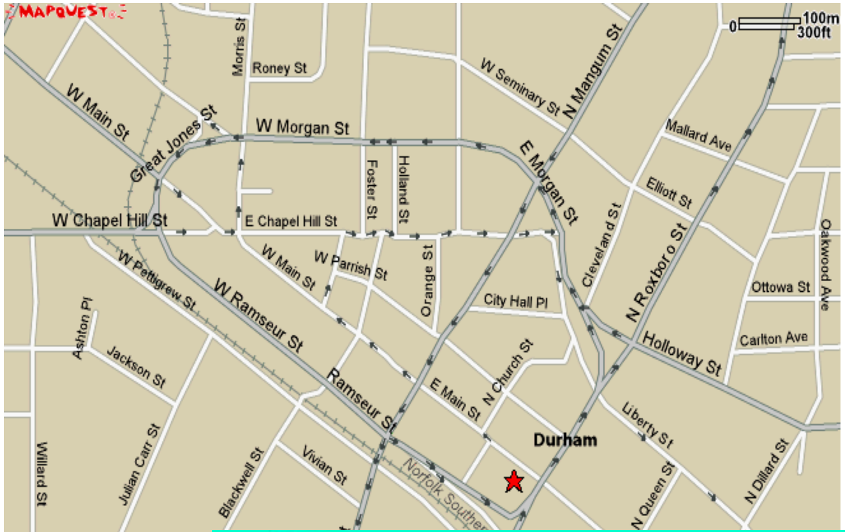
Graph (a.k.a. network) properties

- Nodes and edges
- Node degree and degree distribution
- Characteristic path length
  - shortest path
  - longest shortest path (diameter)
- Community structure

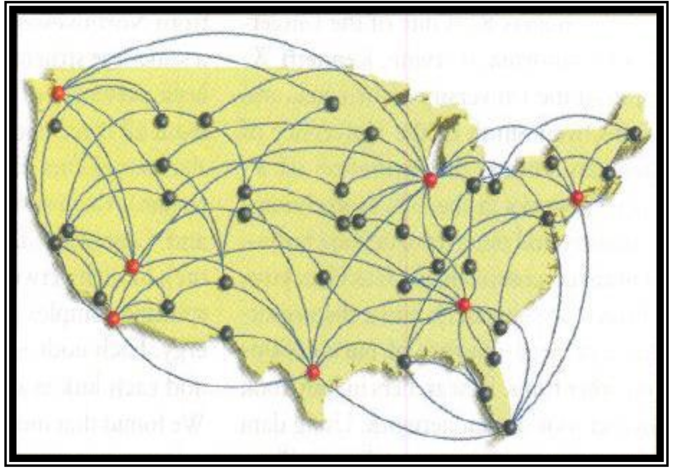


Graphs: familiar examples

Roads

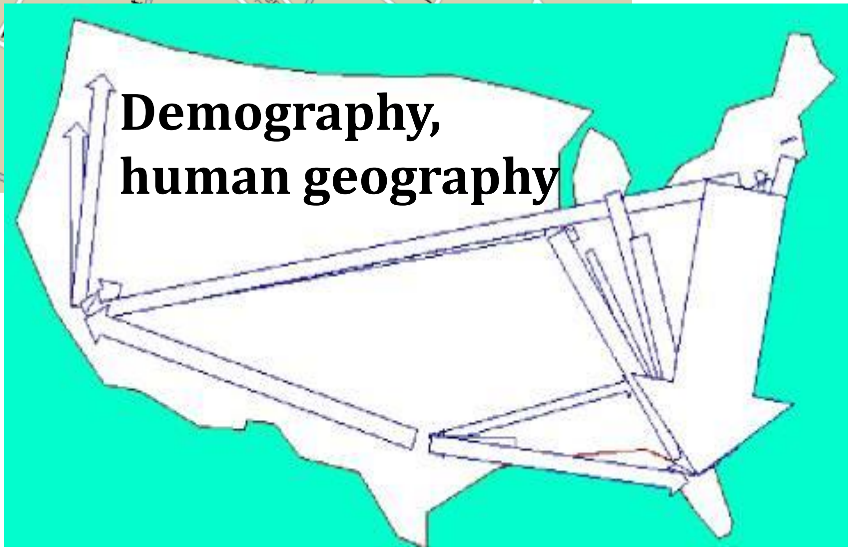


Airports



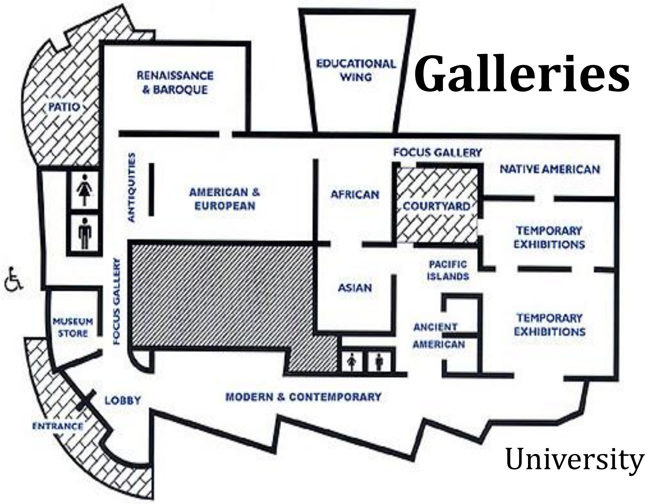
Barabasi & Bonabeau (2003)

Demography, human geography



Waldo Tobler

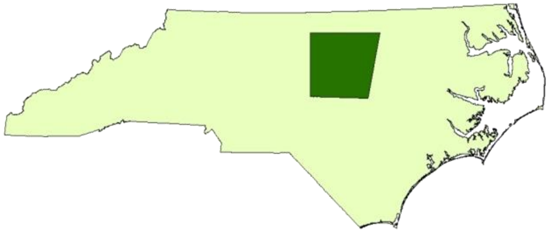
Galleries



University of Miami

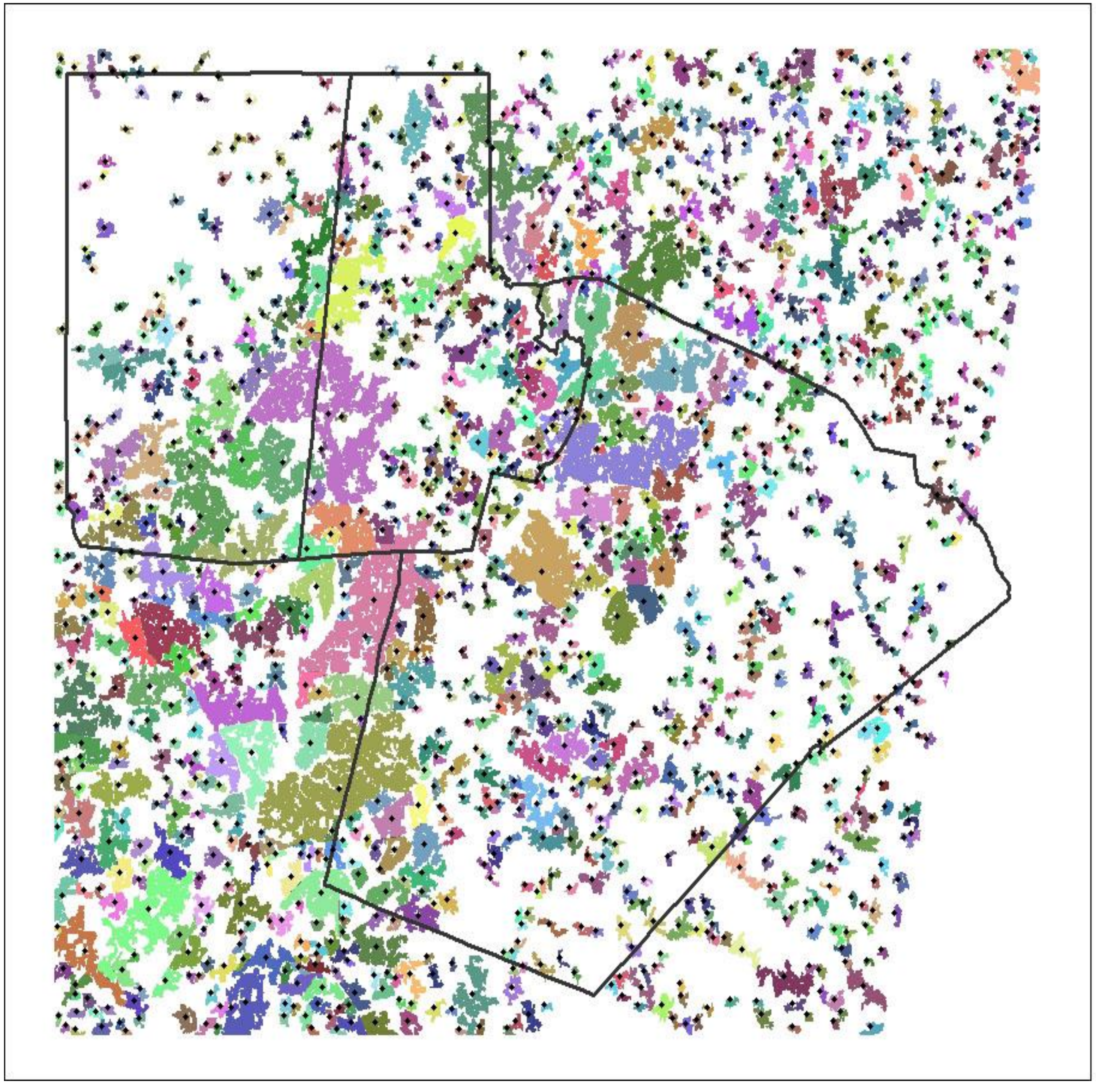
Graph analysis example: Forest birds

Emily Minor, Duke PhD.



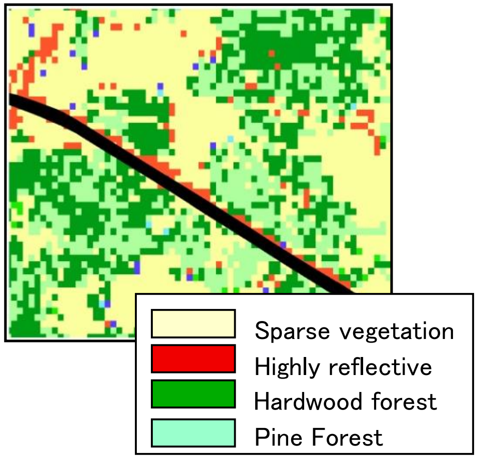
Forest patches
> 25 ha in size

Lang Elliott (Naturesound)



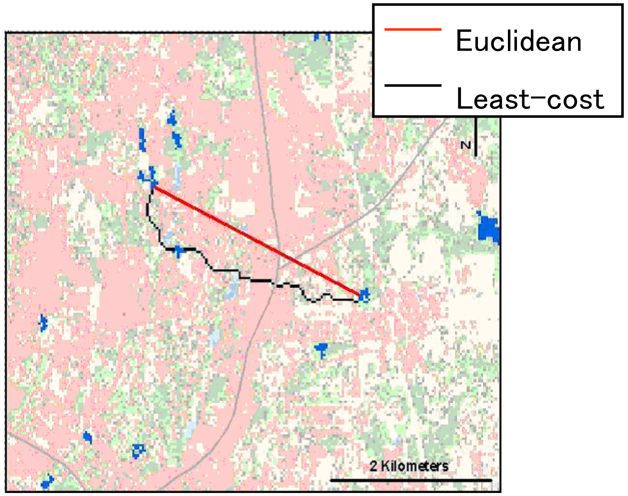
Graph analysis example: Forest birds

Graph construction



<u>Nodes</u>: forest types classified from imagery, aggregated into patches, culled to (arbitrary) size threshold

