Riverine Landscapes:

Exploring Connectivity, Extinction Risk and Biogeography in an Alternative Geometry

Bill Fagan

Dept. of Biology
University of Maryland

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To start, a debt of gratitude…

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17 years of discussions & ideas

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11 papers / manuscripts thus far

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17 years of discussions & ideas

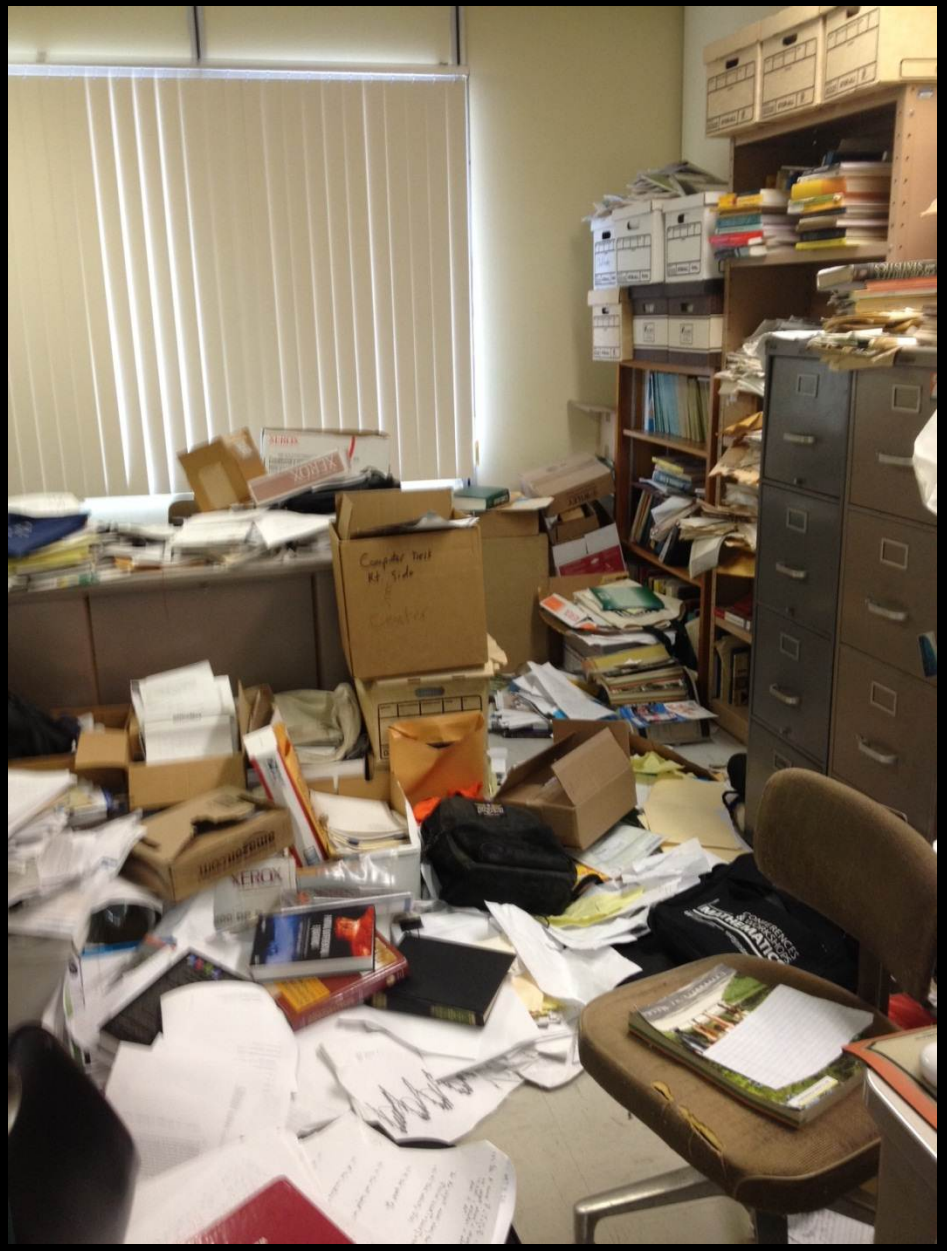
11 papers / manuscripts thus far

260+ journal pages

Collaborations possible because Chris is a mathematician of broad interests.

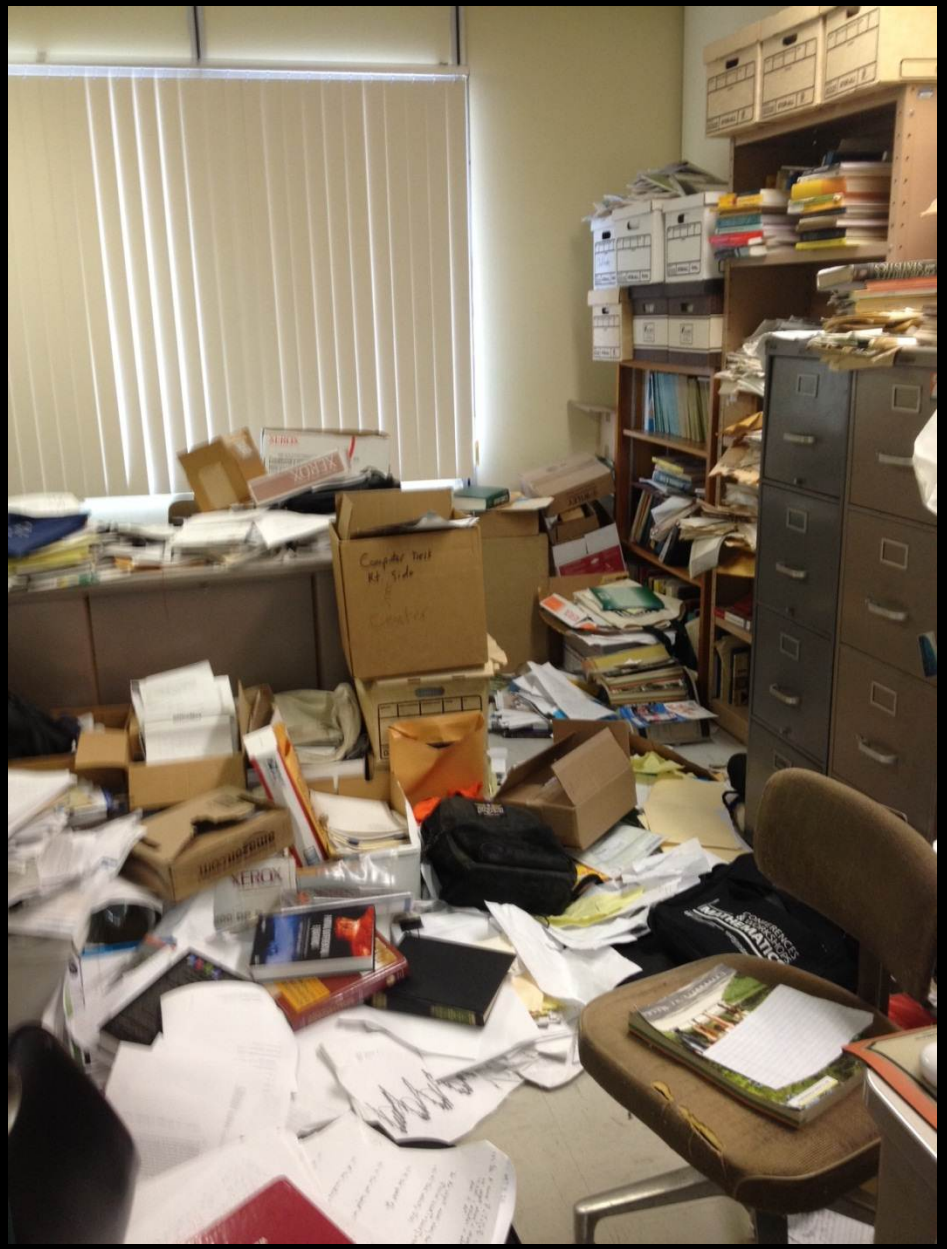
Collaborations possible because Chris is a mathematician of broad interests. His research projects are inspired by features of his environment …

Chris’ Office



Chris' Office

Delicate Bifurcations ?



Chris' Office

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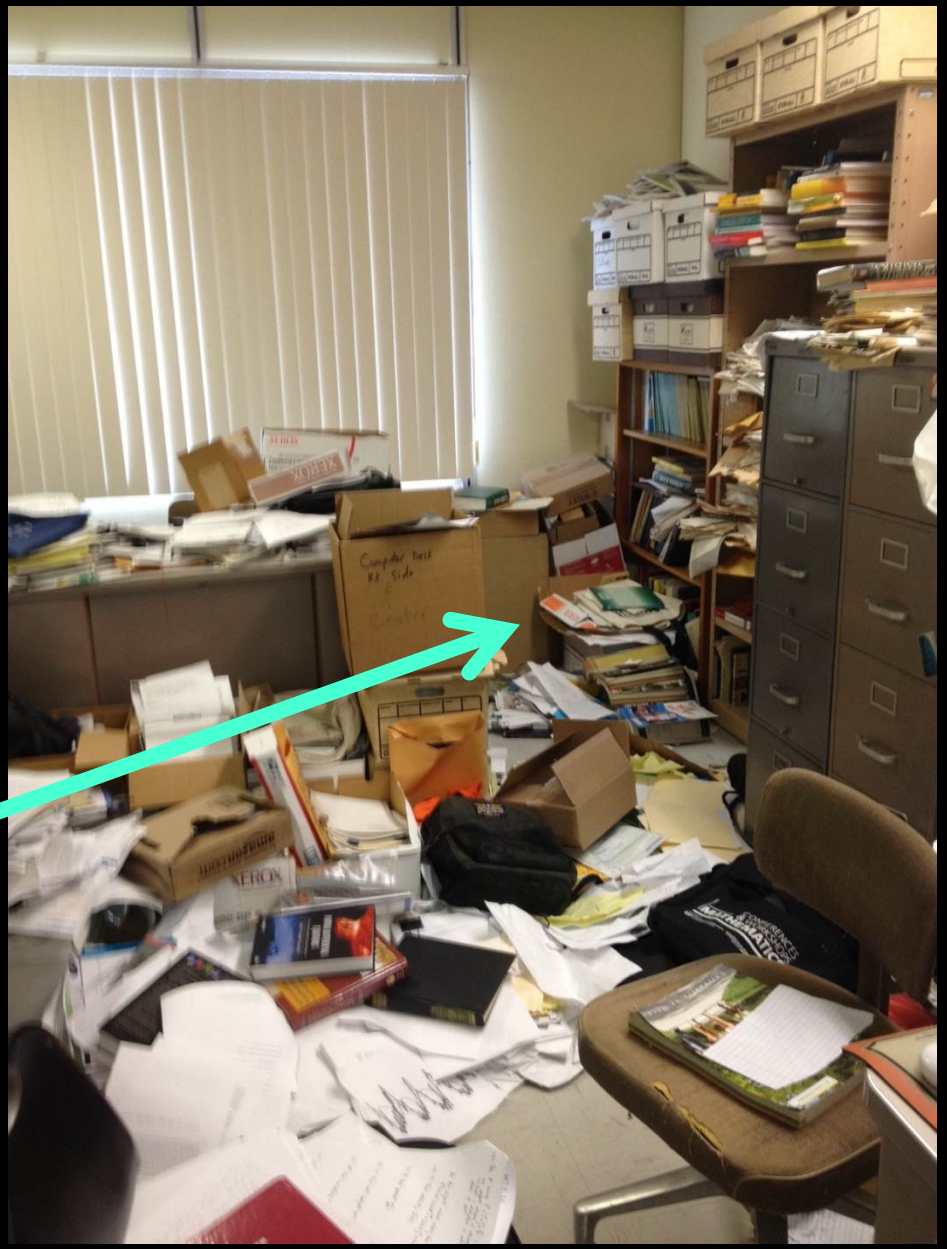
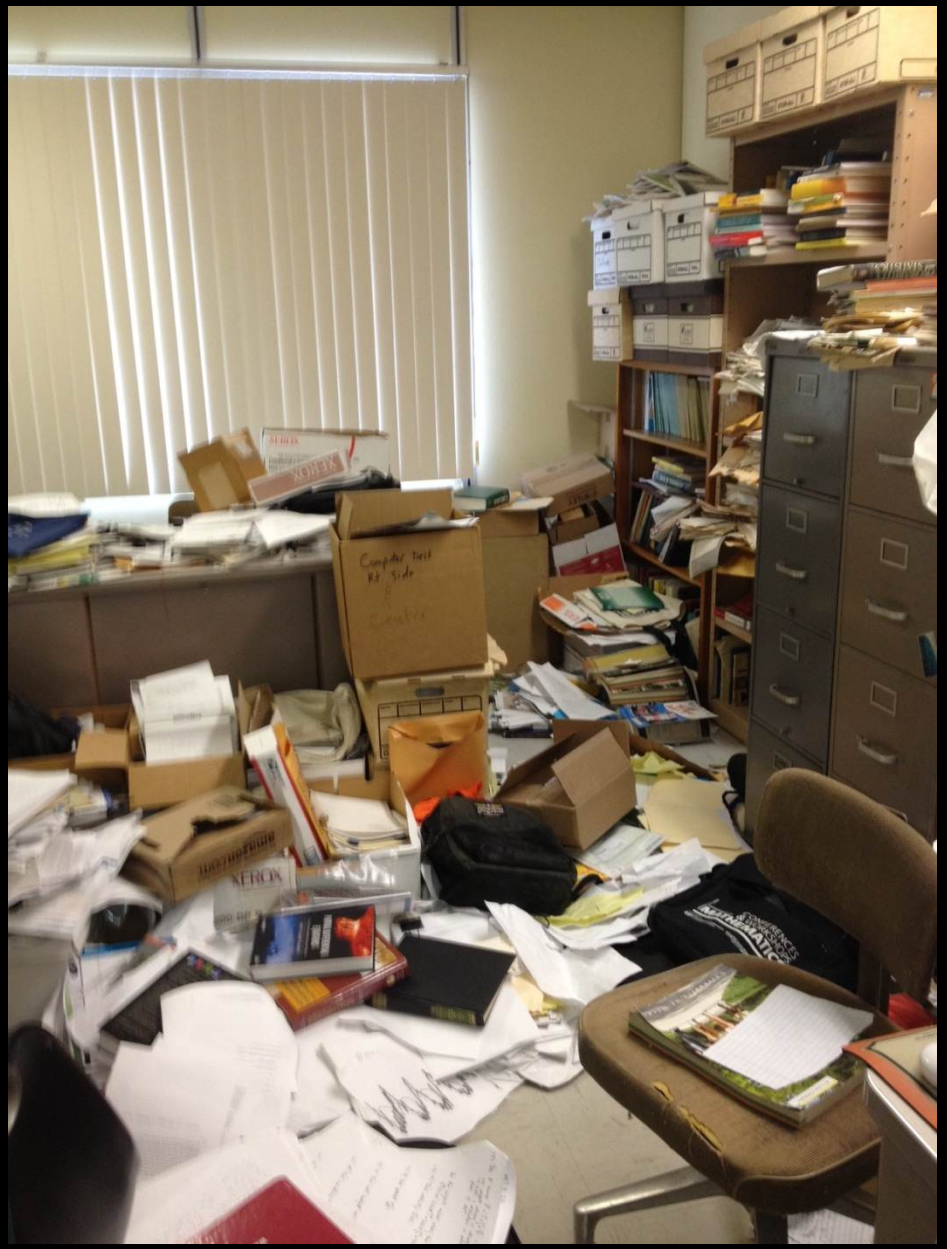


Chris' Office

…Maximum angle of repose

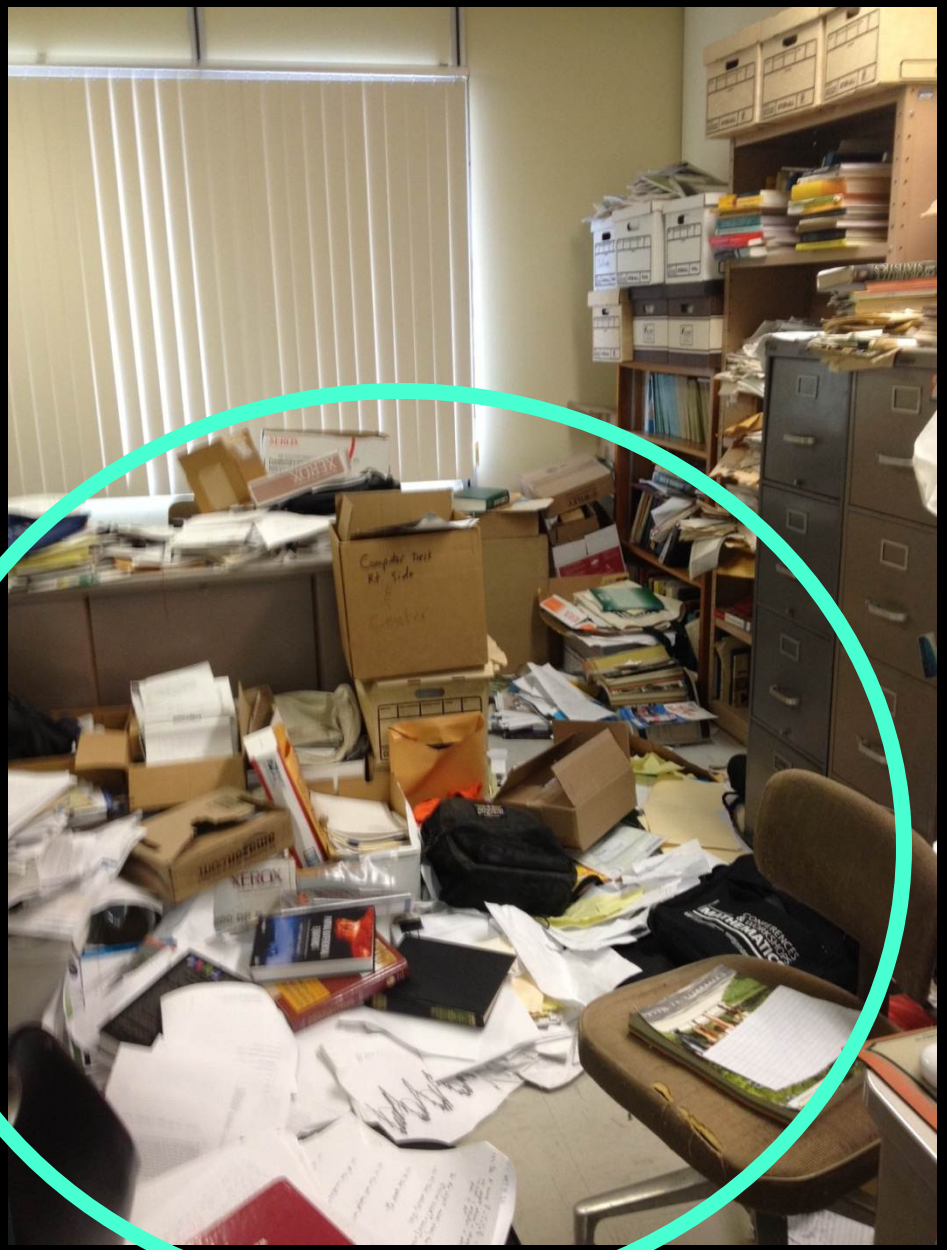
Adaptive Dispersal ?



Chris' Office

Adaptive Dispersal ?

… Experience with barriers to movement



Chris' Office

Optimal Foraging Theory ?

Chris' Office

Optimal Foraging Theory ?

…Proof by contradiction

Chris' Office

Chris Cosner and Steve Cantrell have worked together for decades.

Although there has been convergence, they really are not interchangeable …

Steve Cosner
Municipal Bond Salesman

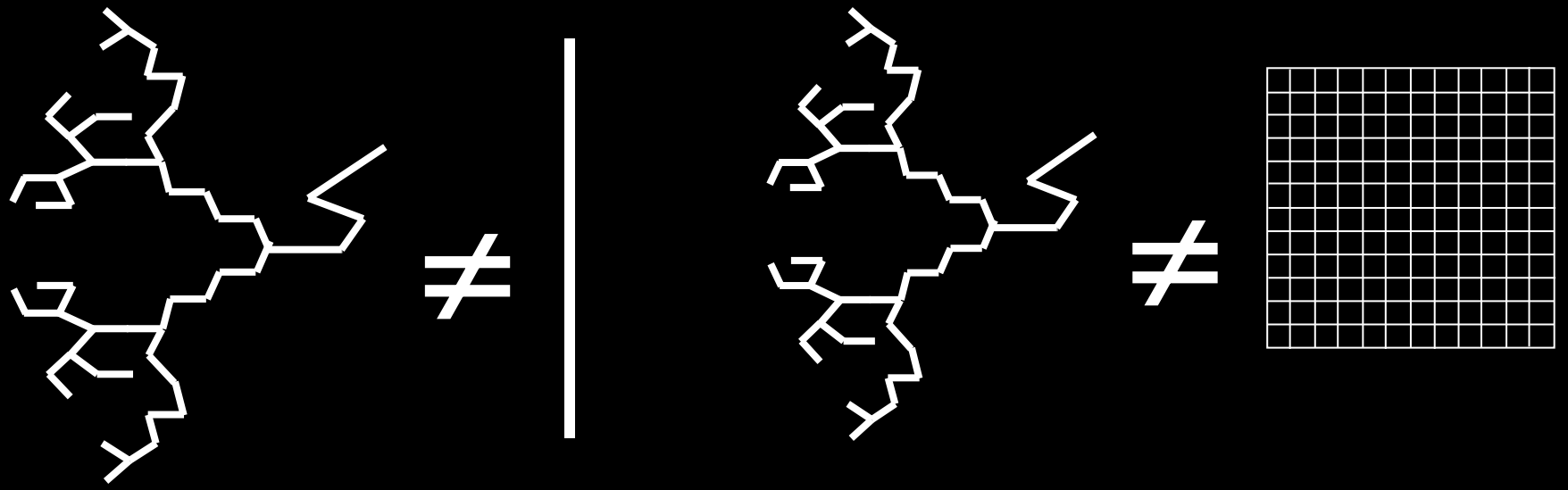
Steve Cosner
Municipal Bond Salesman

Chris Cantrell
Race Car Driver

Riverine Landscapes

- **Not a topic of collaboration with Chris and Steve**
- **But their breadth of interests and openness facilitated my work in this area**

Why Focus on Riverine Landscapes ?



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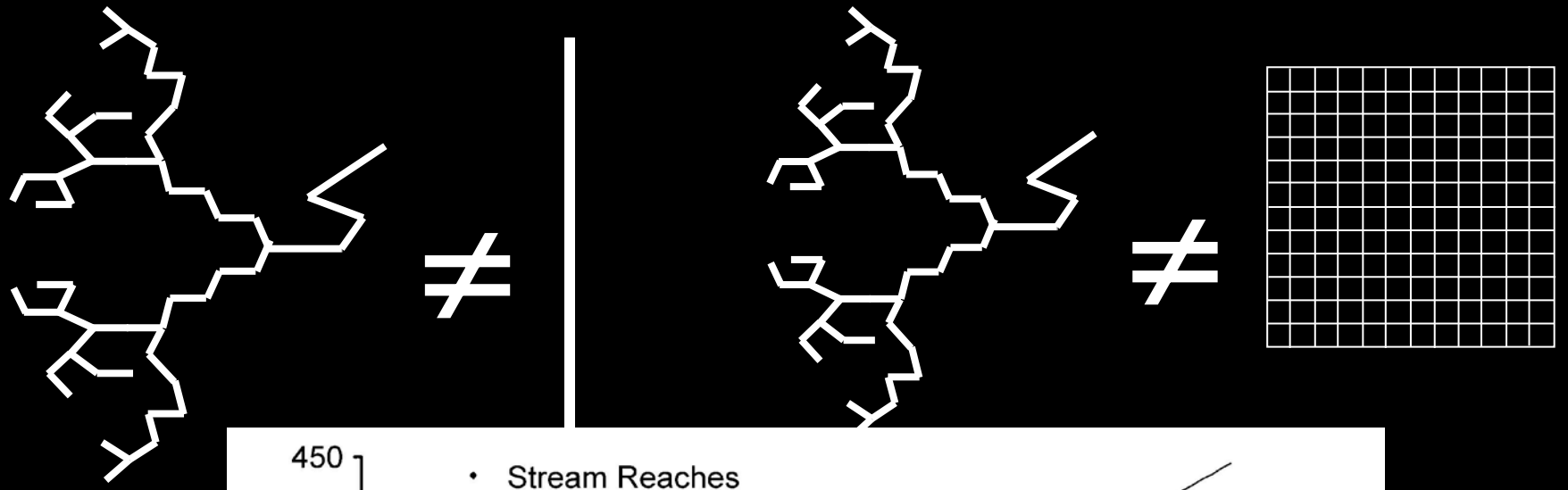

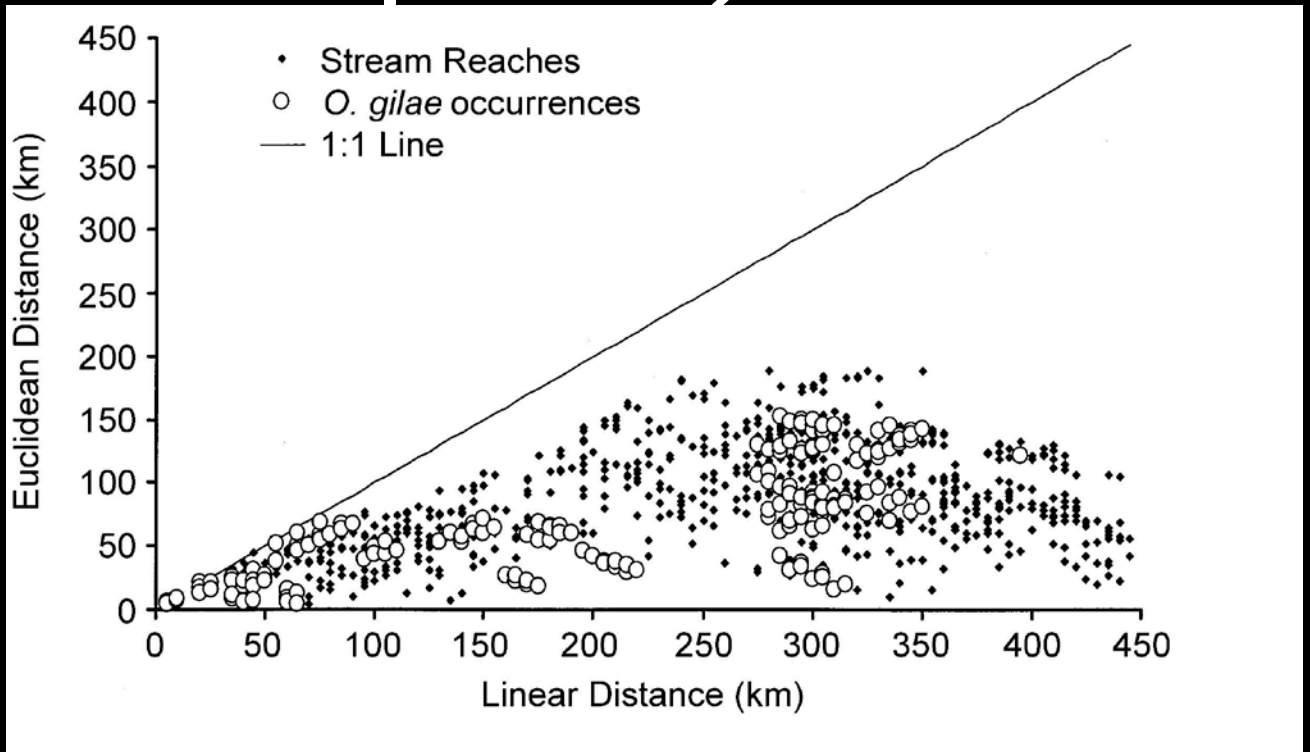

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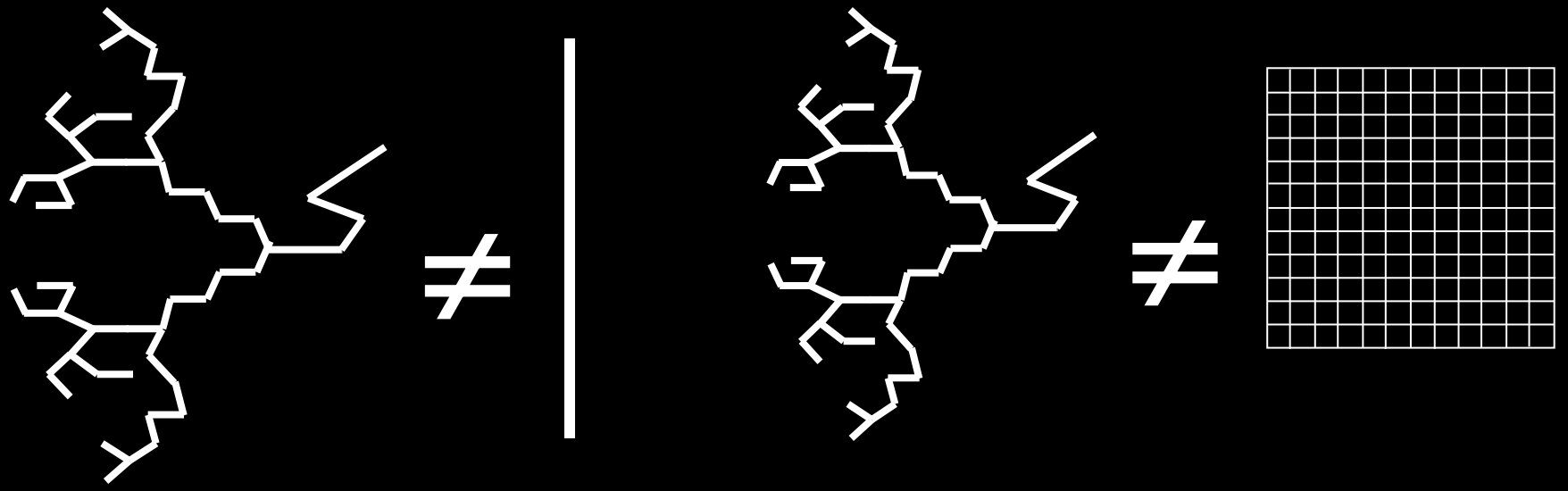
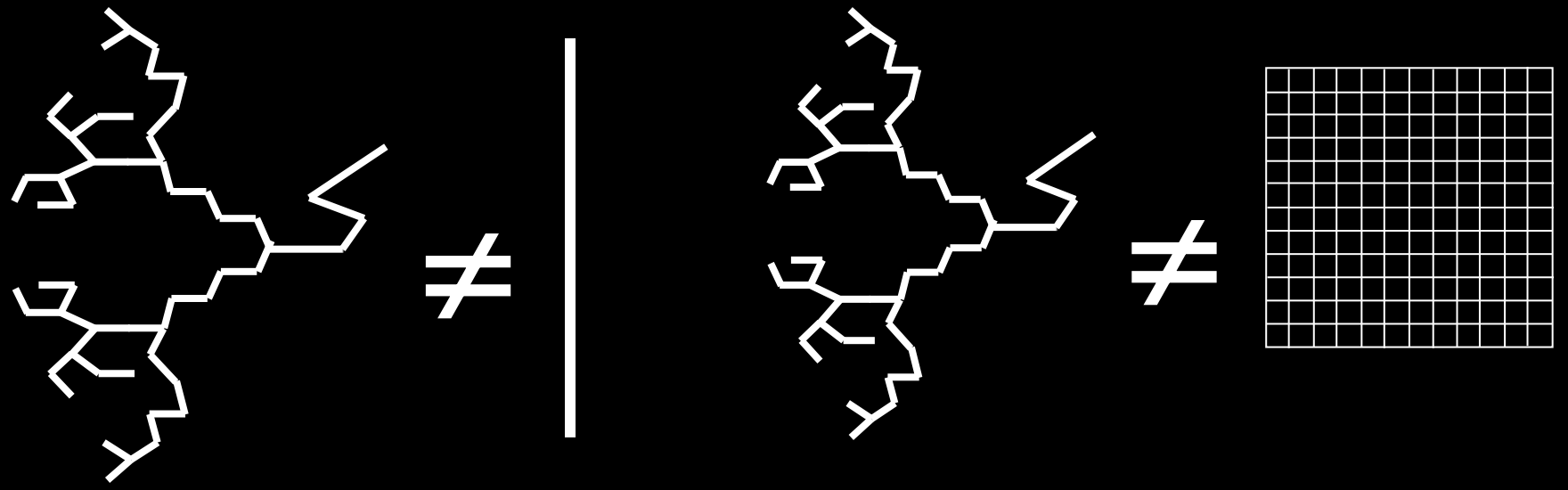


Key features affecting connectivity:

- **Directional biases**
- **Intrinsic effects of configuration**
- **Opportunities for ‘out of network’ movement**
- **Transient connectivity**

Why Focus on Riverine Landscapes ?