<u>Edges</u>: least-cost paths weighted by land cover resistance to dispersal



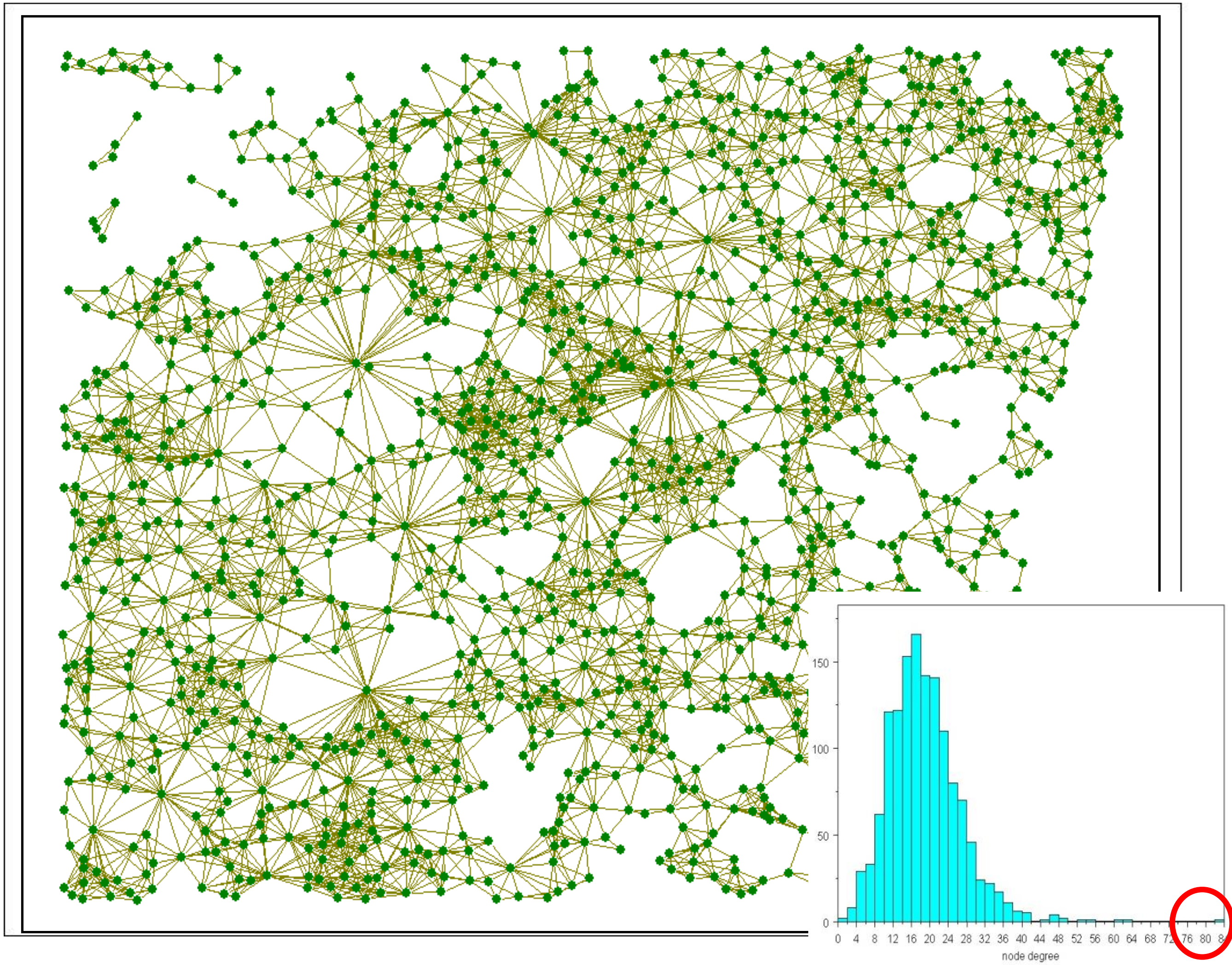
Graph analysis example: Forest birds

Creating a network topology

LCPs area converted into graph edges.

Edges can be weighted by dispersal probability (flux)

Large, highly connected patches (i.e. those with high node degree) appear as hubs

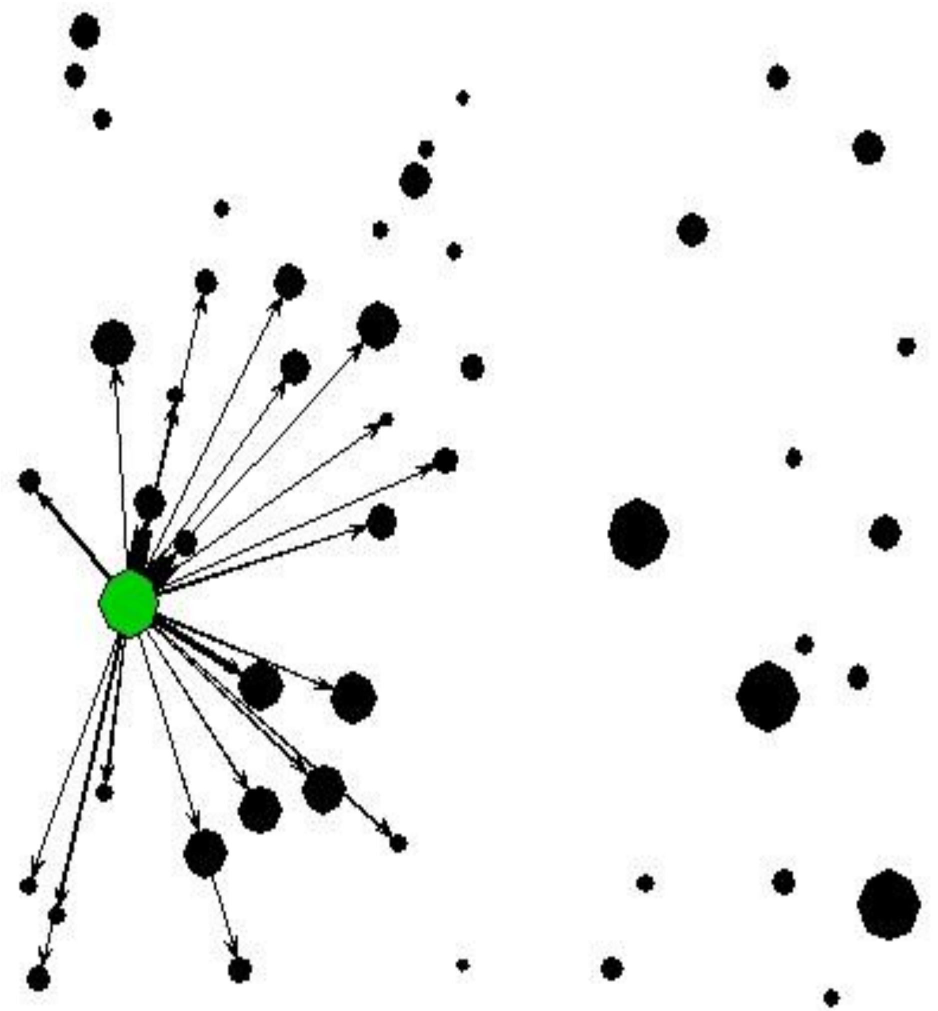


Metapopulations as graphs

Once we have created a topological graph, we can describe its properties

- Node list and attributes
  - (X,Y), area, quality …
- Edge matrices:
  - adjacency (Boolean)
  - distance or functional distance
  - dispersal probability (undirected edges)
  - area-weighted dispersal flux (directed arcs)

Metapopulations: Sources & Sinks



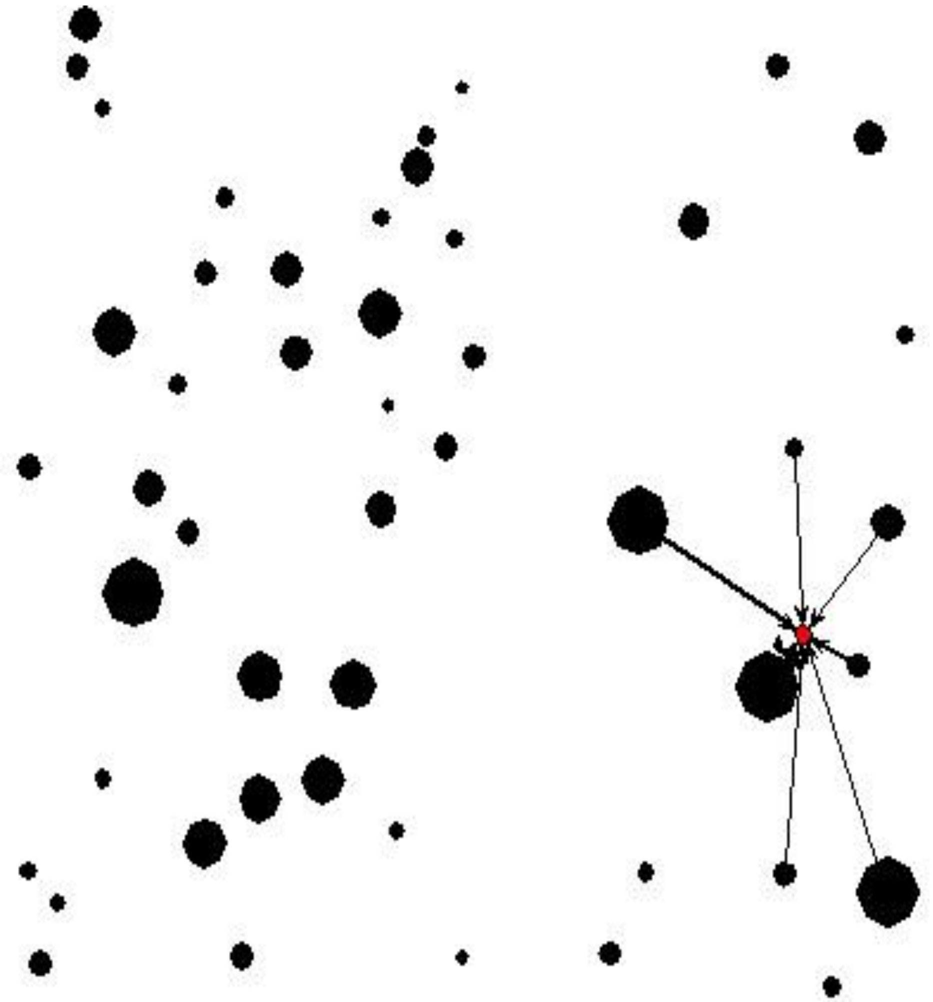
Source
a patch with high
total outflux
to nearby patches

$W_{ij} = A_i \exp(-kD_{ij})$

A = area (proxy for pop'n)
D = distance
k = distance decay factor

Metapopulations: Sources & Sinks

Sink
a patch with
high total influx
but low outflux



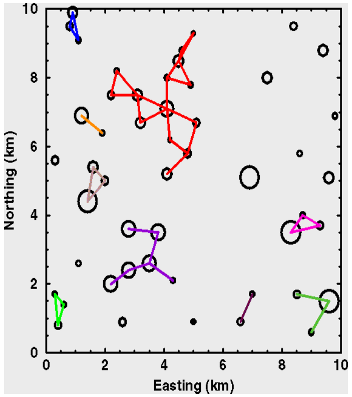
Metapopulations: Connectivity

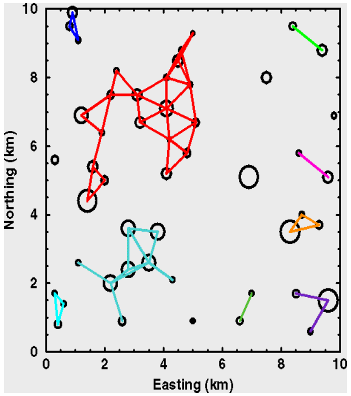
Goals:

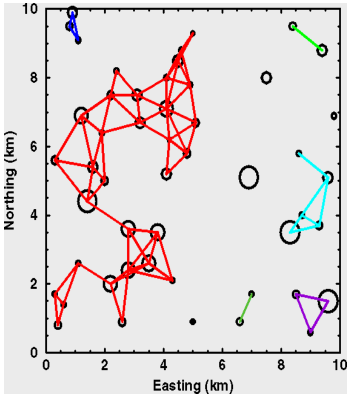
- Make the network optimally connected to reduce risk while ensuring recovery from disturbance (“spreading of risk” model)

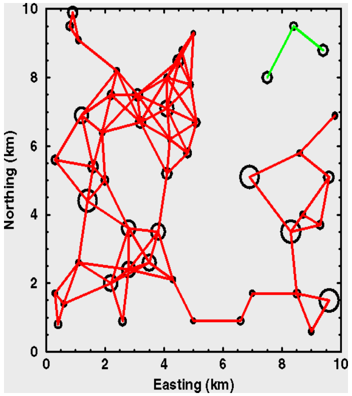
- Find the well-connected “backbone” of a network

Subgraphs: edge thresholding


d*=750 m

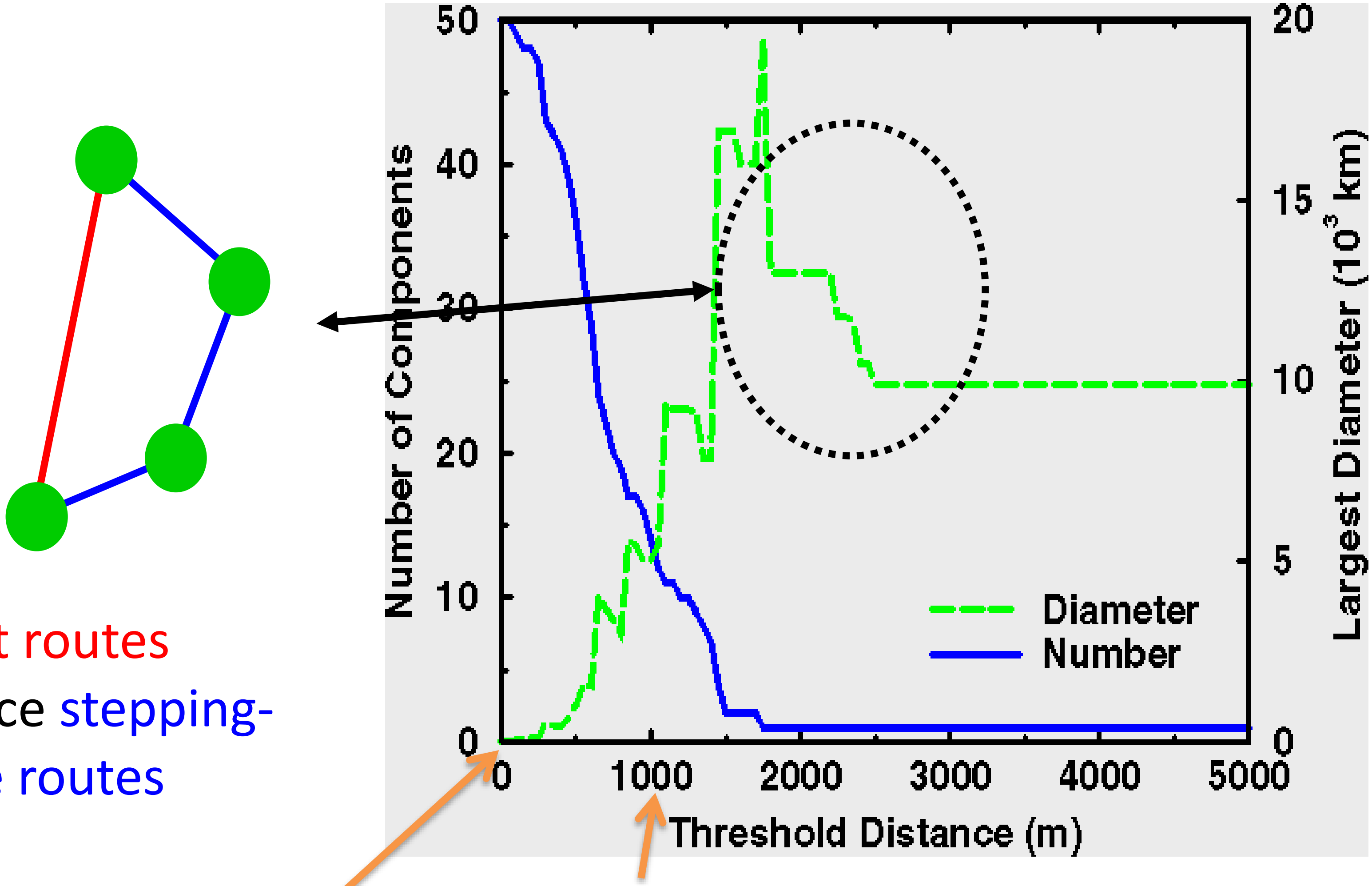

1000 m


1250 m


1500 m

Largest component defines graph diameter

Edge-thinning: trends



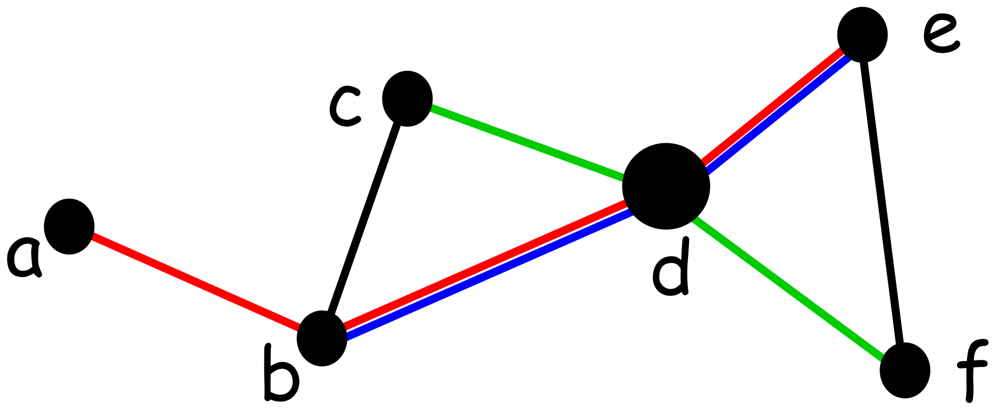
direct routes replace stepping-stone routes

No edges in graph; everything disconnected

Only edges < 1000 m kept in graph;

Betweenness centrality

- Number of shortest paths that include that node



Node “d” is in paths ae, be, cf, …
it is *central* to the graph because
it is *between* a lot of nodes

Metapopulations as graphs

- Graph models can represent source/sink models as well as spreading-of-risk models (and apparently any other model)
- Graph algorithms provide optimal solutions to many network tasks concerned with routing or network flow (reserve system design?)
- There's a *lot* more available …
  - social network theory
  - network optimization

Are you a node?

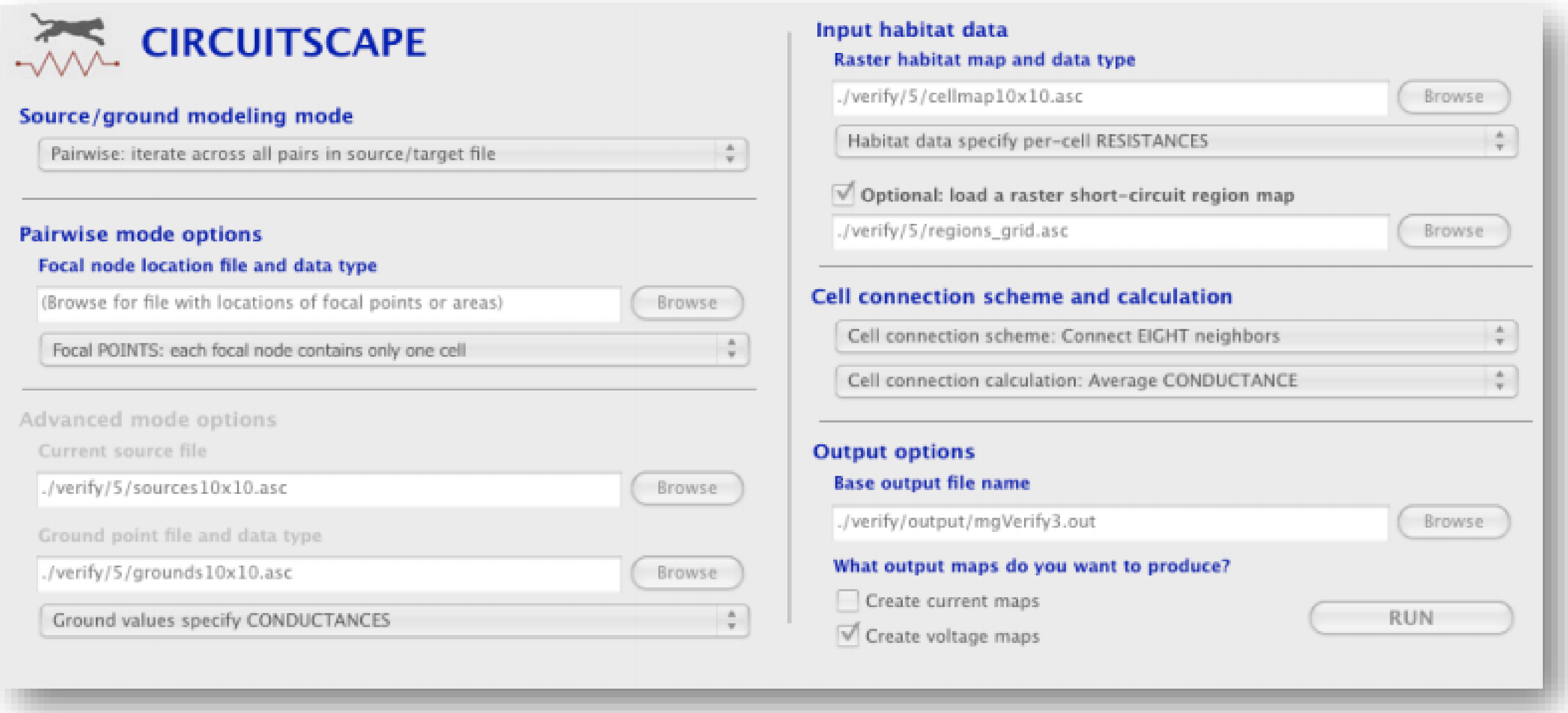
Graph analysis: Summary

- Network (graph) theory provides a ready body of data structures and algorithms for applications concerned with connectivity
- These seem readily amenable to source/sink and spreading-of-risk metapopulation models
- Initial applications have been promising
- Software is increasingly available (and mostly free—but not necessarily user-friendly)

Connectivity: Summary

- Context of a patch among neighboring patches (i.e. connectivity) allows us to evaluate landscapes beyond just habitat quantity and quality; it enables us to incorporate metapopulation dynamics into the analysis.
- Spatial analysis (Euclidean & cost distance) provides useful information regarding connectivity
- However, additional techniques (circuit theory and graph theory) are used to overcome computational and technical limitations

Circuitscape



CIRCUITSCAPE

Source/ground modeling mode

Pairwise: iterate across all pairs in source/target file

Pairwise mode options

Focal node location file and data type

(Browse for file with locations of focal points or areas)

Focal POINTS: each focal node contains only one cell

Advanced mode options

Current source file

./verify/5/sources10x10.asc

Ground point file and data type

./verify/5/grounds10x10.asc

Ground values specify CONDUCTANCES

Input habitat data

Raster habitat map and data type

./verify/5/cellmap10x10.asc

Habitat data specify per-cell RESISTANCES

☑ Optional: load a raster short-circuit region map

./verify/5/regions_grid.asc

Cell connection scheme and calculation

Cell connection scheme: Connect EIGHT neighbors

Cell connection calculation: Average CONDUCTANCE

Output options

Base output file name

./verify/output/mgVerify3.out

What output maps do you want to produce?