Key features affecting connectivity:

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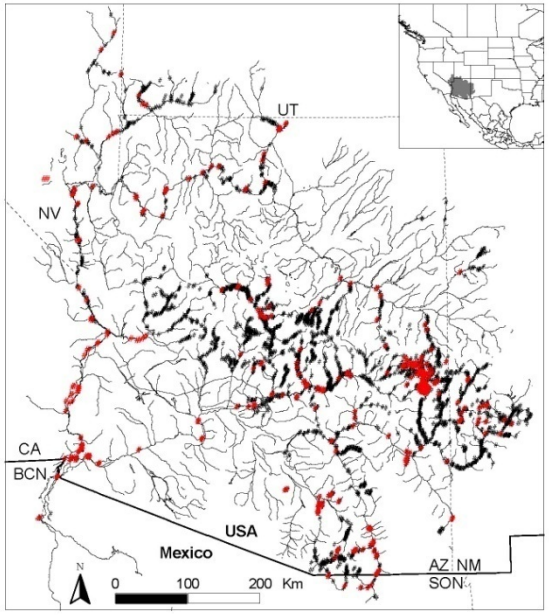
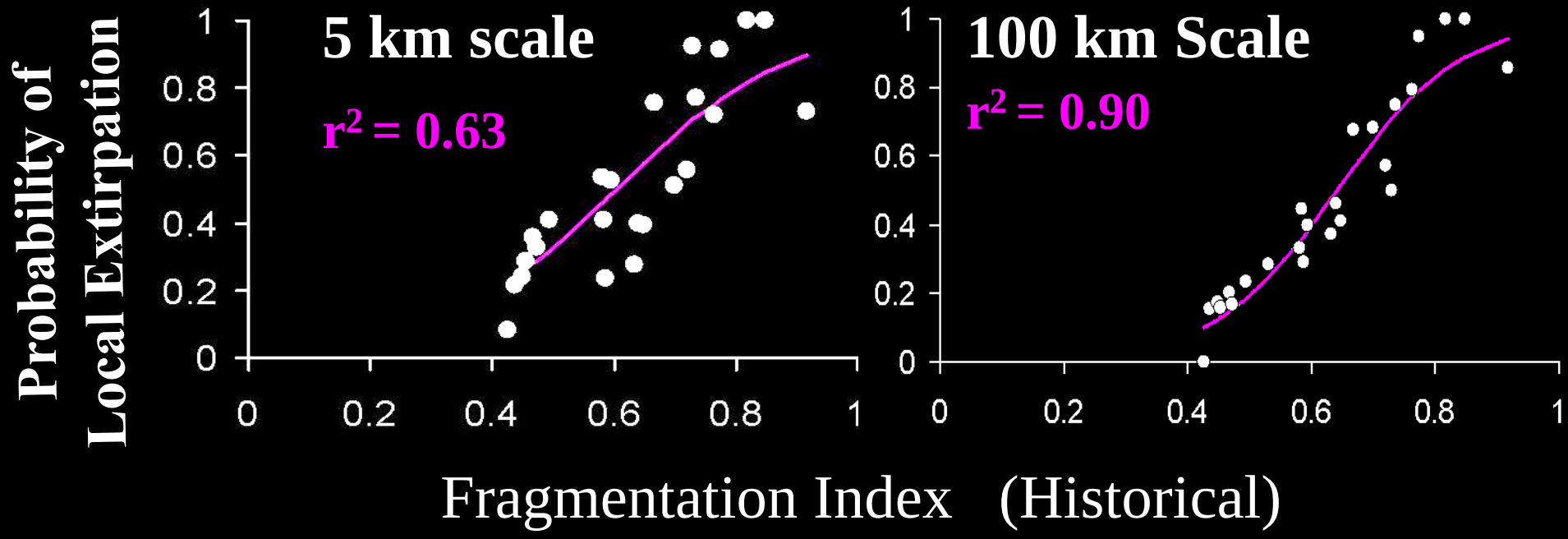
Connectivity is Critical for Species Persistence in Riverine Landscapes



Sonoran Desert Fishes Database

Fagan et al.
Ecology. 2002.
Ecology, 2005.
Cons. Biol., 2005.

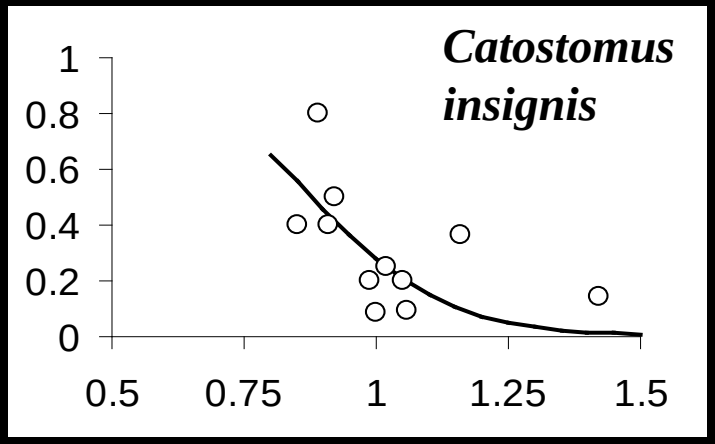
Species with Fragmented Historical Distributions Are Predisposed to Extinction

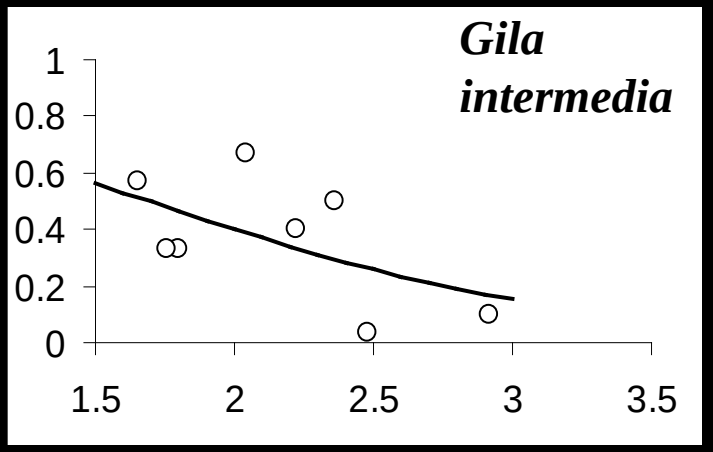


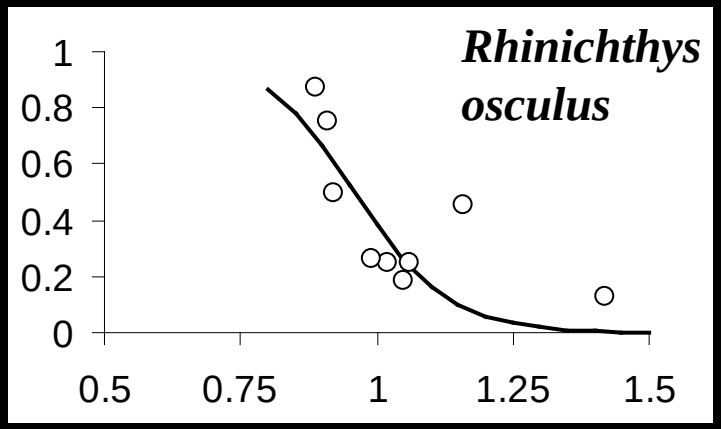
Fagan et al. *Ecology.* 2002, 2005.

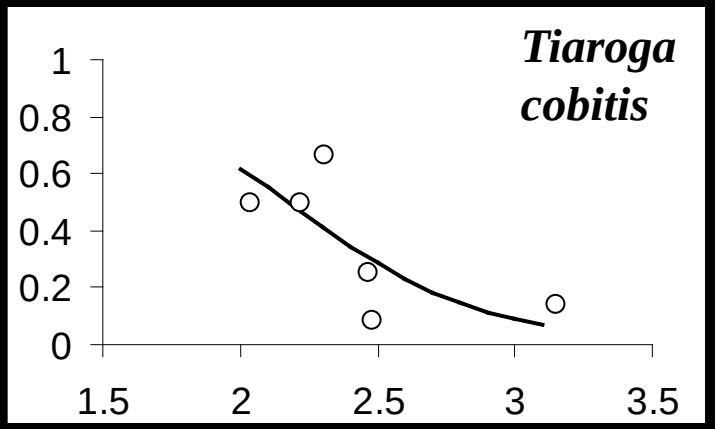
Geometric Opportunities for Recolonization Facilitate Persistence

Probability of Local Extirpation









Network 'Branchiness'

T_1

Network 'Branchiness'

R_T

→ Analyses for Gila River HUC-8 Watersheds

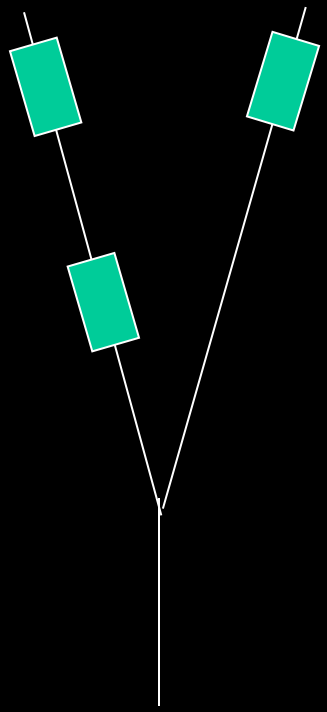
Fagan et al. 2010. *Spatial Ecology*

“Out-of-network” Movement by Stream Salamanders

Desmognathus fuscus

Desmognathus monticola

Branched system
3 capture sites
(replicated twice)



2470 uniquely marked animals

3461 captures

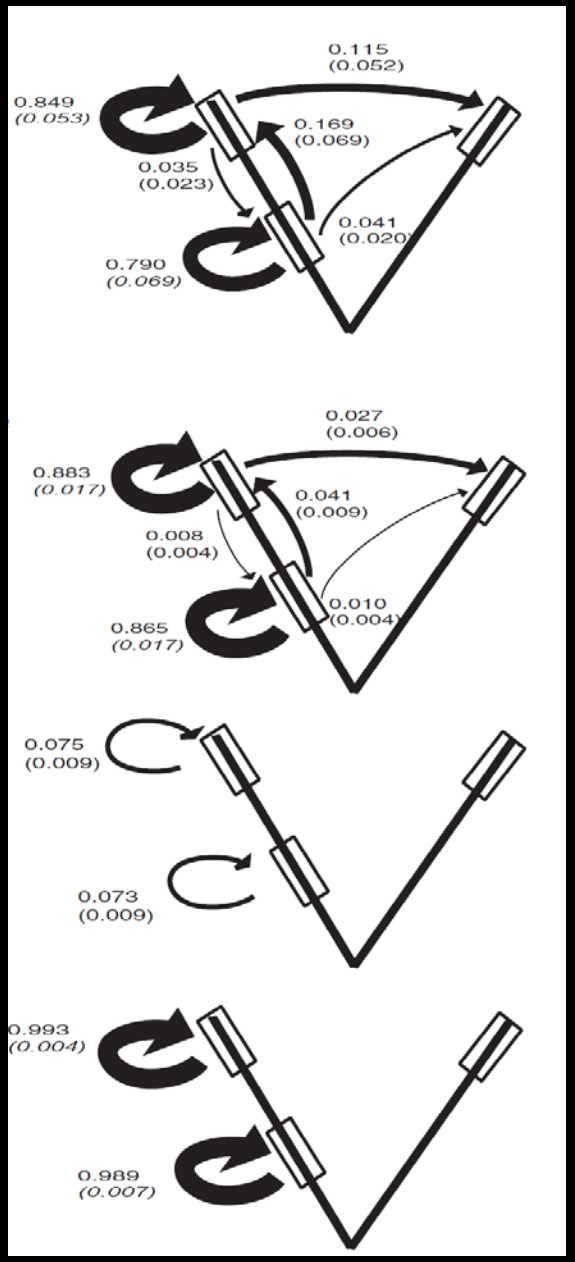
Estimate:

- **overland movement**
- **instream movement**
- **growth**
- **survival**

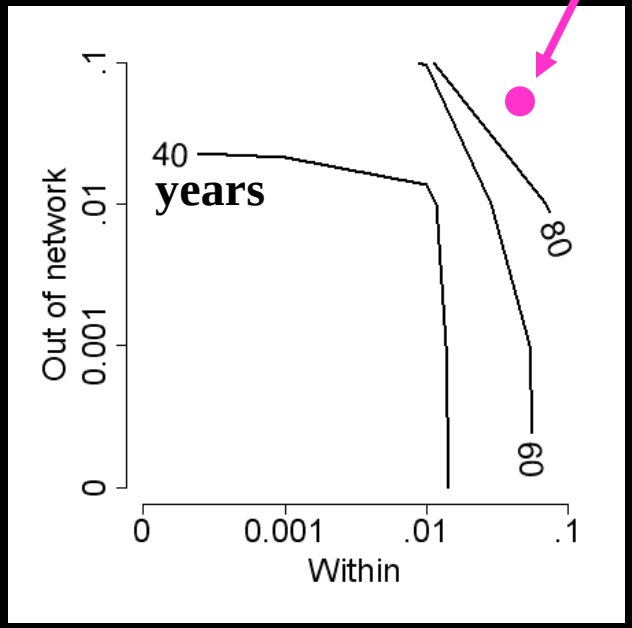
Grant et al. 2010. PNAS

“Out-of-network” Movement Enhances Salamander Persistence

State-based model with detectability to estimate movement transitions

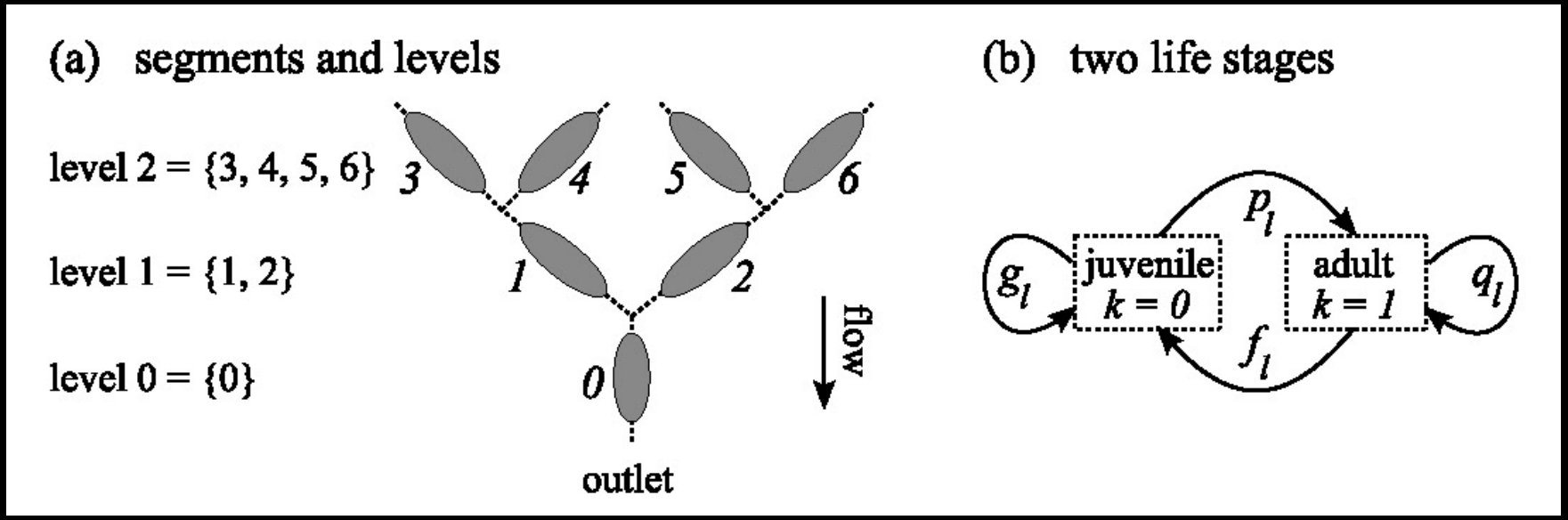


Stochastic model of extinction risk to gauge contributions of out-of-network movement



Grant et al. 2010. PNAS

Modeling Populations: Matrix Demography for River Networks

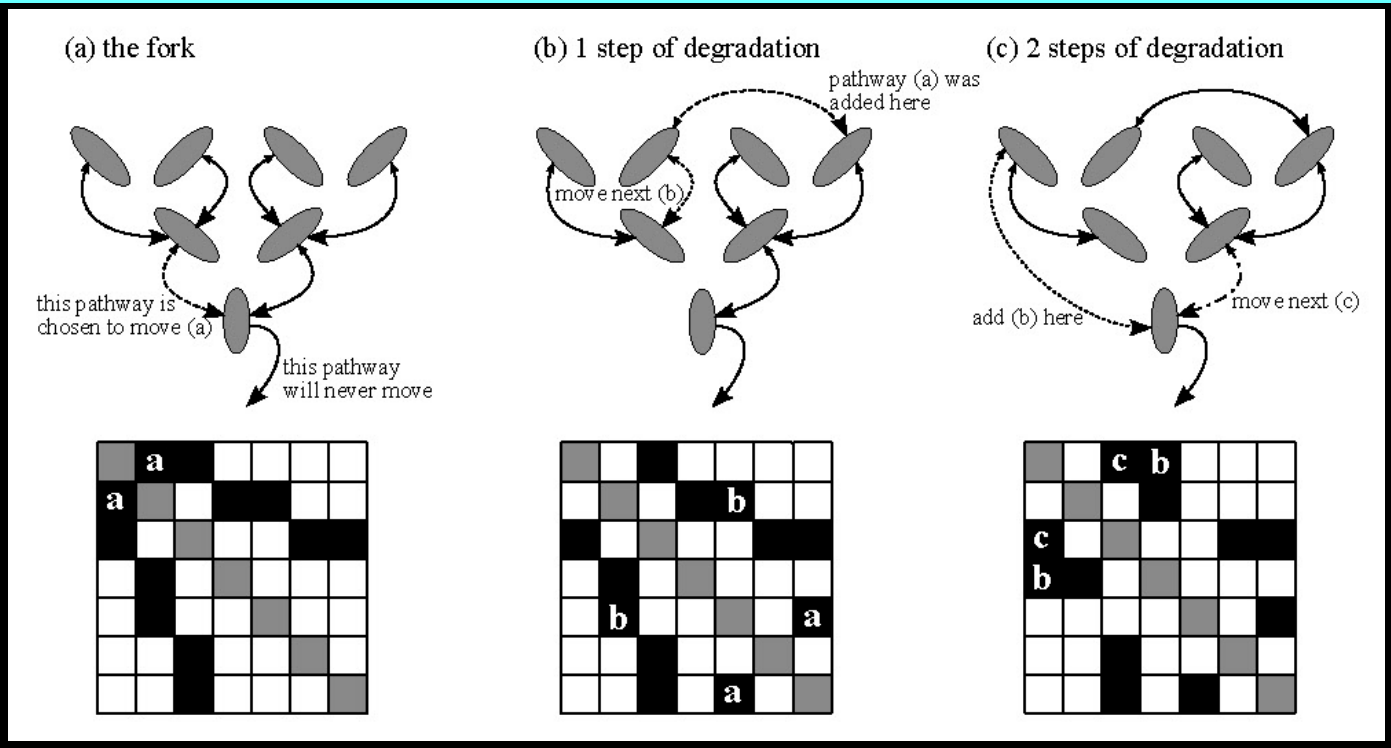


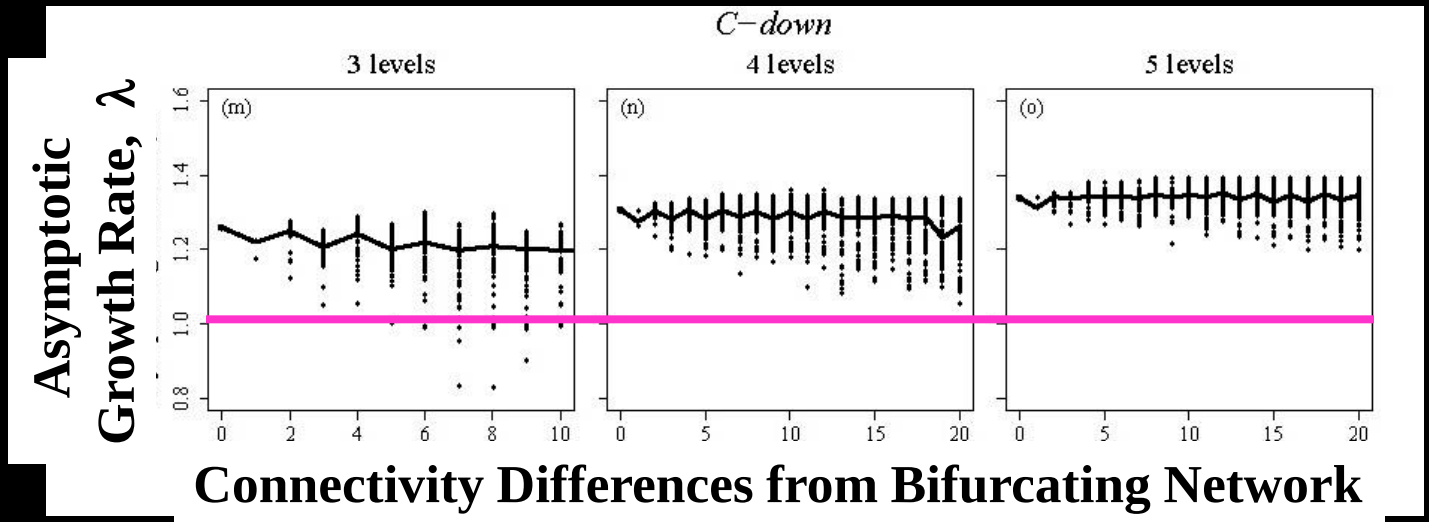
→ Matrix representation of dendritic network and life-cycle

→ Vec-permutation technique of Hunter and Caswell (2005) to transform matrix from by-patch to by-stage

Goldberg et al. 2010. Theoretical Ecology

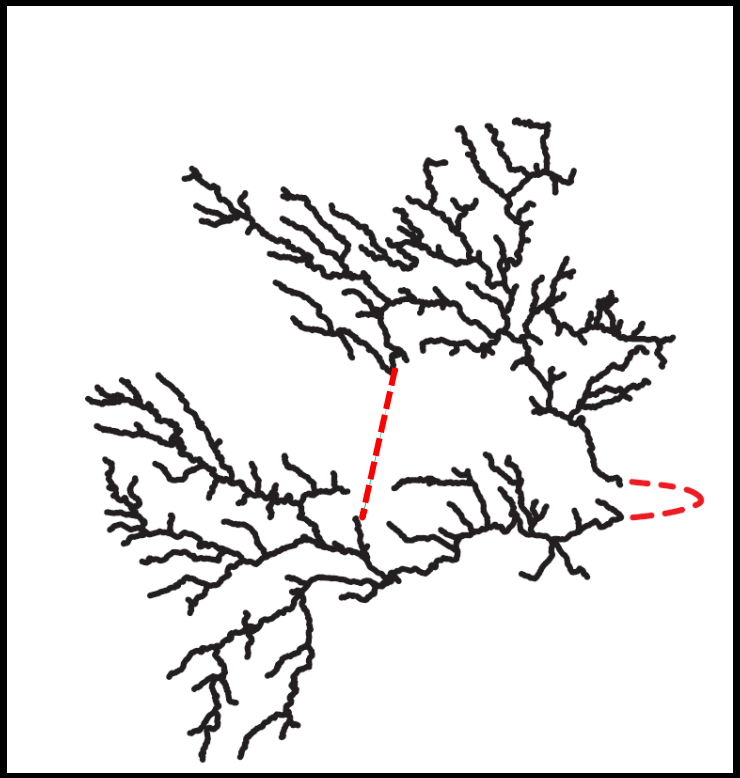
Changes in Network Topology Alter Population Growth Rates





Goldberg et al. 2010. Theoretical Ecology

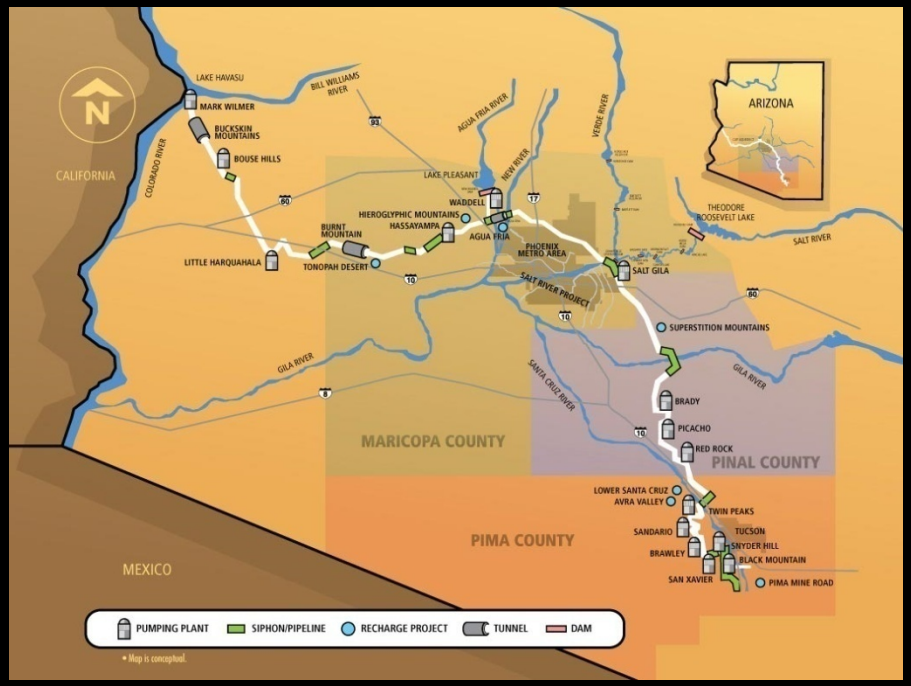
How do changes in geometry and connectivity influence biodiversity ?



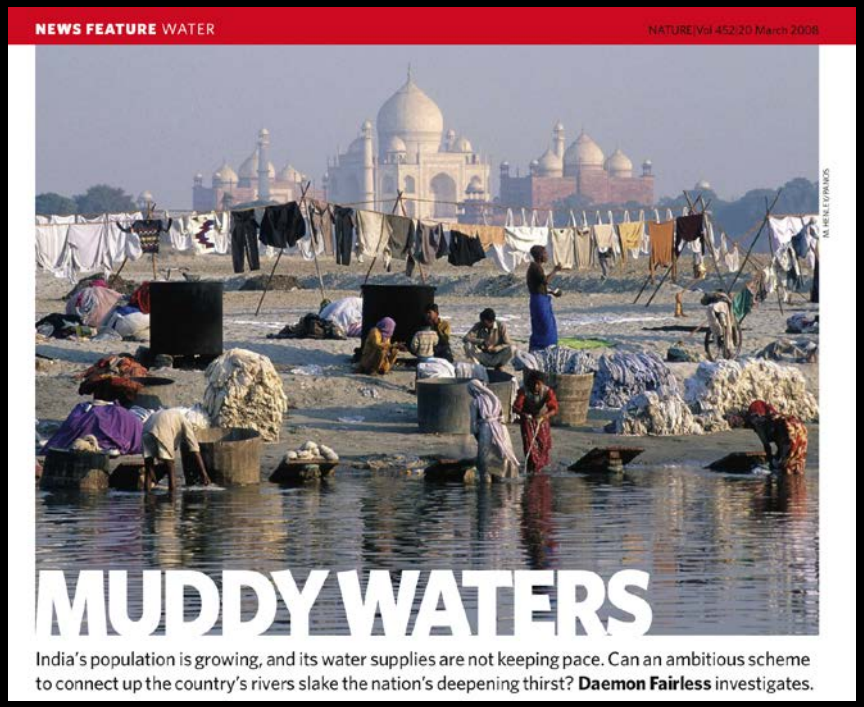
Creating links between watersheds creates a new, larger, watershed with different properties from either original watershed