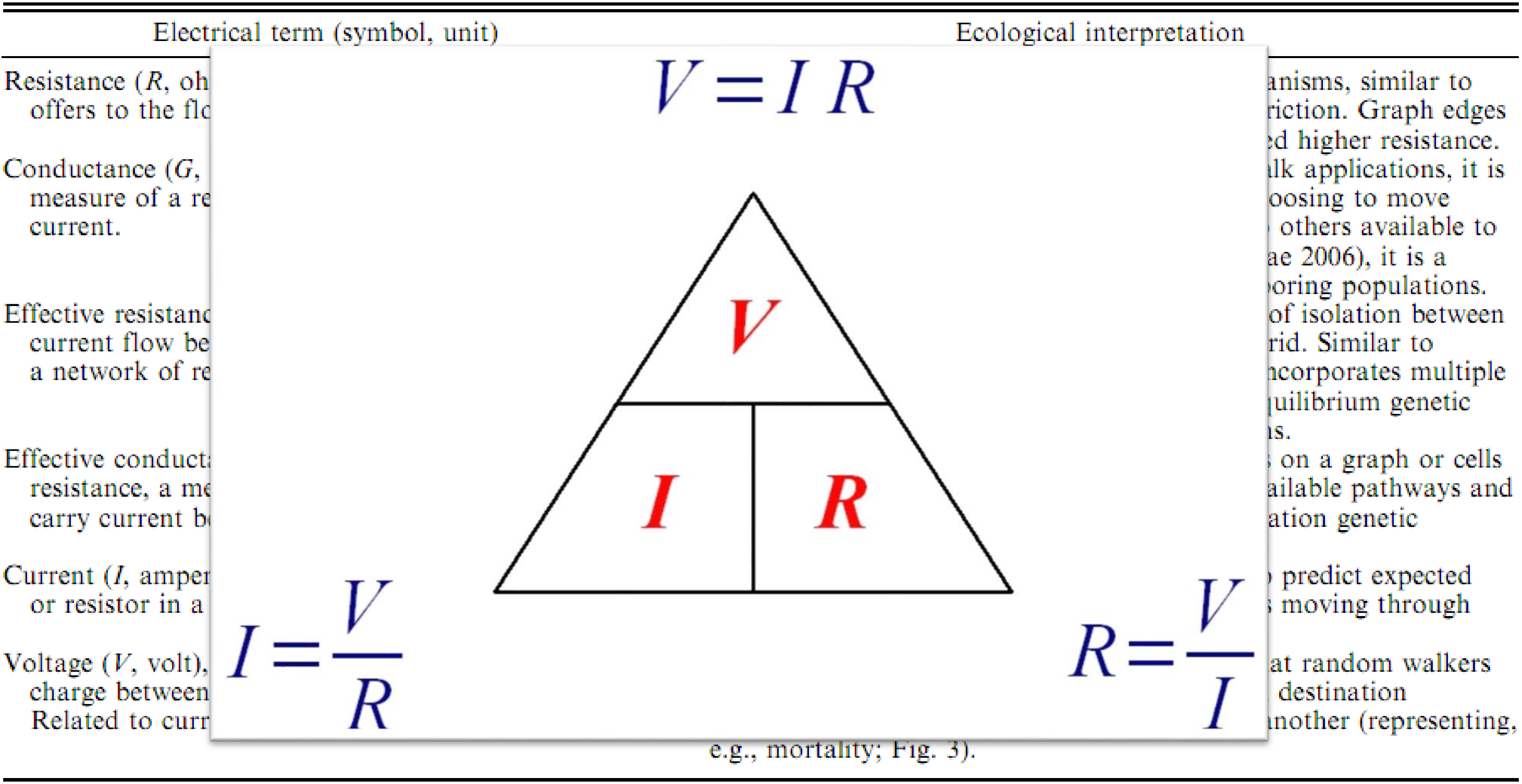
☐ Create current maps

☑ Create voltage maps

http://www.circuitscape.org/

Circuit theory

multiple pathways in electrical networks increase connectivity…



Electrical term (symbol, unit)	Ecological interpretation
Resistance (R, oh offers to the flo	anisms, similar to riction. Graph edges d higher resistance.
Conductance (G, measure of a re current.	lk applications, it is oosing to move others available to ae 2006), it is a oring populations.
Effective resistanc current flow be a network of re	of isolation between rid. Similar to ncorporates multiple uilibrium genetic ıs.
Effective conduct resistance, a me carry current b	on a graph or cells ailable pathways and ation genetic
Current (I, amper or resistor in a	predict expected moving through
Voltage (V, volt), charge between Related to curr	at random walkers destination nother (representing, e.g., mortality; Fig. 3).

$$V = I R$$

$$I = \frac{V}{R}$$

$$R = \frac{V}{I}$$

McRae et al, 2008

Circuit theory

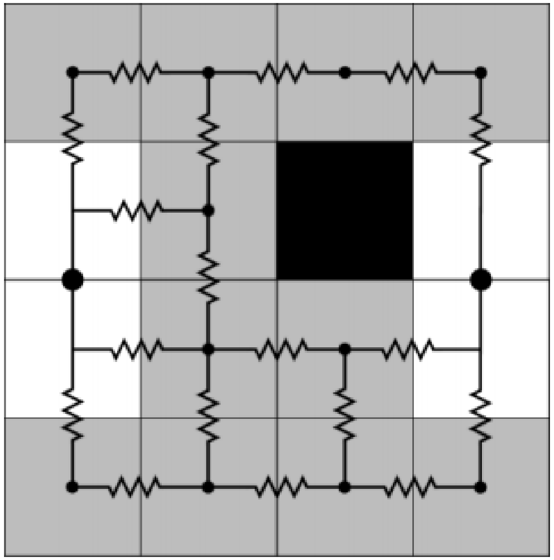
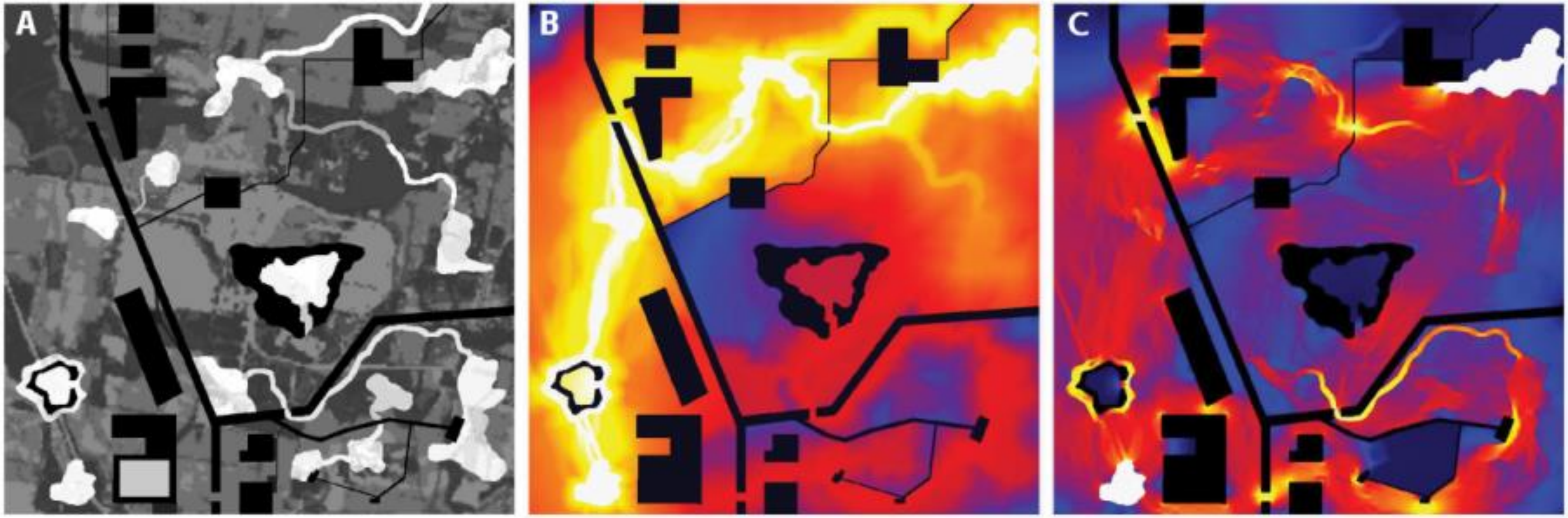


FIG. 4. A simple landscape represented as both a grid and a circuit. The landscape contains two contiguous patches of 0-resistance cells (open), dispersal habitat of finite resistance (gray), and one "barrier" cell with infinite resistance (black). Cells with finite resistance are replaced with nodes (small dots), and adjacent nodes are connected by resistors. Patches of cells with 0 resistance are each consolidated into a single node (large dots). Connections between diagonal neighbors and nonadjacent cells can also be incorporated, the latter representing "hops" over intervening cells. Current sources, voltage sources, and ground connections can be added as in Figs. 2 and 3.



How large of a landscape can I analyze with Circuitscape?

- The size of grids that can be analyzed depends on how much RAM Circuitscape can address. We have solved grids with 100 million cells on Linux systems. However, 32-bit Windows and Mac operating systems limit the amount of RAM that Python can address, meaning that only landscapes in the neighborhood of 1-6 million cells can be solved on these systems, even when they have lots of RAM.

- Users can generally coarsen their grids and get results that closely approximate those run at fine-scale resolution (see McRae et al. 2008). To solve the largest grids, we recommend that users find a 64-bit Windows or Linux system with lots of RAM, and follow the instructions for installing on 64-bit Windows or Linux.

- We are working to push these limits, through the use of more efficient algorithms and parallel computing. Please see the user guide for hints on getting the most out of the memory you have.