Humans Manipulate Riverine Connectivity on Massive Scales

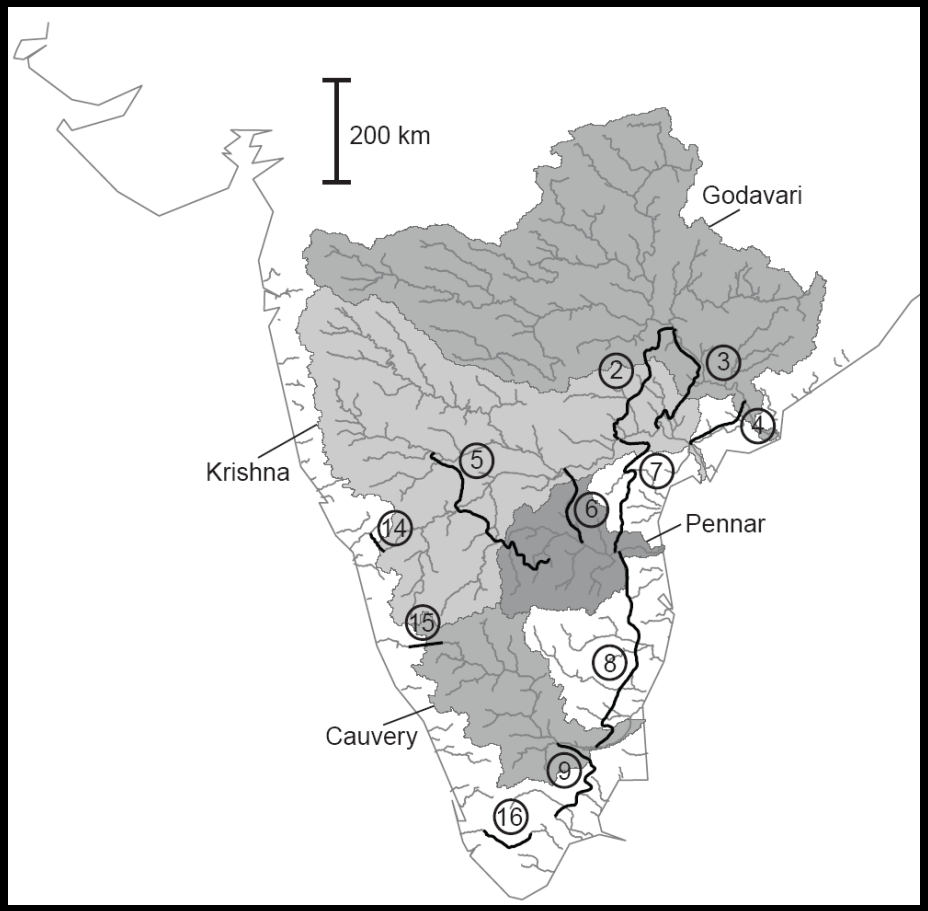
Central Arizona Project



India's Interbasin Water Transfer Project

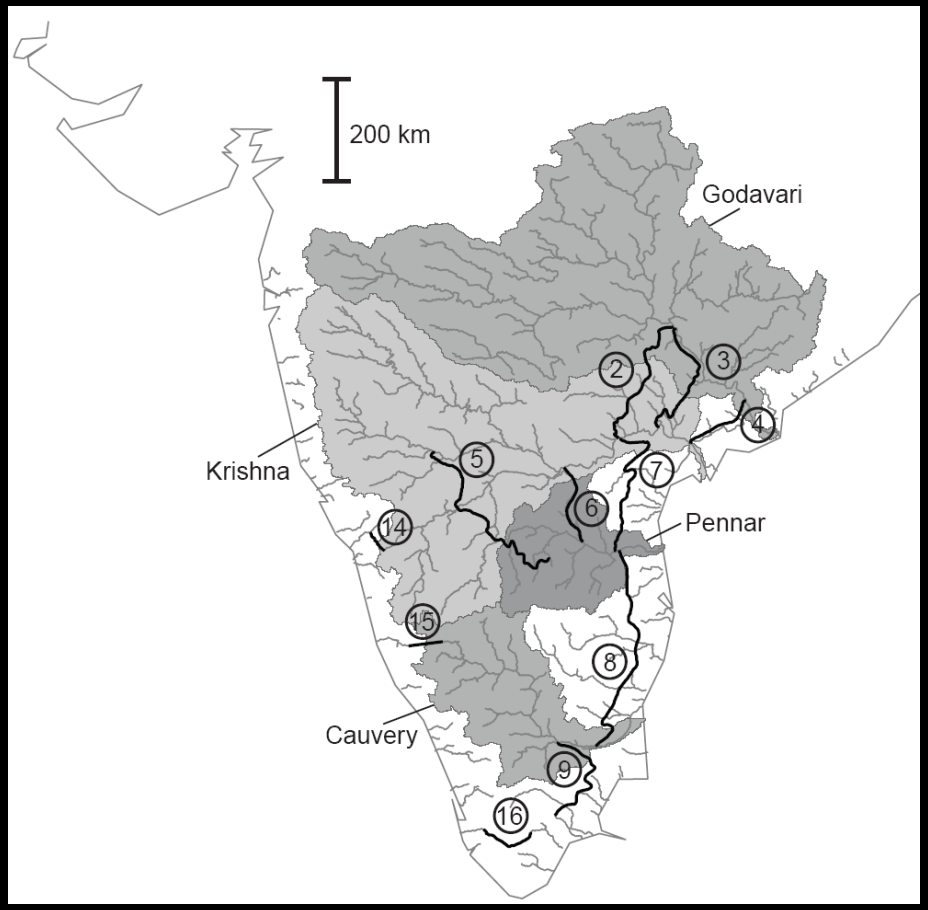


India's Inter Basin Water Transfer (IBWT) Project



The goal: To divert water from water-rich areas (reducing flooding) to water-scarce areas (reducing drought)

India's Inter Basin Water Transfer (IBWT) Project



Little research done to understand what may happen biologically.

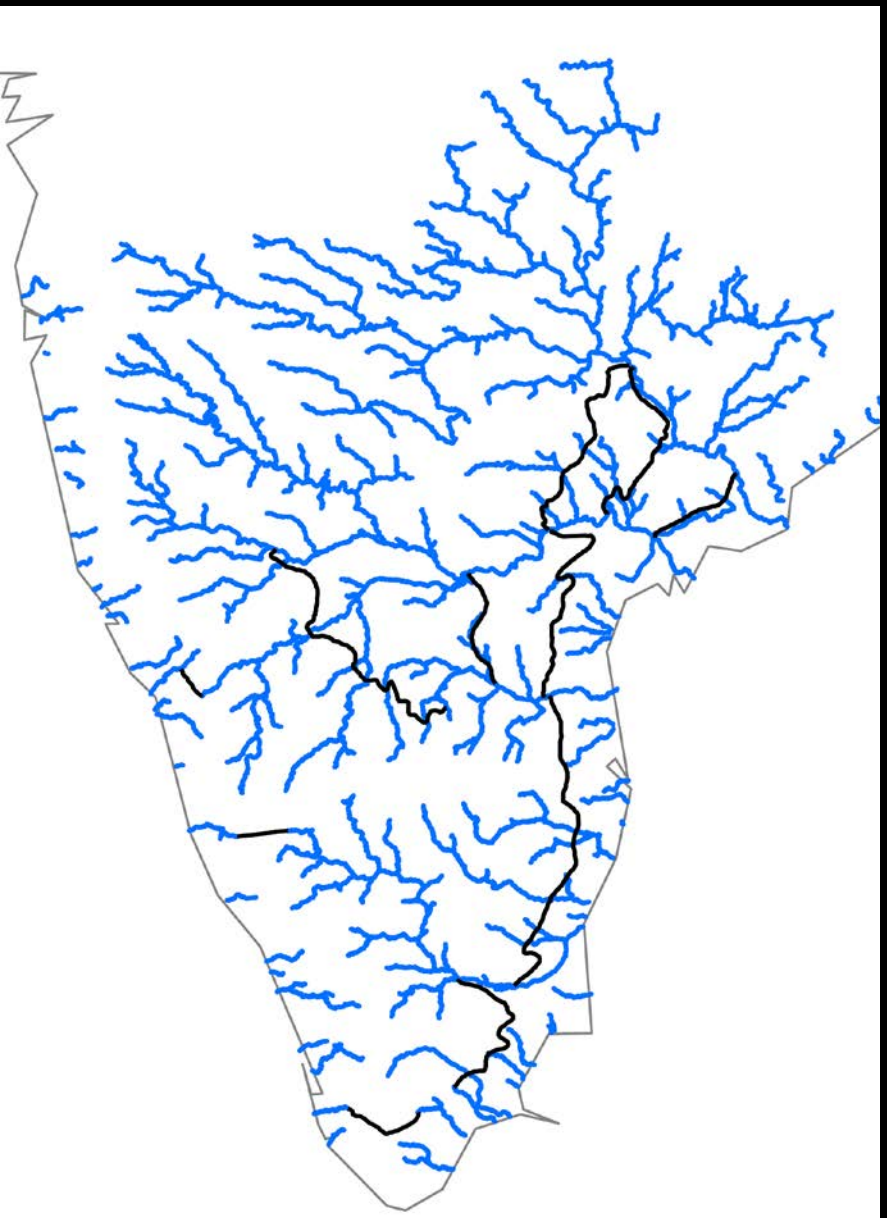
Two approaches:

1) **Theoretical model**
2) **Database-driven model and analysis**

Lynch et al. Water Resources Research. 2011.

Grant et al. PLOS One. 2012.

Modeling Approach:

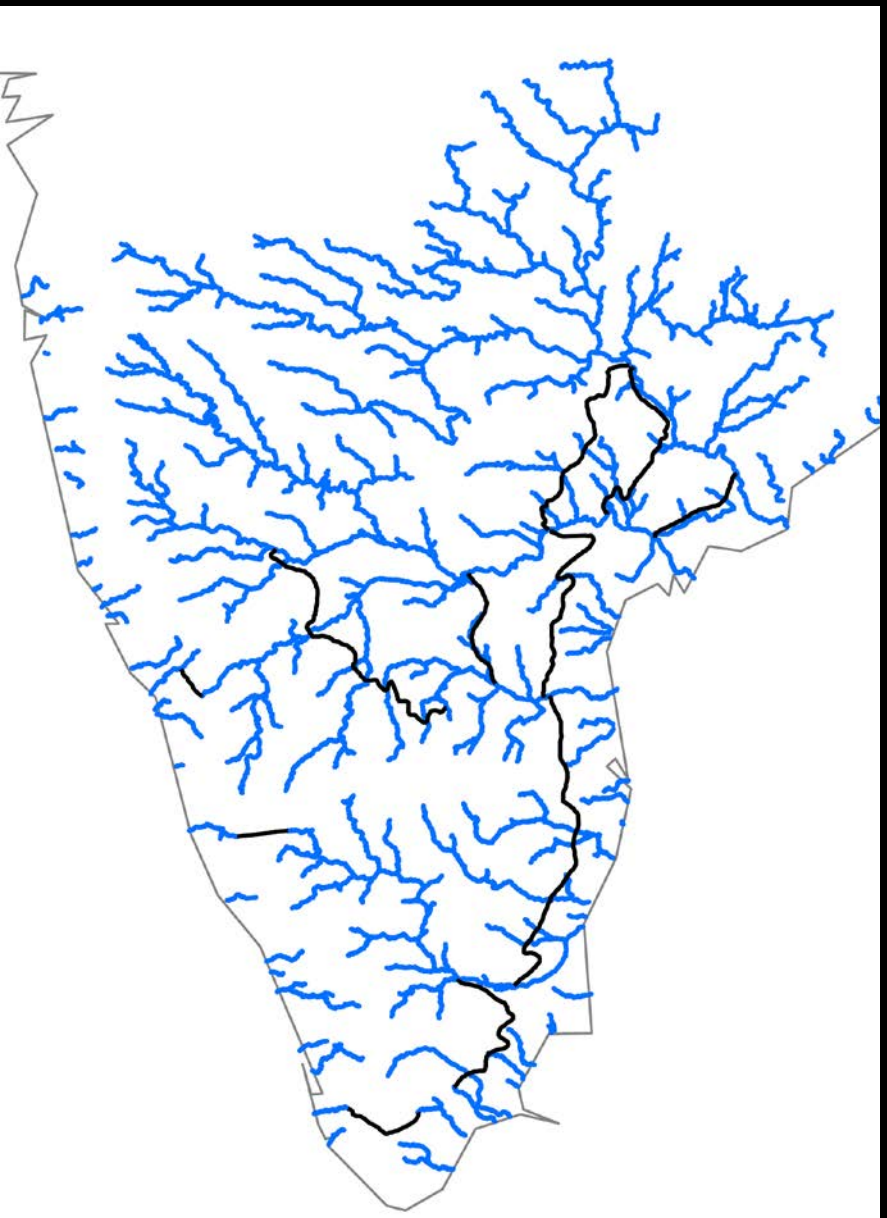


Apply a neutral metacommunity model to the river network of the Indian Peninsula

Objectives:

1. **How do new links affect local species richness (LSR) and total species richness (TSR) ?**
2. **How does movement behavior mediate the effects of network relinking ?**
3. **What link properties mediate the effects of network relinking ?**

Modeling Approach:

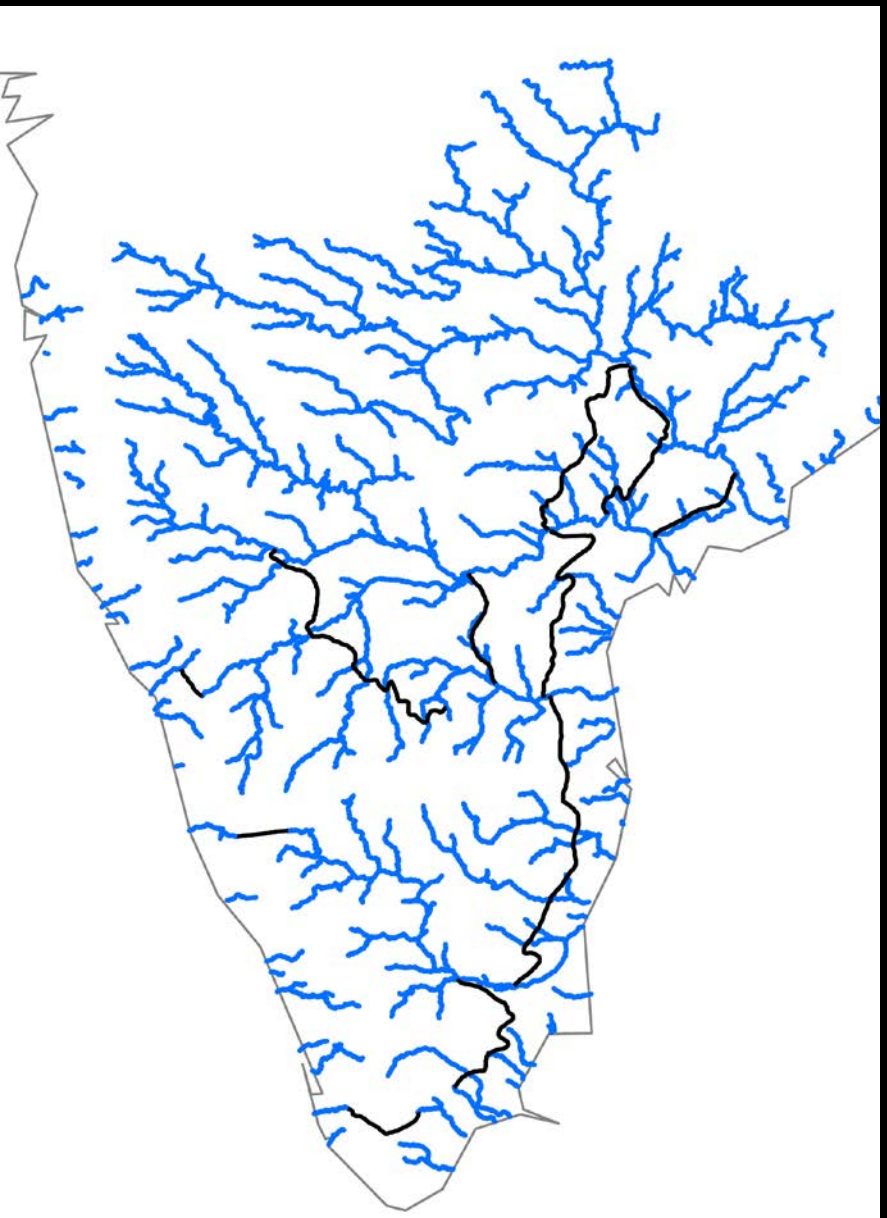


Apply a neutral metacommunity model to the river network of the Indian Peninsula

Methods:

- Stochastic model featuring "neutral competition" for space
  - Fixed capacity for individuals at a site
  - Replacements for dead individuals drawn from a pool consisting of local populations, long distance immigrants, and, rarely, new species

Modeling Approach:

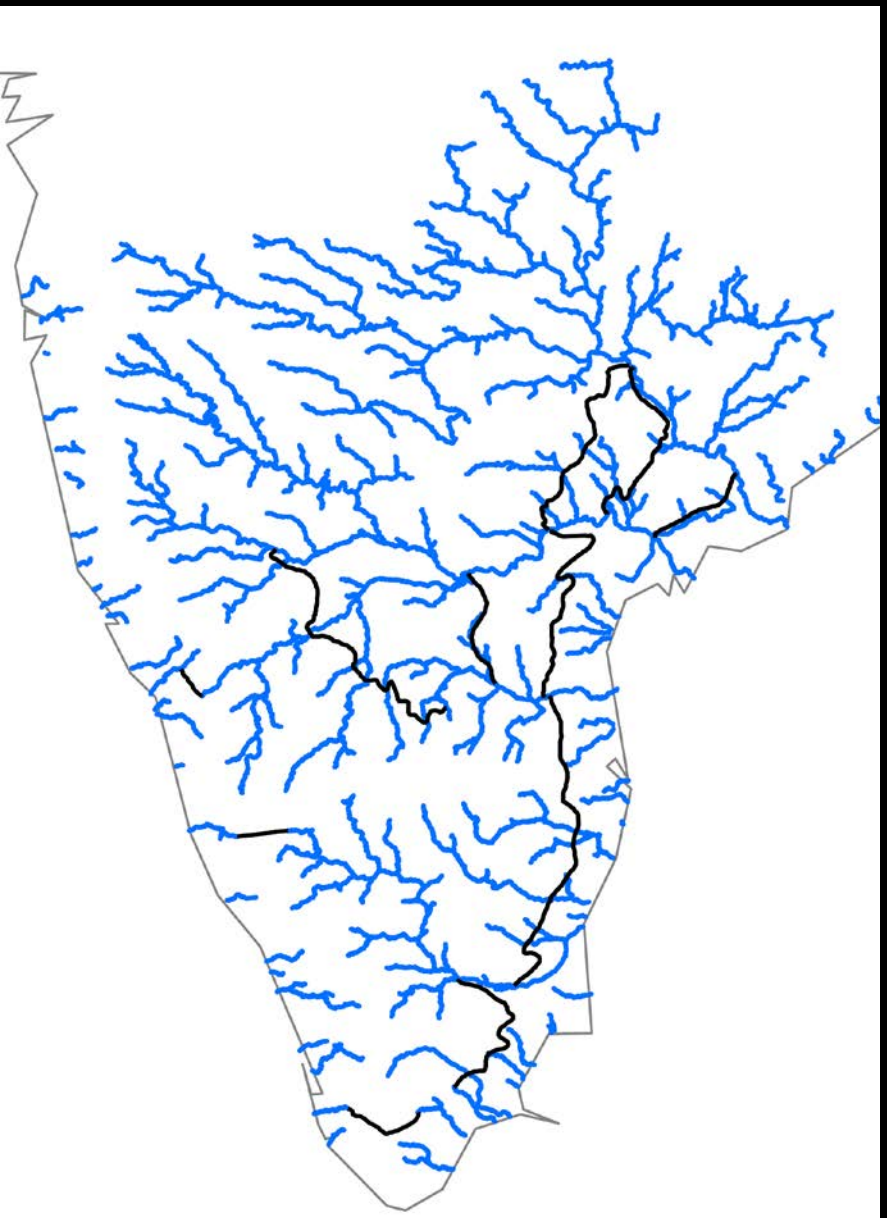


Apply a neutral metacommunity model to the river network of the Indian Peninsula

Methods:

- Stochastic model featuring "neutral competition" for space
- Realistic network geometry
- Local community capacity proportional to watershed area (or reach length)

Modeling Approach:



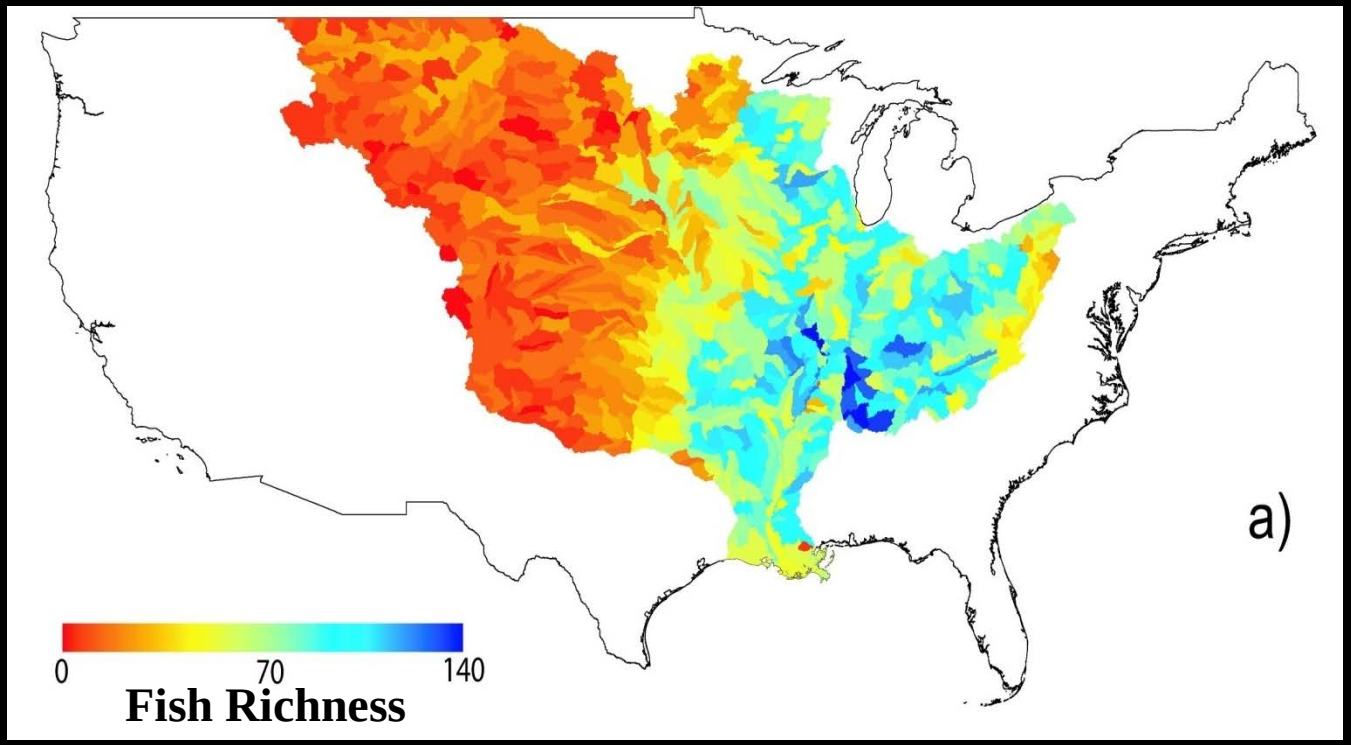
Apply a neutral metacommunity model to the river network of the Indian Peninsula

Methods:

- Stochastic model featuring "neutral competition" for space
- Realistic network geometry
- Local community capacity proportional to watershed area (or reach length)
- Four free parameters:
  - Community capacity proportionality constant
  - Diversification rate
  - Dispersal kernel coefficients (2)

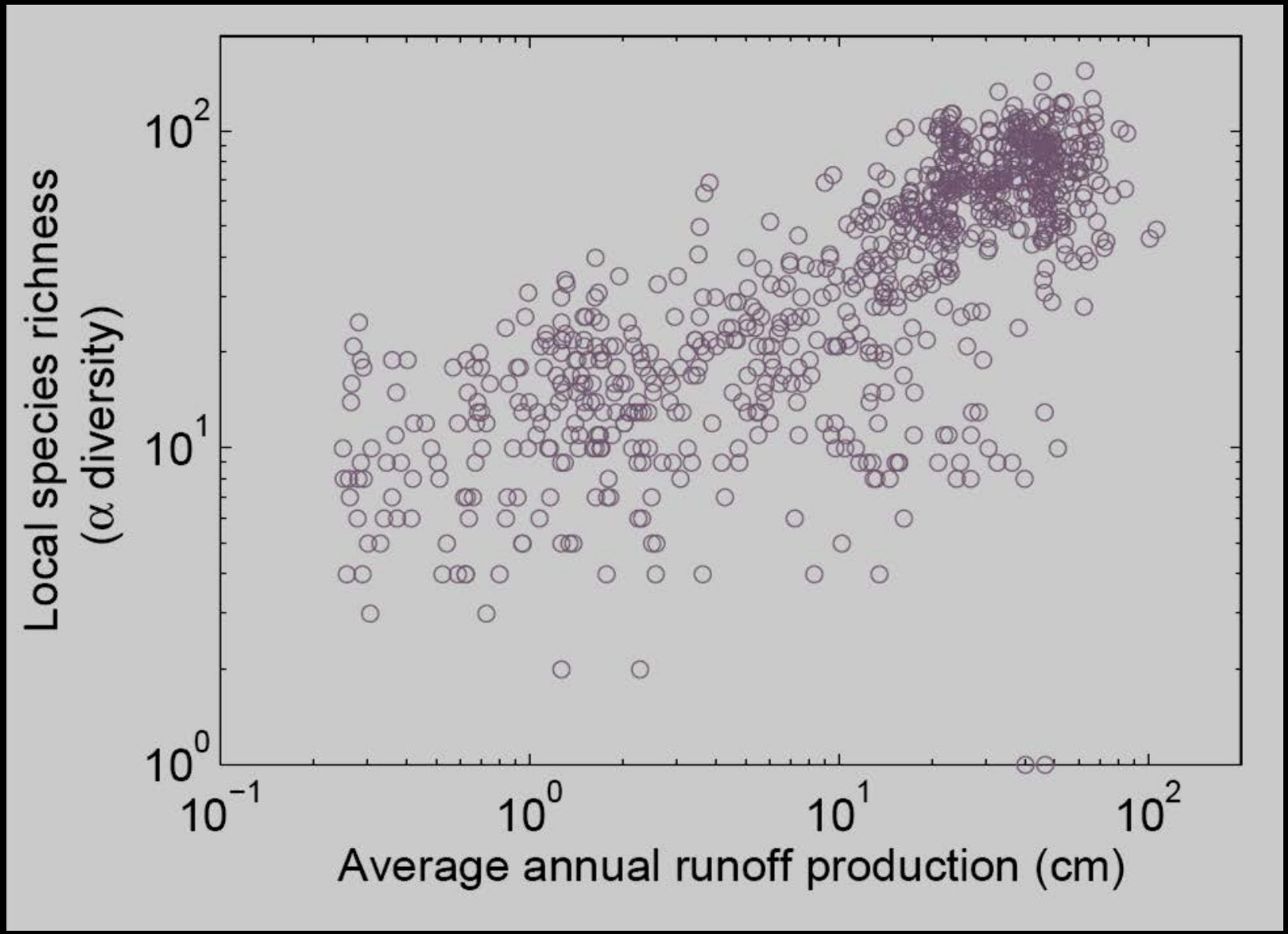
Approach has proven useful before …

Using a neutral model to reconstruct biogeographic patterns in the Mississippi-Missouri River System

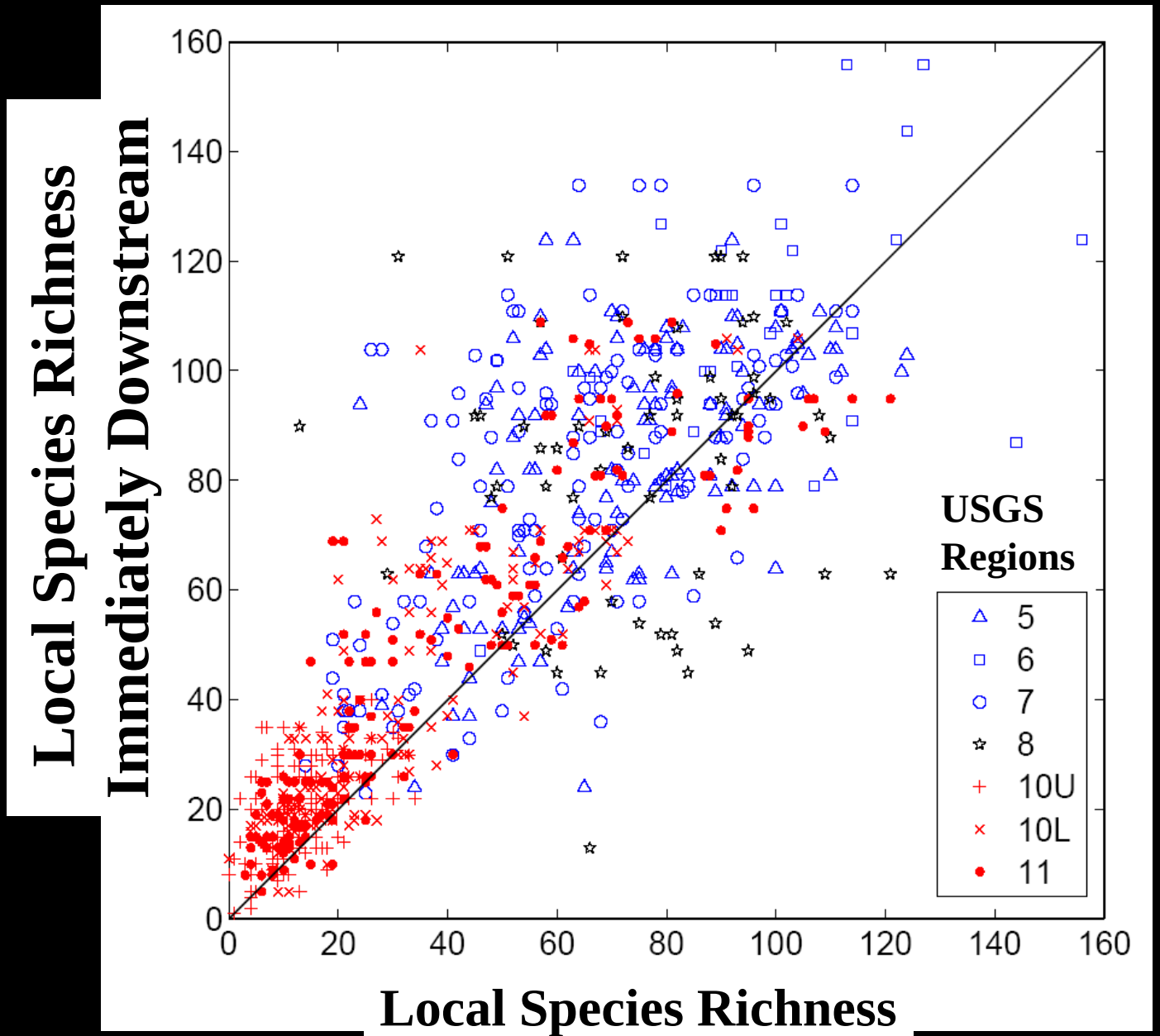


Muneepeerakul et al. 2008. *Nature*.

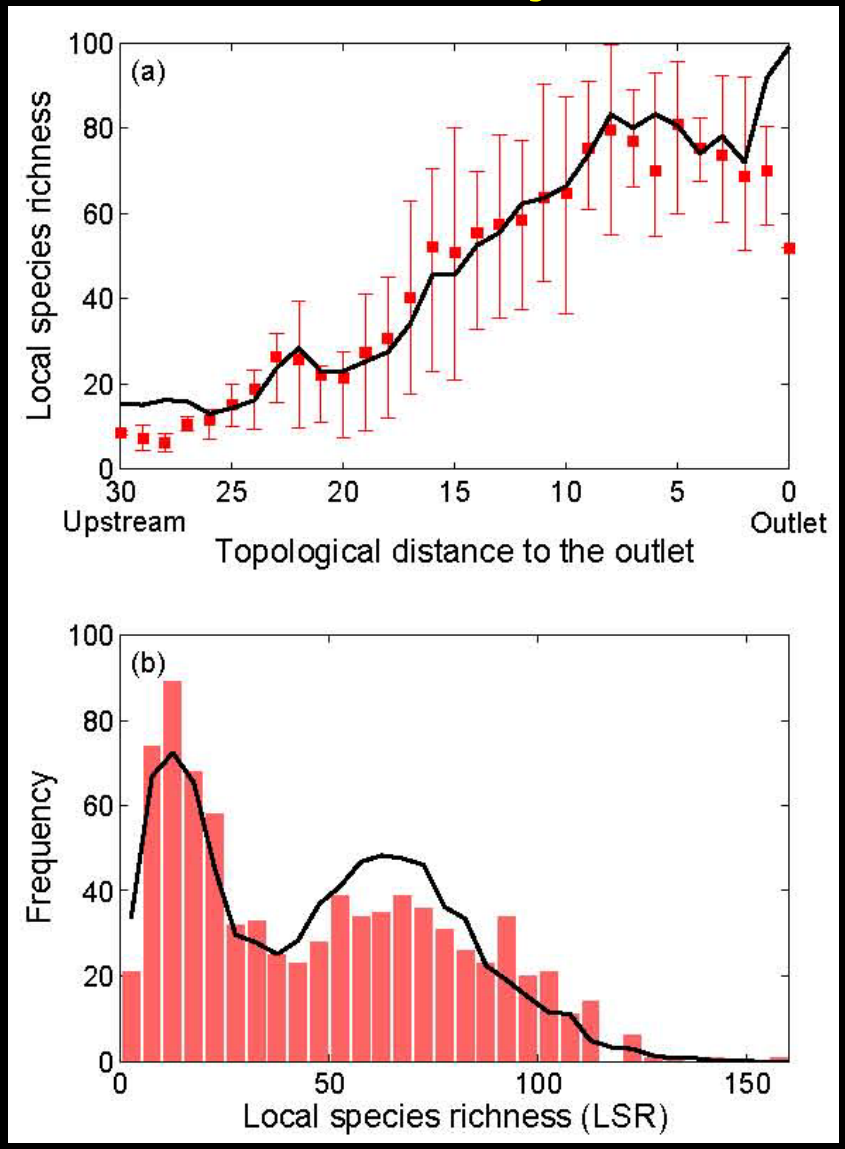
Precipitation and runoff are important determinants of fish diversity in Mississippi-Missouri River System