Circuit theory

Advantages

- Provides intuitive analytic analogues for resistance, conductance, and flow over networks depicted as 'wiring diagrams'
- Allows multiple pathways to be modeled between node pairs
- Each path can be quantified in terms of relative flow rates
- Relative flow rates integrated over all possible paths

Disadvantages

- Extremely computationally intensive
- Circuit links cannot be directional

Agent-based analysis (simulation)

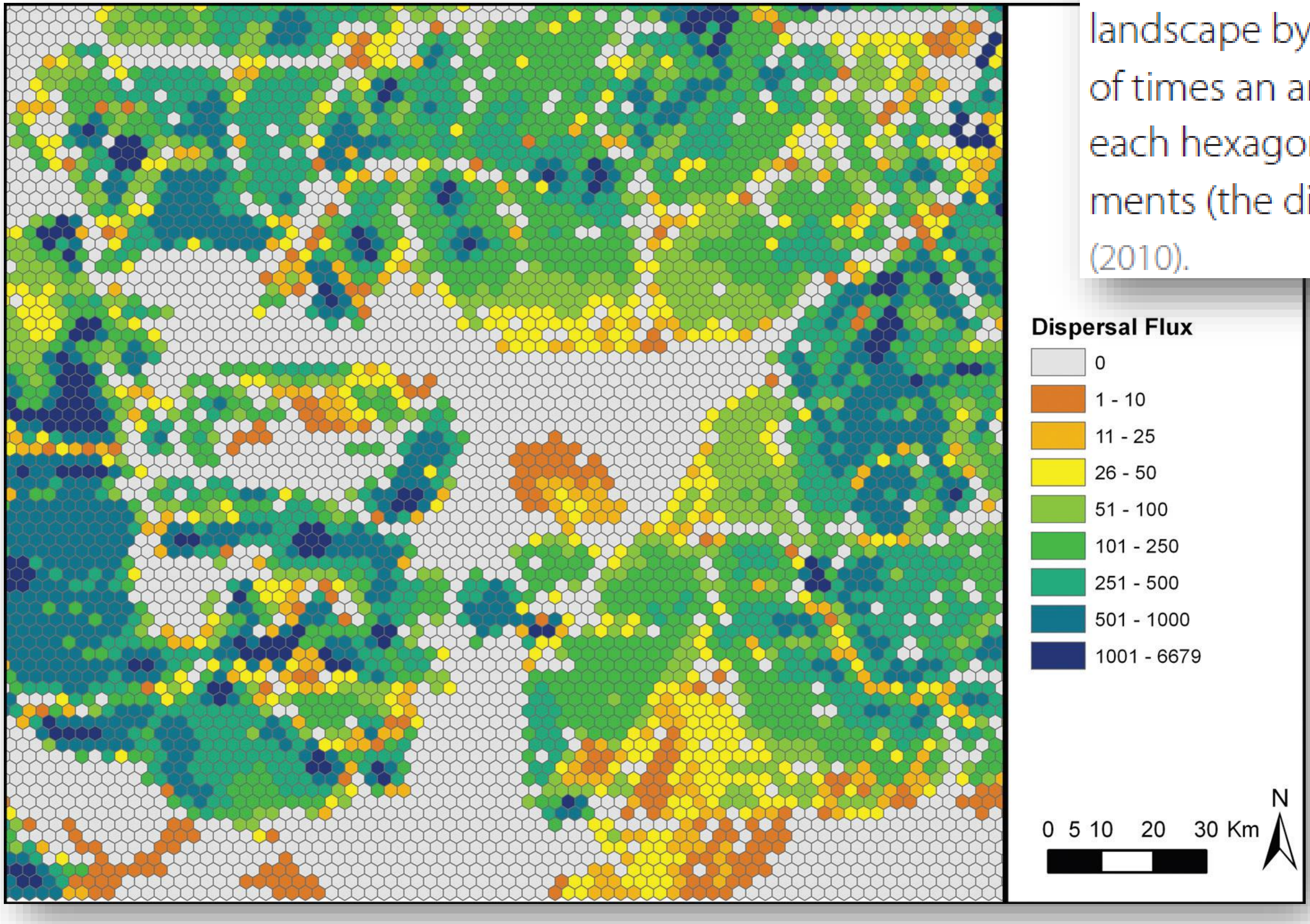
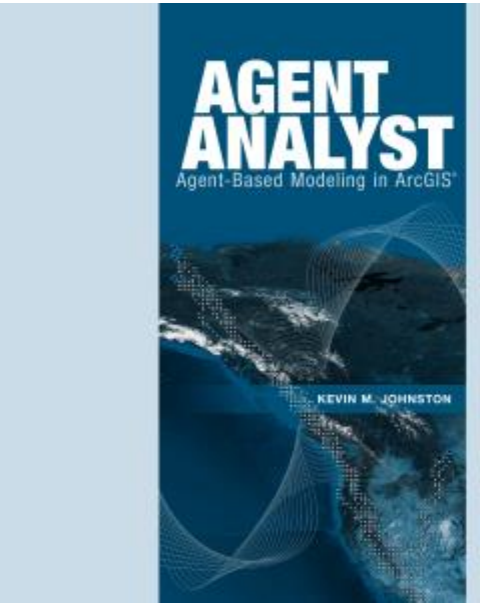


Figure 10.5b. HexSim can quantify simulated movement rates through a landscape by recording the number of times an animal passes through each hexagon during dispersal movements (the dispersal flux). WHCWG (2010).

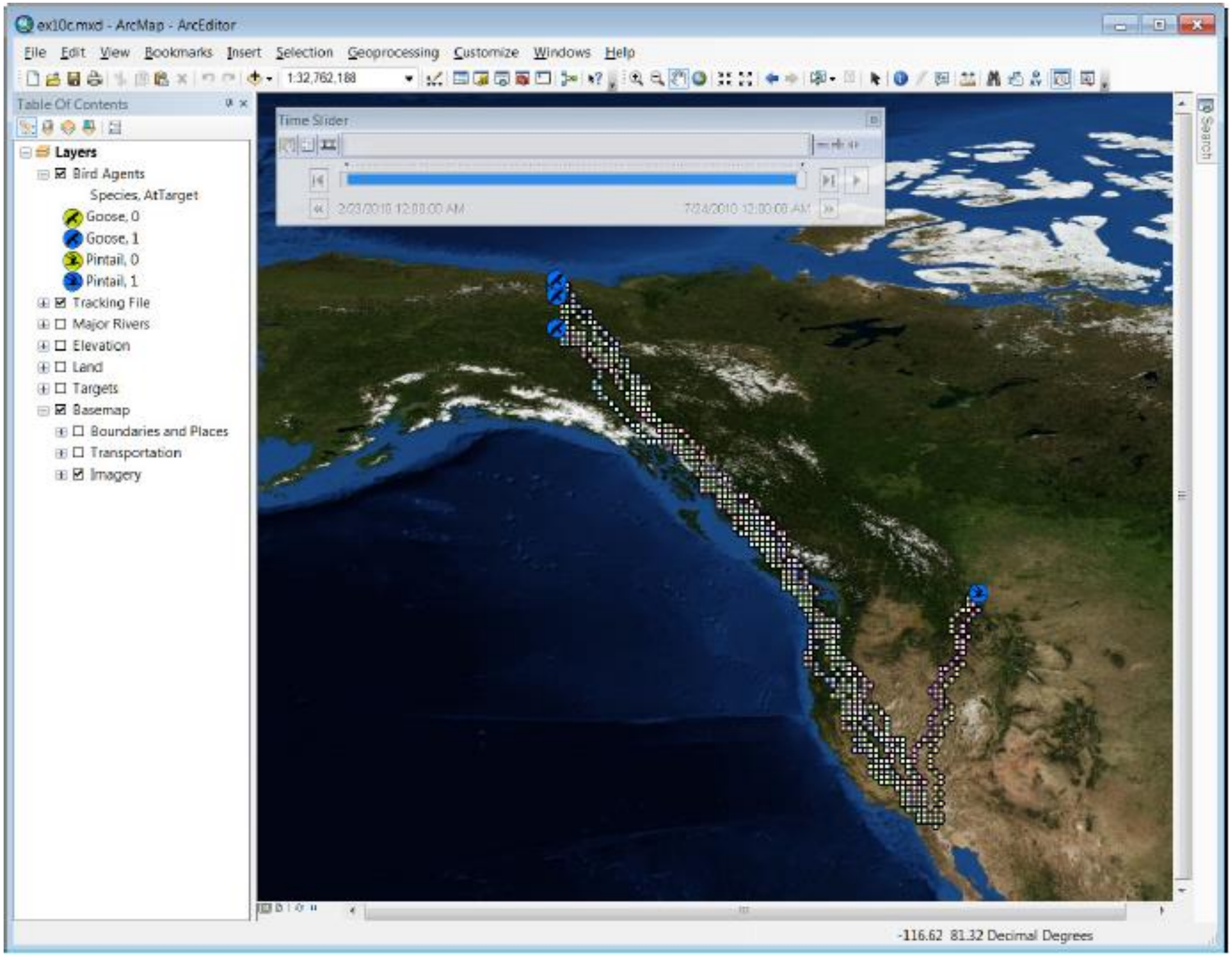
Agent-based analysis (simulation)



AGENT ANALYST

Agent-Based Modeling in ArcGIS®

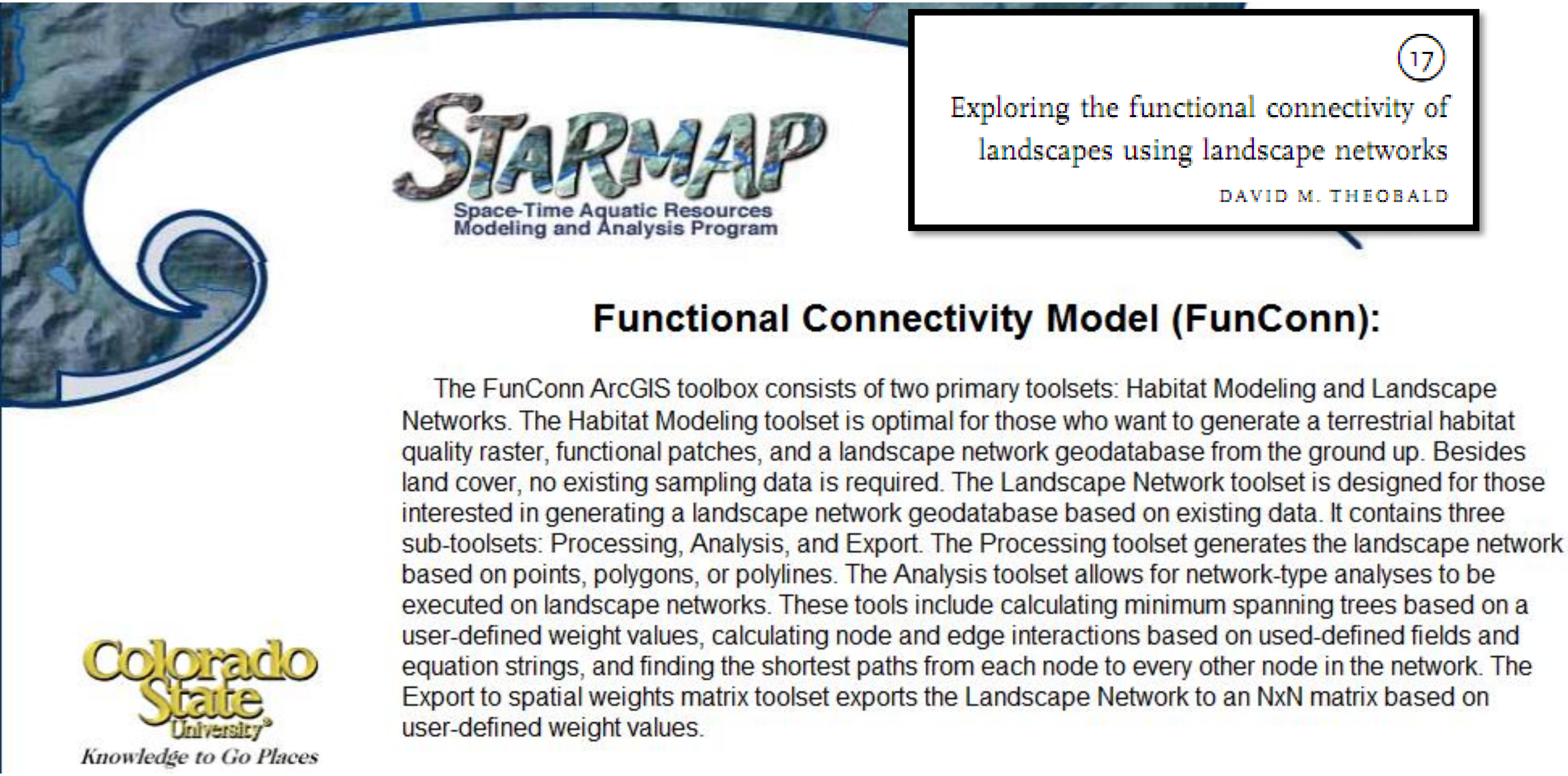
KEVIN M. JOHNSTON



Layers
- ☑ Bird Agents
  - Species, AtTarget
  - Goose, 0
  - Goose, 1
  - Pintail, 0
  - Pintail, 1
- ☑ Tracking File
- ☐ Major Rivers
- ☐ Elevation
- ☐ Land
- ☐ Targets
- ☑ Basemap
  - ☐ Boundaries and Places
  - ☐ Transportation
  - ☑ Imagery

http://resources.arcgis.com/en/help/agent-analyst/

Functional Connectivity: *FunConn*



⑰

Exploring the functional connectivity of landscapes using landscape networks

DAVID M. THEOBALD

Functional Connectivity Model (FunConn):