But riverine geometry also matters



Neutral model captures key aspects of:
α diversity



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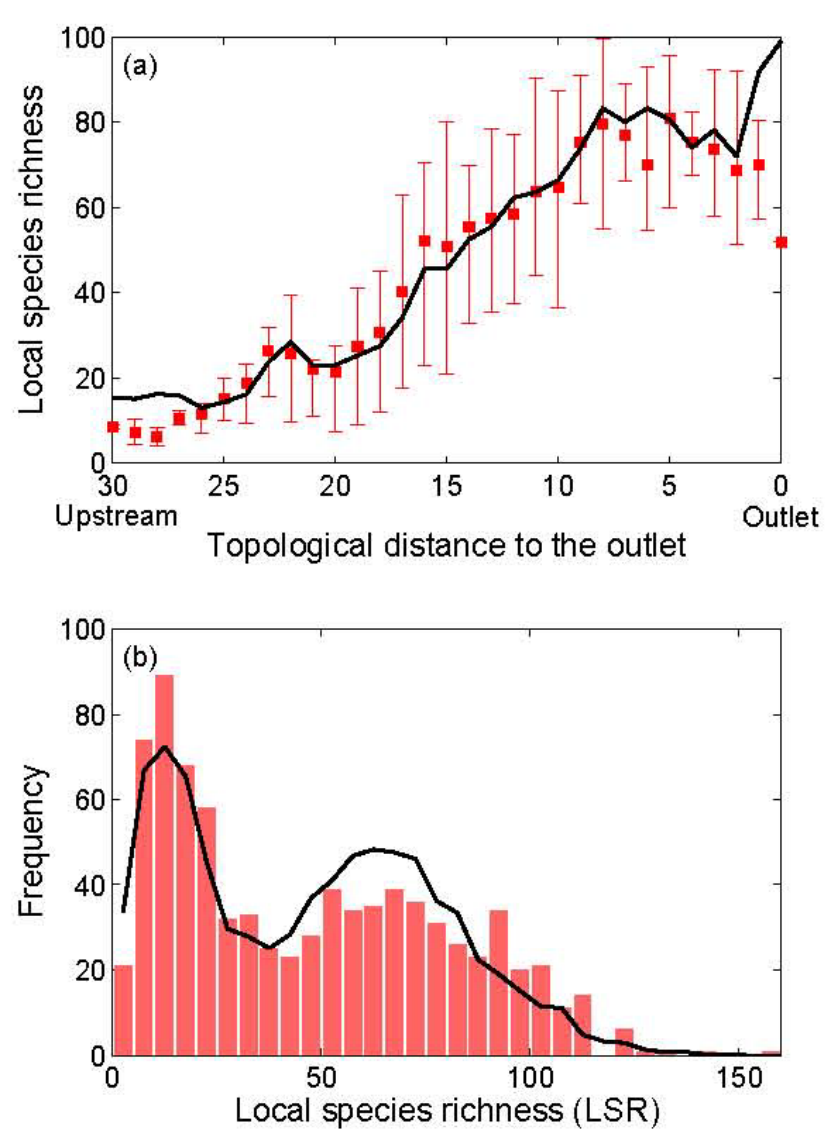
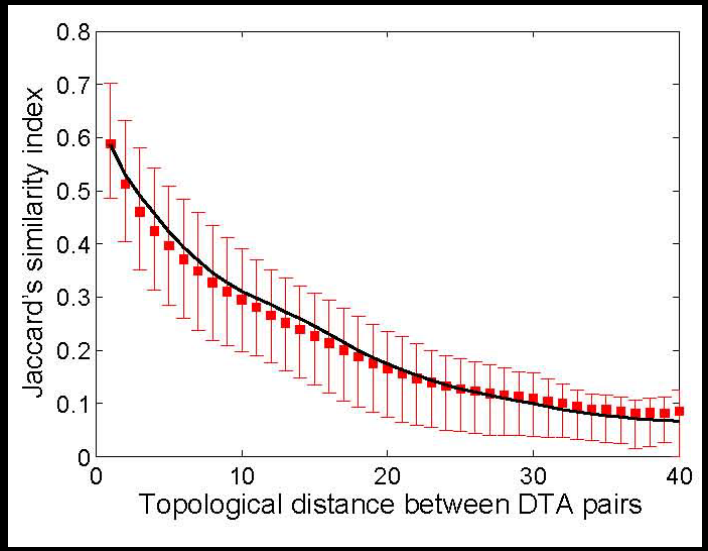


β diversity



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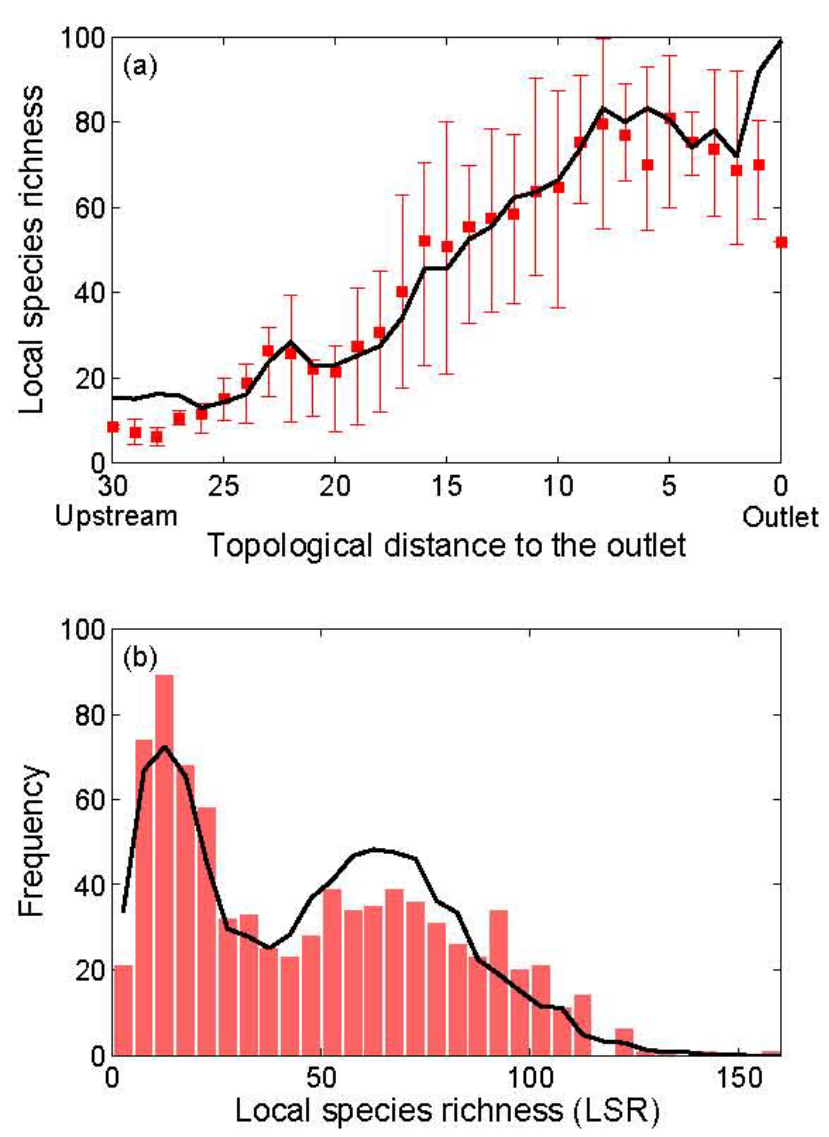
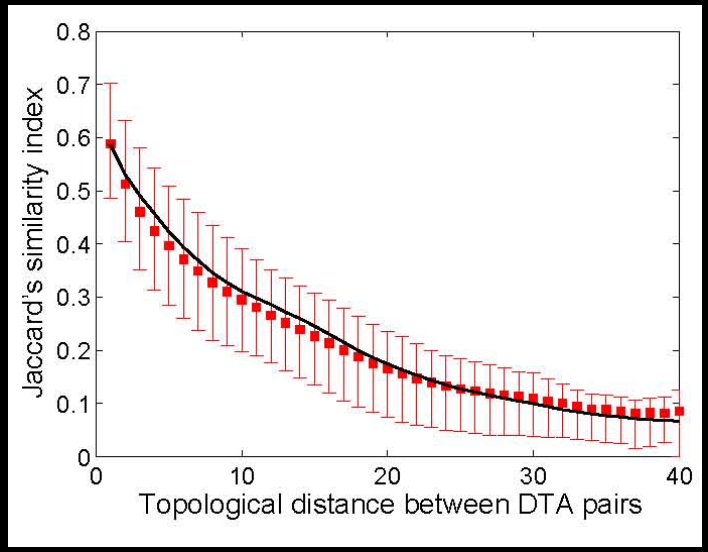
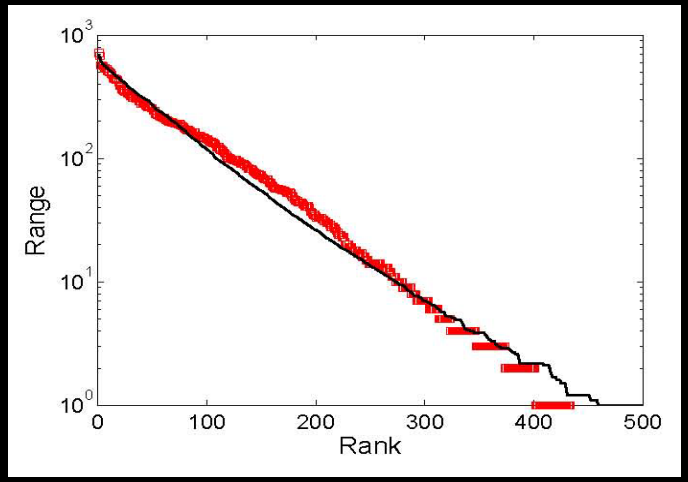


β diversity

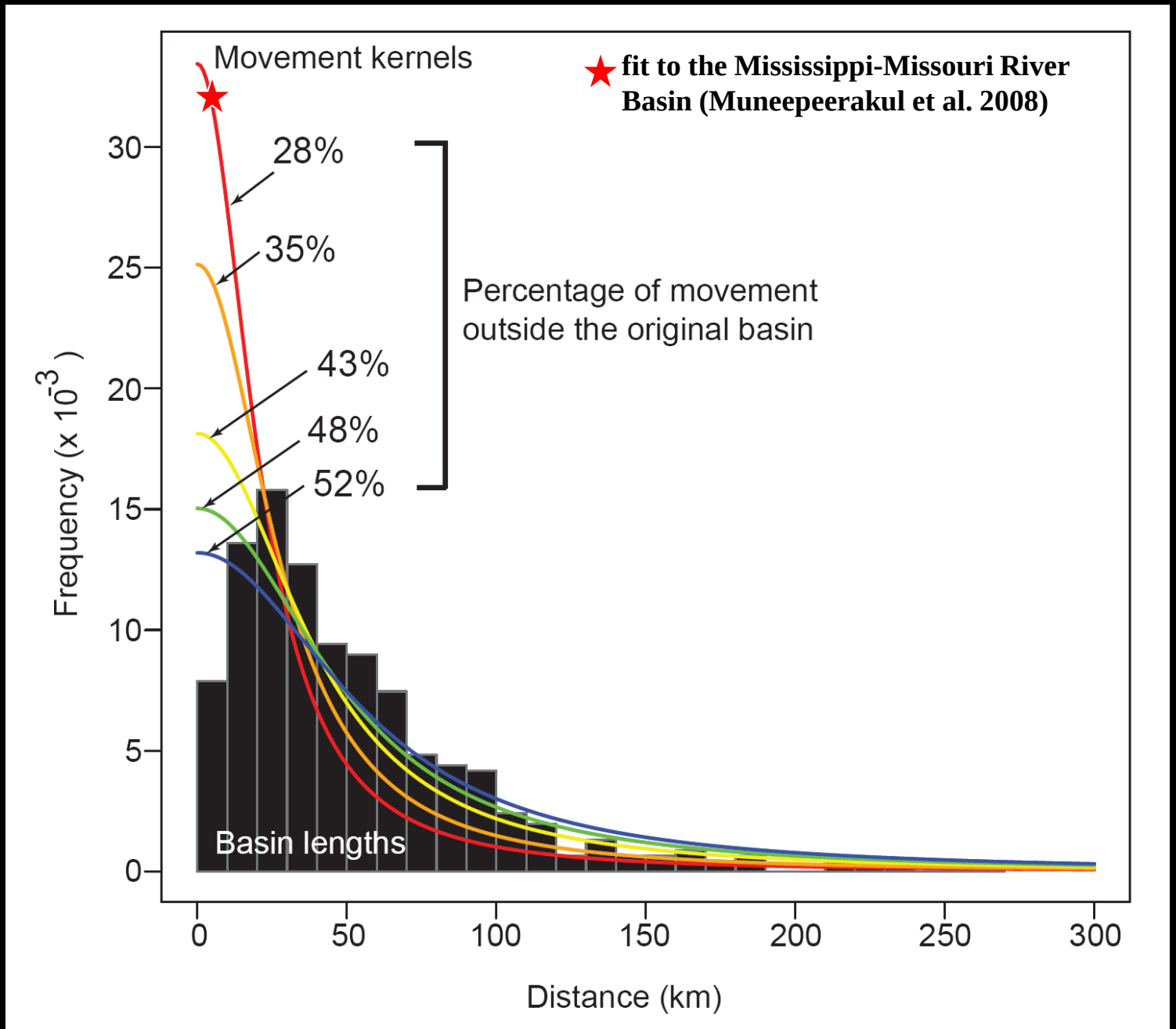


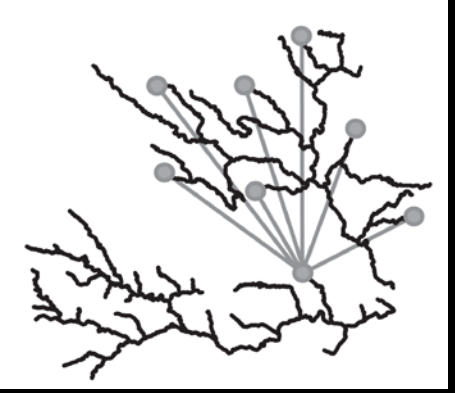
Geographic Range Size Distribution



Muneepeerakul et al. 2008. *Nature*.