The FunConn ArcGIS toolbox consists of two primary toolsets: Habitat Modeling and Landscape Networks. The Habitat Modeling toolset is optimal for those who want to generate a terrestrial habitat quality raster, functional patches, and a landscape network geodatabase from the ground up. Besides land cover, no existing sampling data is required. The Landscape Network toolset is designed for those interested in generating a landscape network geodatabase based on existing data. It contains three sub-toolsets: Processing, Analysis, and Export. The Processing toolset generates the landscape network based on points, polygons, or polylines. The Analysis toolset allows for network-type analyses to be executed on landscape networks. These tools include calculating minimum spanning trees based on a user-defined weight values, calculating node and edge interactions based on used-defined fields and equation strings, and finding the shortest paths from each node to every other node in the network. The Export to spatial weights matrix toolset exports the Landscape Network to an NxN matrix based on user-defined weight values.

http://www.nrel.colostate.edu/projects/starmap/funconn_index.htm

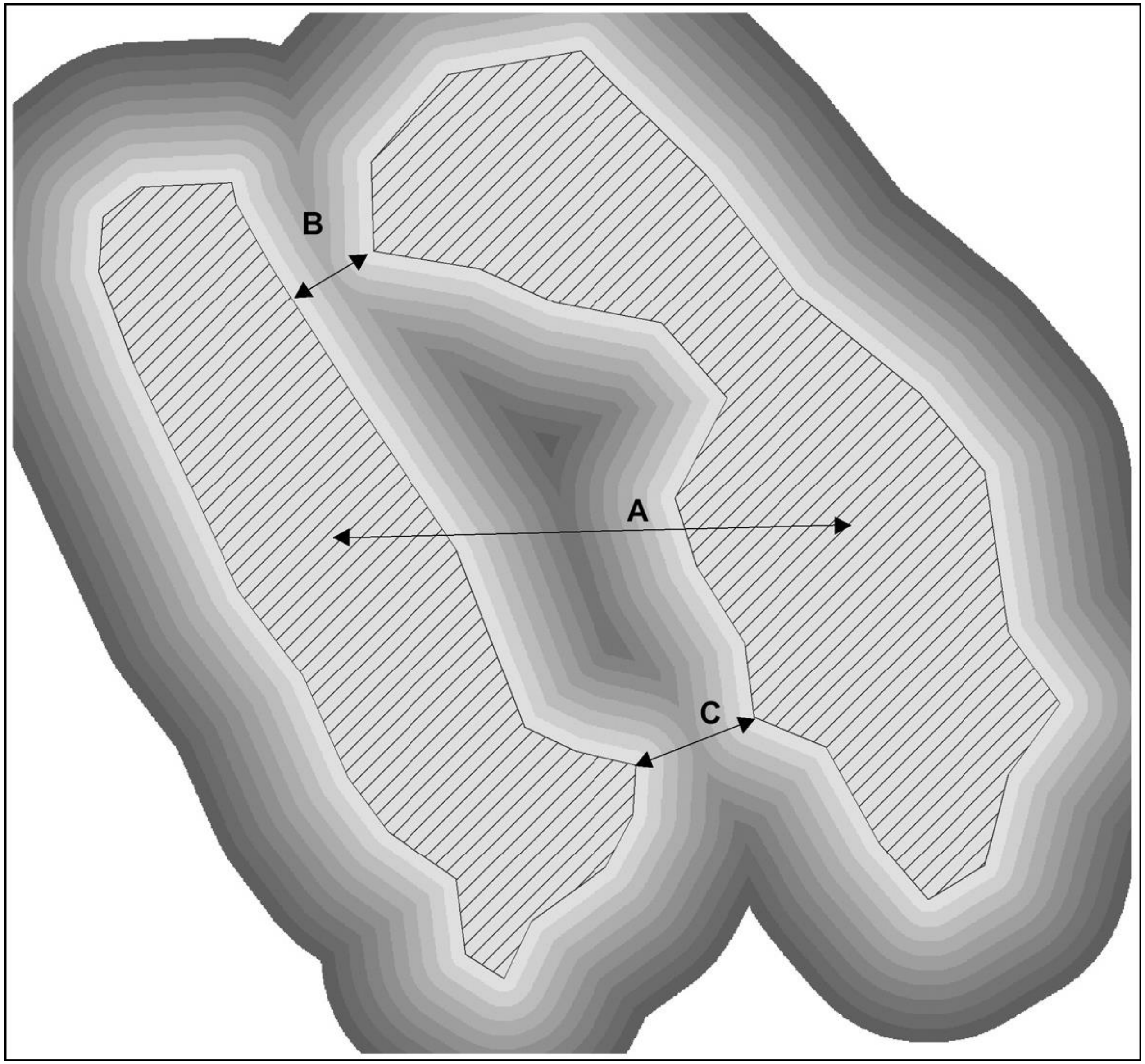
FunConn: Euclidean patch distances

A center to center patch distance = 46.5 km

B edge-to-edge = 8.7 km

C edge-to-edge = 11.7 km

Pathway B is the minimum least-cost pathway, while pathway C is an additional pathway. The gray tones radiating from the patches are straight-line distance buffers out to 13 km away from the edge of patches.



Theobald 2006

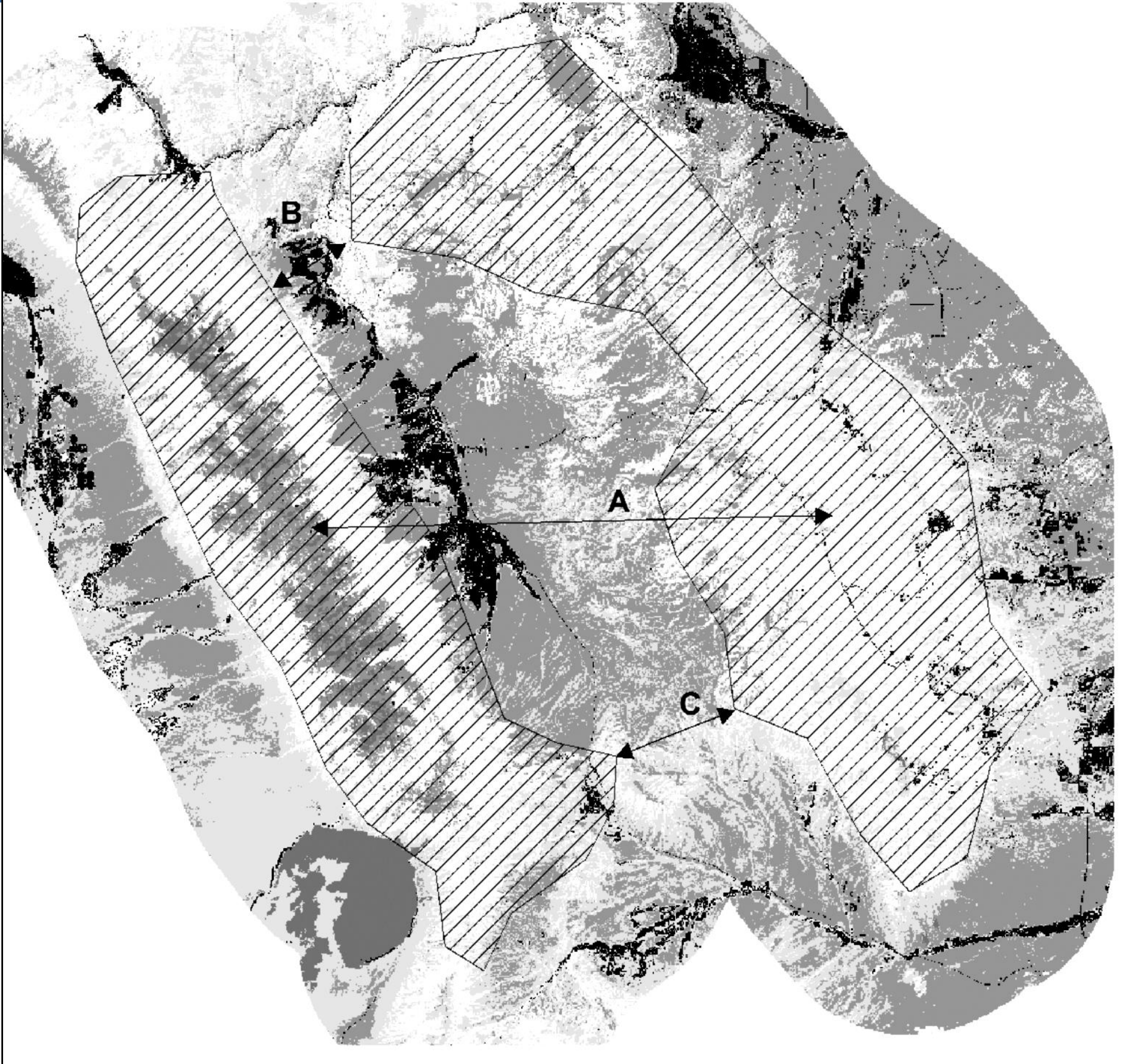
FunConn: Cost patch distances

with a <u>permeability</u> surface

- <u>lighter</u> shades = higher-permeability landcover (e.g. coniferous forest, shrubland, and wetlands) *easier to pass through*
- <u>darker</u> shades = lower permeability landcover (e.g. agricultural cropland, urban areas, and highways) *harder to pass through*

Route B is physically shorter, but passes through harder to navigate (more costly) land covers

Theobald 2006



FunConn: Least cost paths

The least-cost distances (as a pseudo-elevation surface generated from cost distances)

peaks and ridges are higher cost-weights

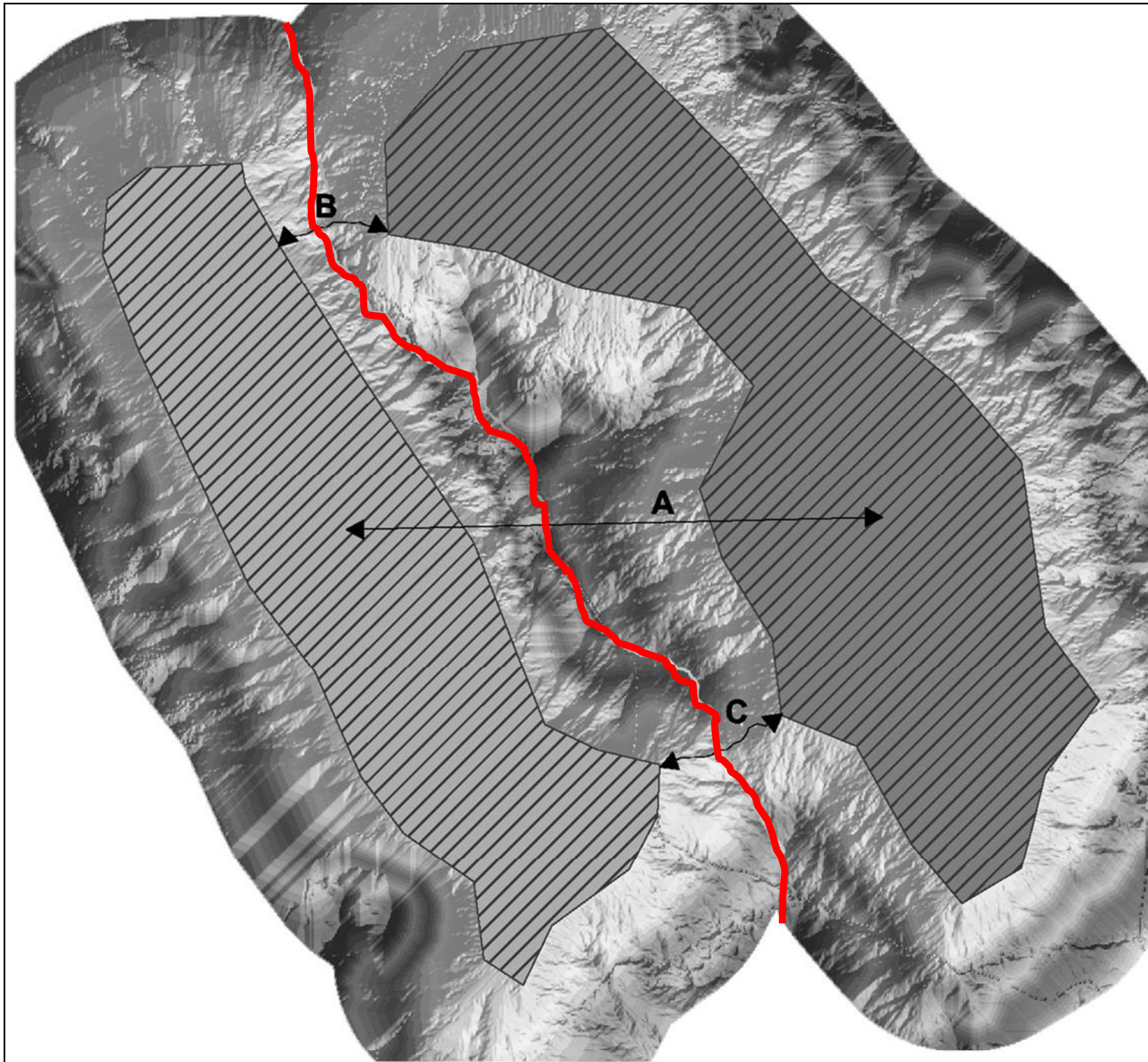
least-cost distance:

B = 12 km

C = 18 km (although C could have been less than B, given different cover types in the intervening matrix).

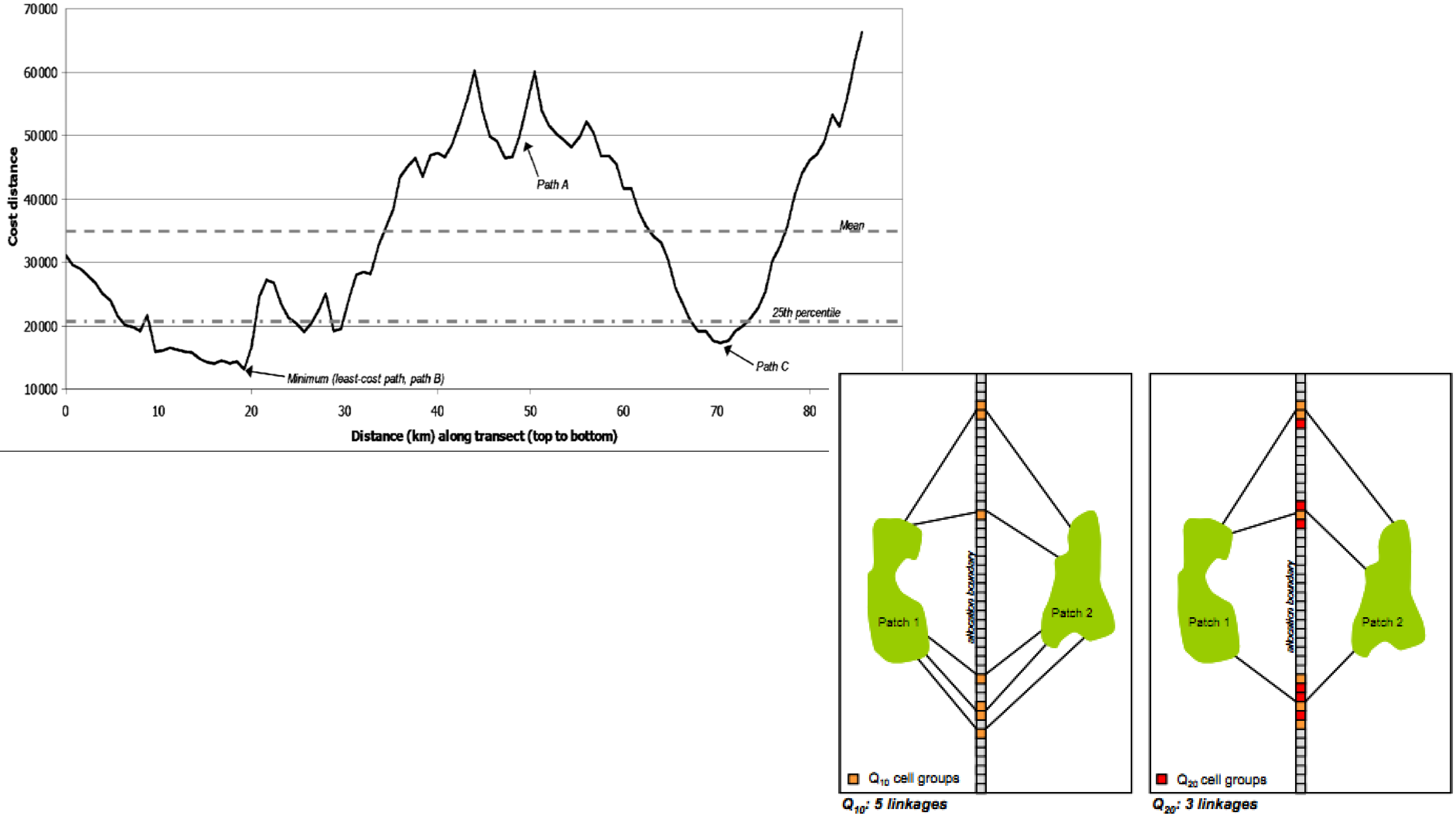
Red line = Allocation Boundary

Theobald 2006



FunConn: Finding multiple LCPs

Costs along allocation boundary



Q_{10}: 5 linkages

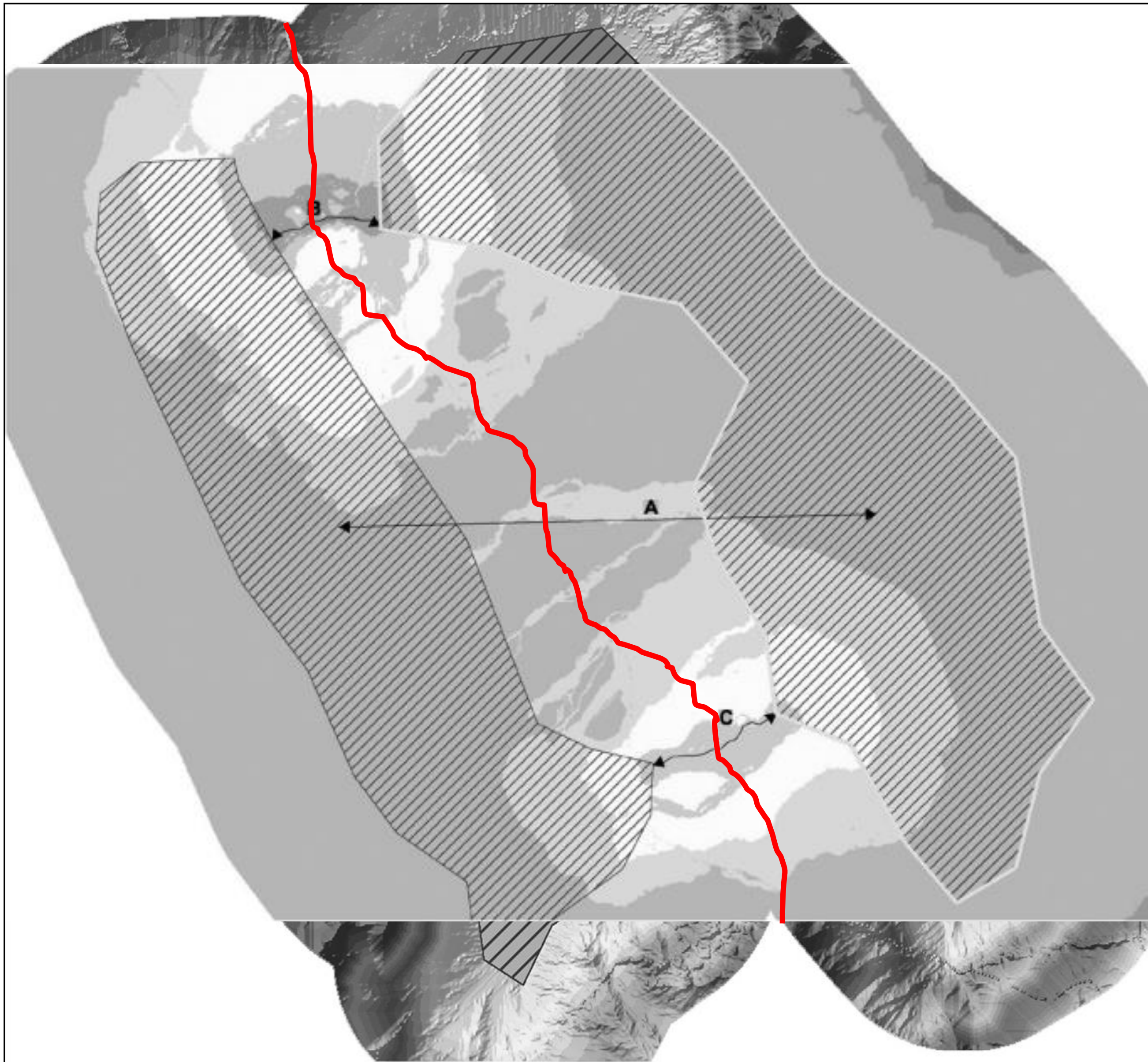
Q_{20}: 3 linkages

FunConn: Finding corridors

Corridors between patches can be determined by generating a corridor surface calculated by adding the least-cost distance surface generated from one patch to the least-cost distance surface generated from an adjacent patch.

Smaller values on this corridor surface depict locations that are near the optimal pathway, while larger values are less optimal.

The corridor for the 10th percentile distance is shown as dark gray (under pathway B), while the 25th percentile corridor is shown by light gray surrounding pathway B and under pathway C (bounded by the white area).



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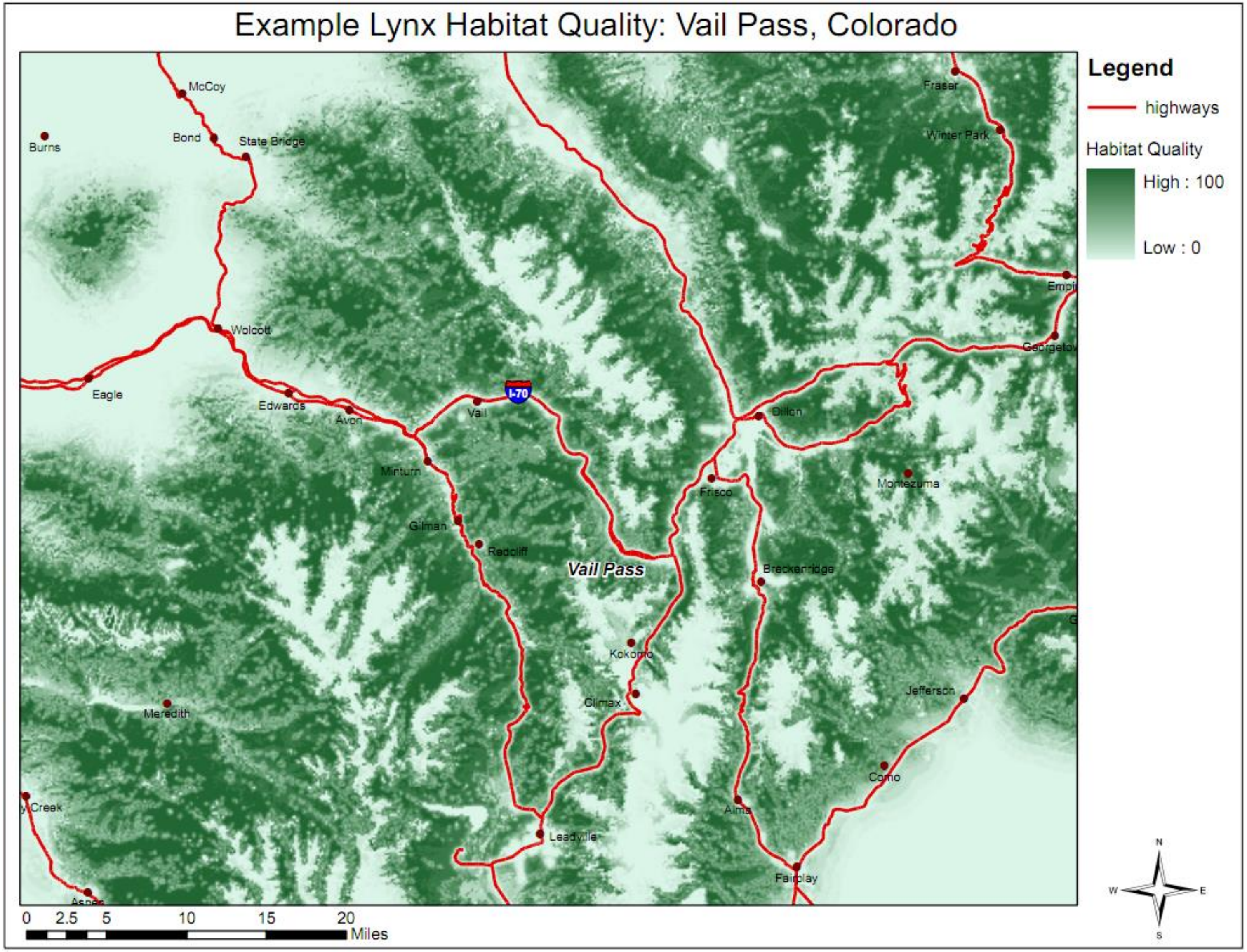
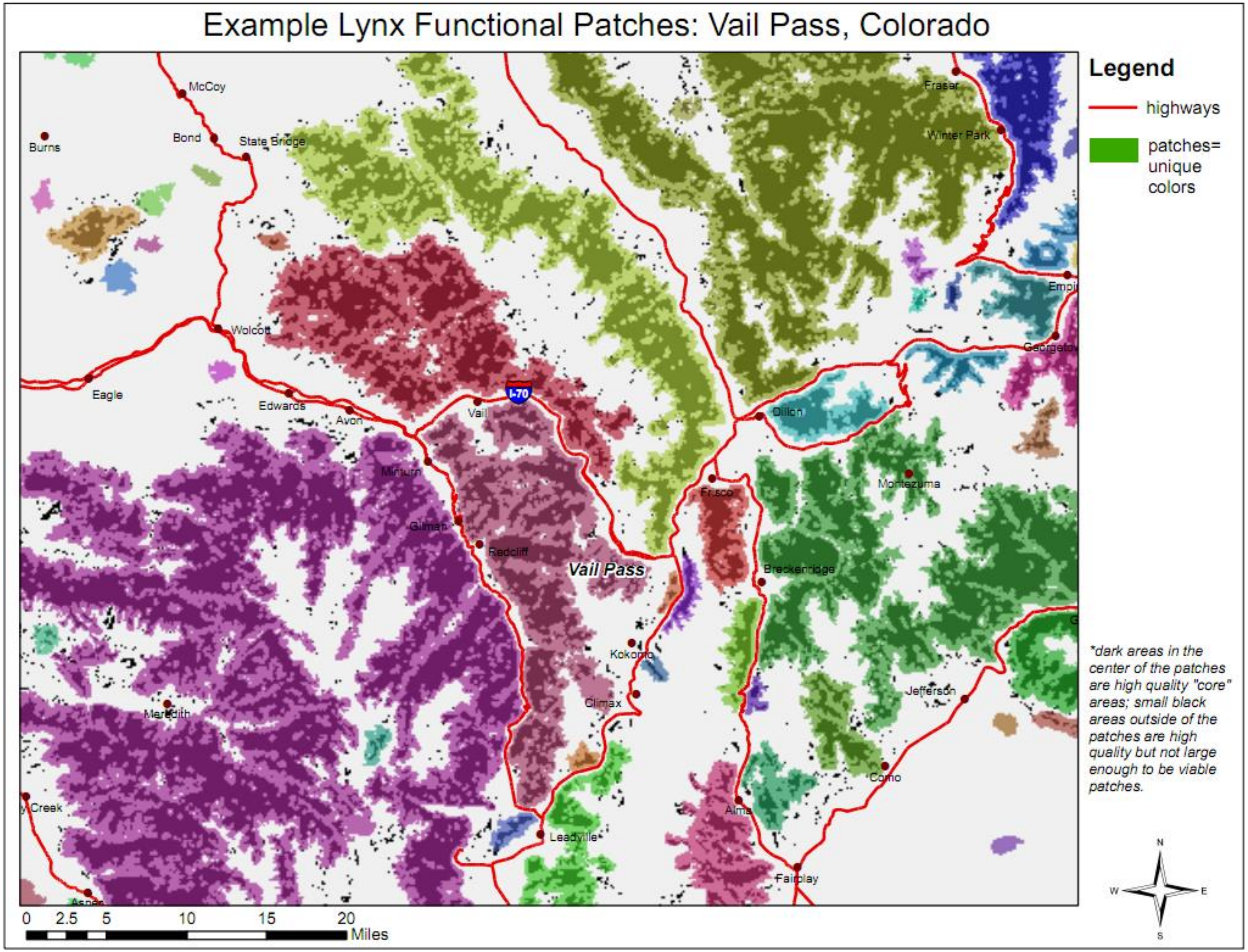
FunConn: Lynx example



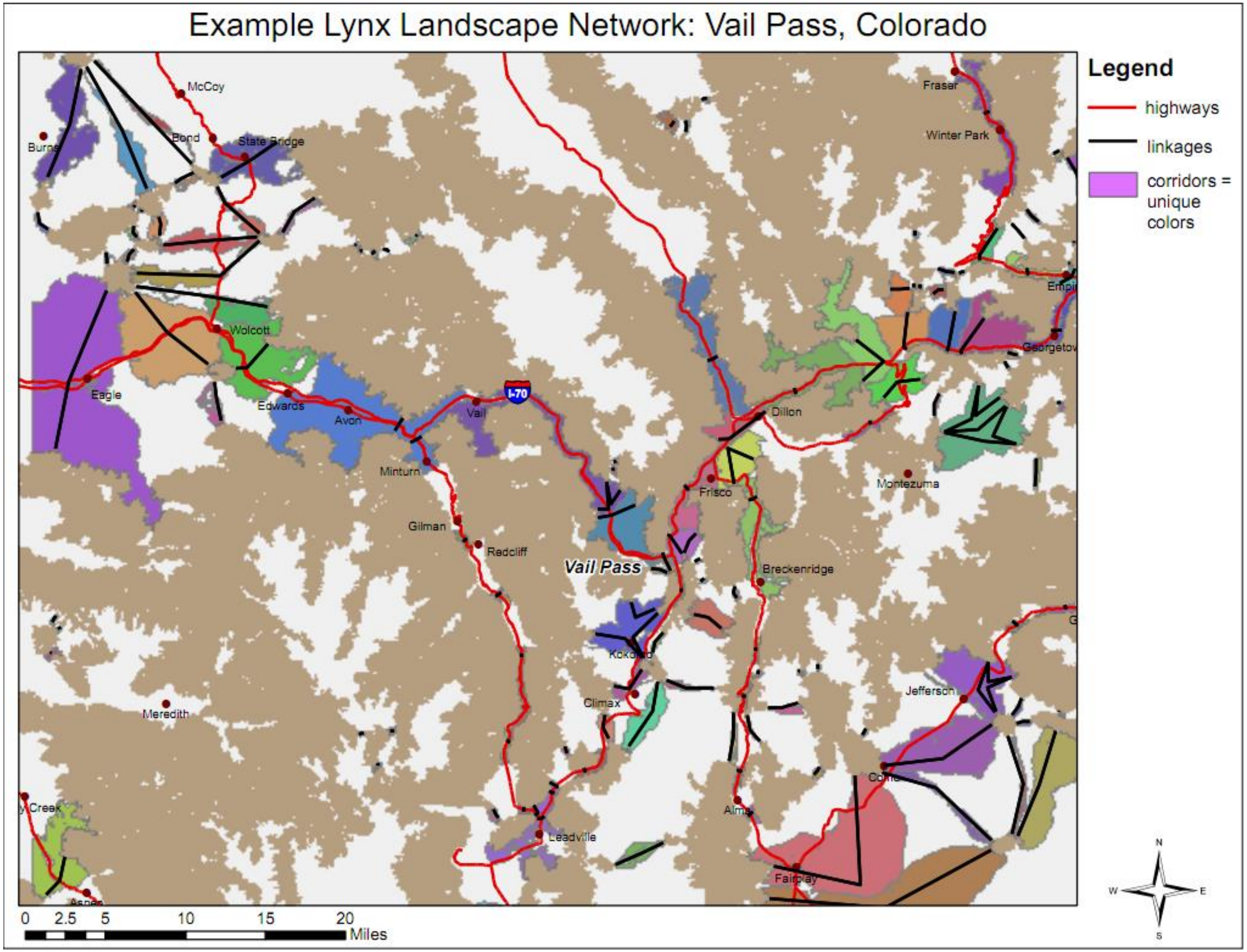
Example Lynx Habitat Quality: Vail Pass, Colorado

FunConn: Lynx example


Example Lynx Functional Patches: Vail Pass, Colorado

*dark areas in the center of the patches are high quality "core" areas; small black areas outside of the patches are high quality but not large enough to be viable patches.

FunConn: Lynx example



FunConn

Summary:

- Analysis of the costs along the allocation boundary provides a quantitative evaluation of the connectivity among patch pairs
- FunConn allows multiple least cost paths and least cost corridors to be calculated for adjacent patch pairs

BUT:

- FunConn is limited to nearby patches; ignores patches beyond ones immediately adjacent to studied one
- Any changes in the landscape requires analysis to be re-done