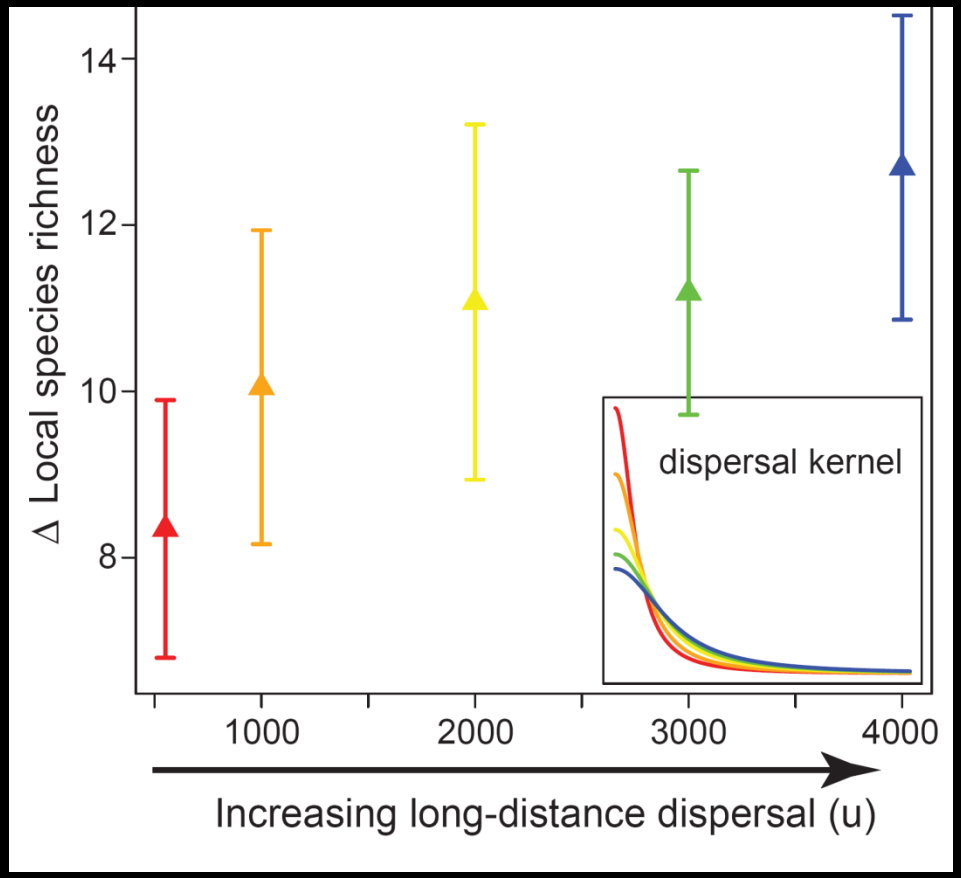
Back to Indian Rivers: Alternative movement kernels





Long-term Impact of Interbasin Relinking

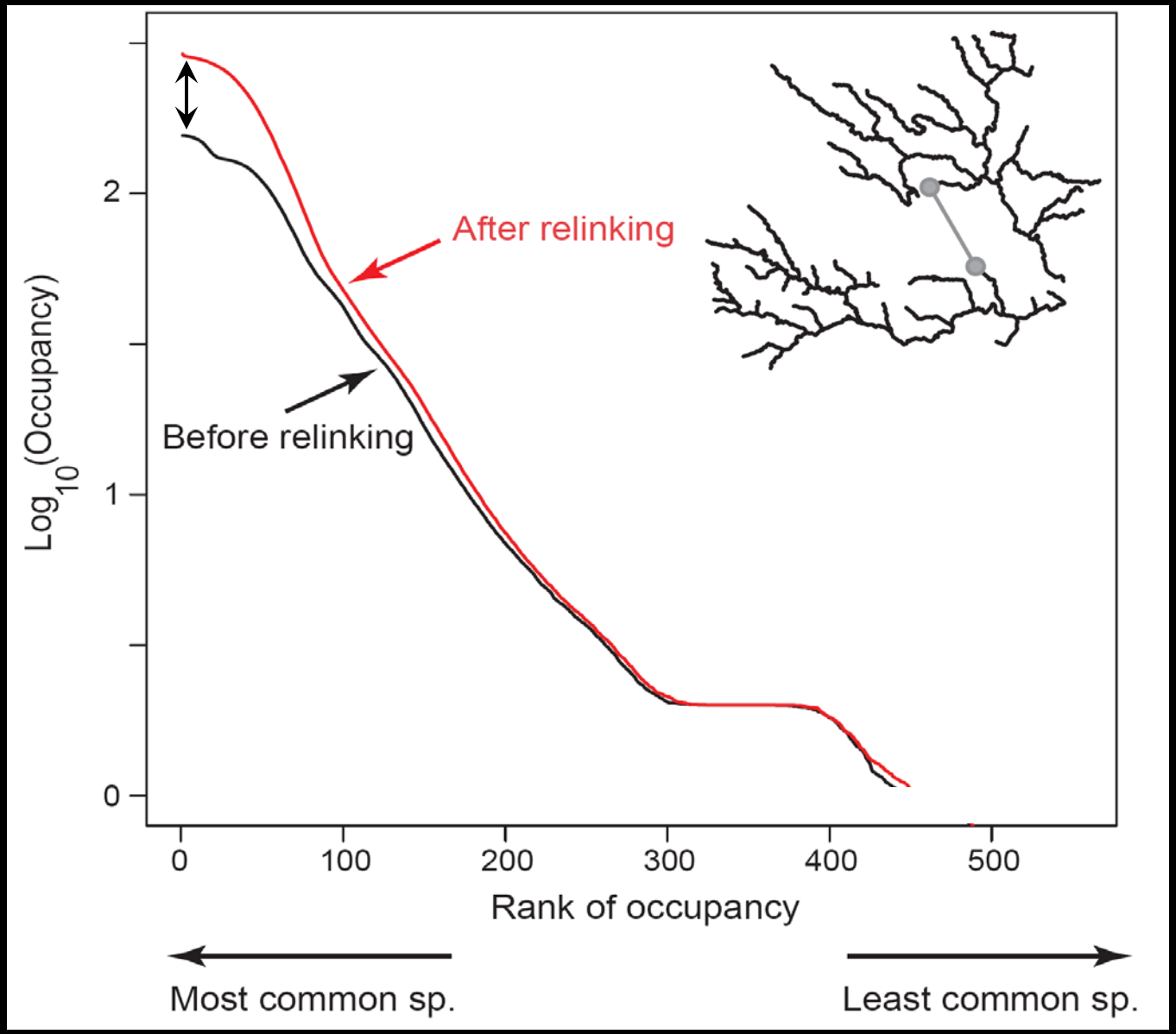
Alternative linkages
Krishna-Godavari



Long distance dispersal amplifies changes in local species richness

Lynch et al. Water Resources Research. 2011.

Common Species Become Even More Common After Relinking

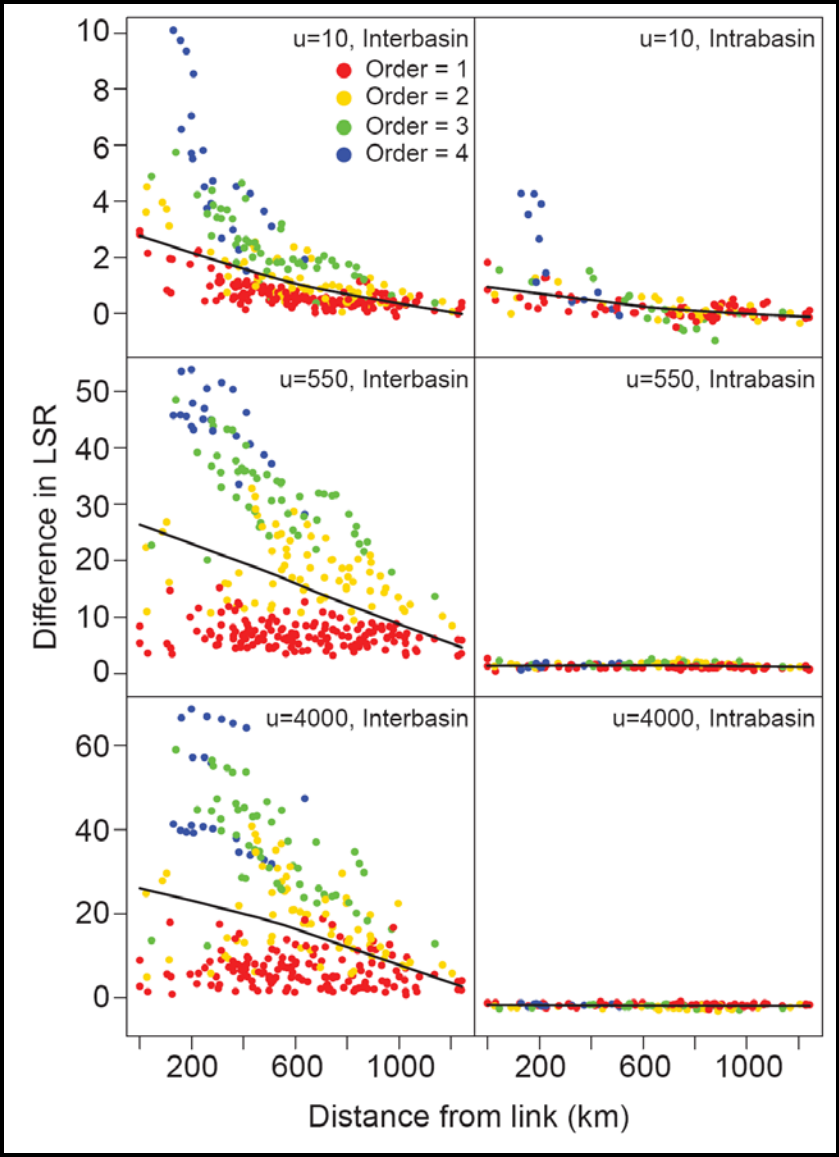


Lynch et al. Water Resources Research. 2011.

Where and When Are Changes in Species Richness Most Pronounced ?

Interbasin Links

- Large order streams
- Near site of new link
- Impacts increase with long-distance dispersal

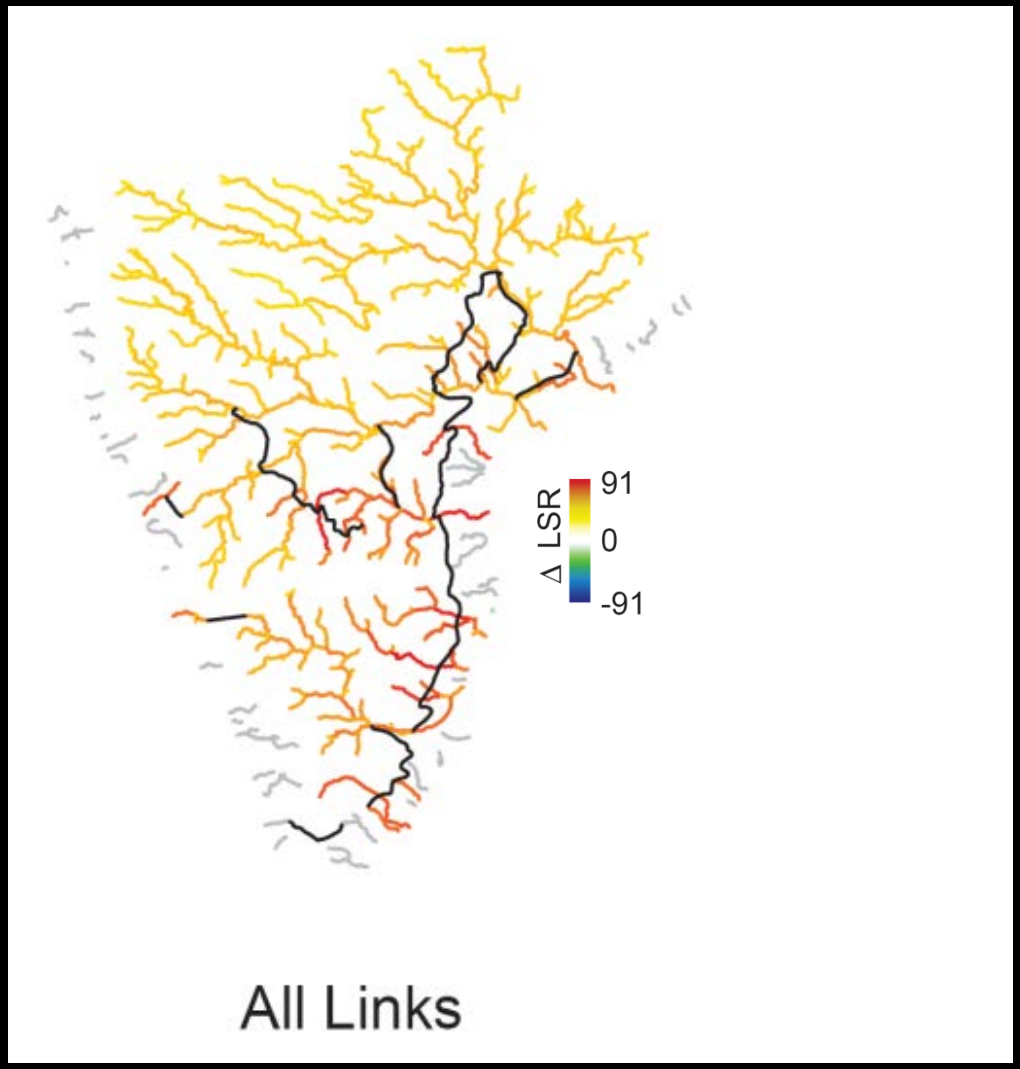


Intrabasin Links

- Minimal effects

Lynch et al. Water Resources Research. 2011.

Predicted LONG-TERM Impacts of All the Proposed Peninsular IBWT Links



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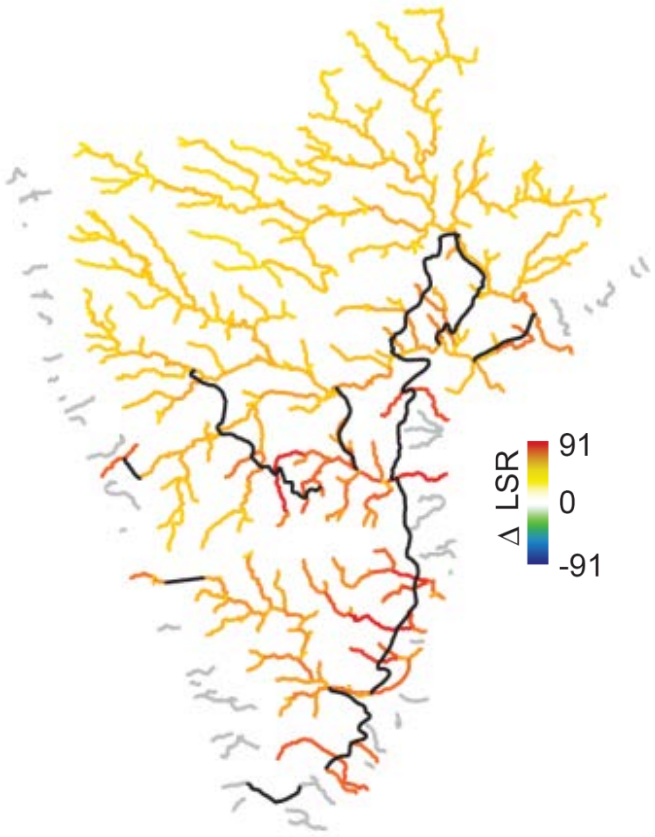
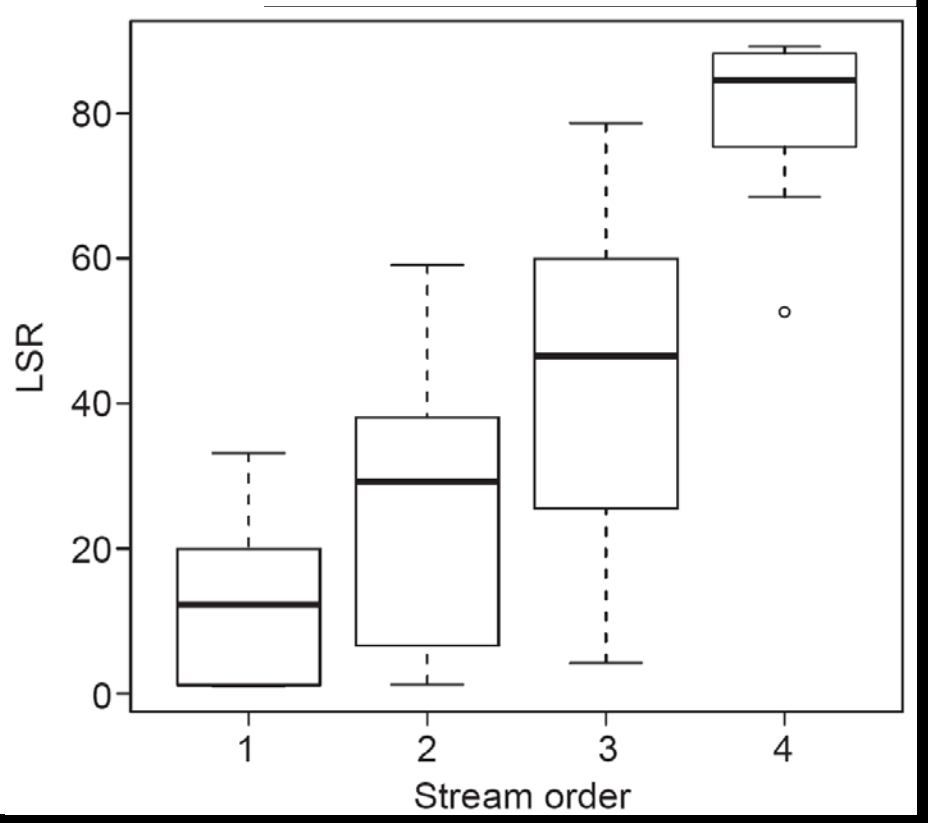


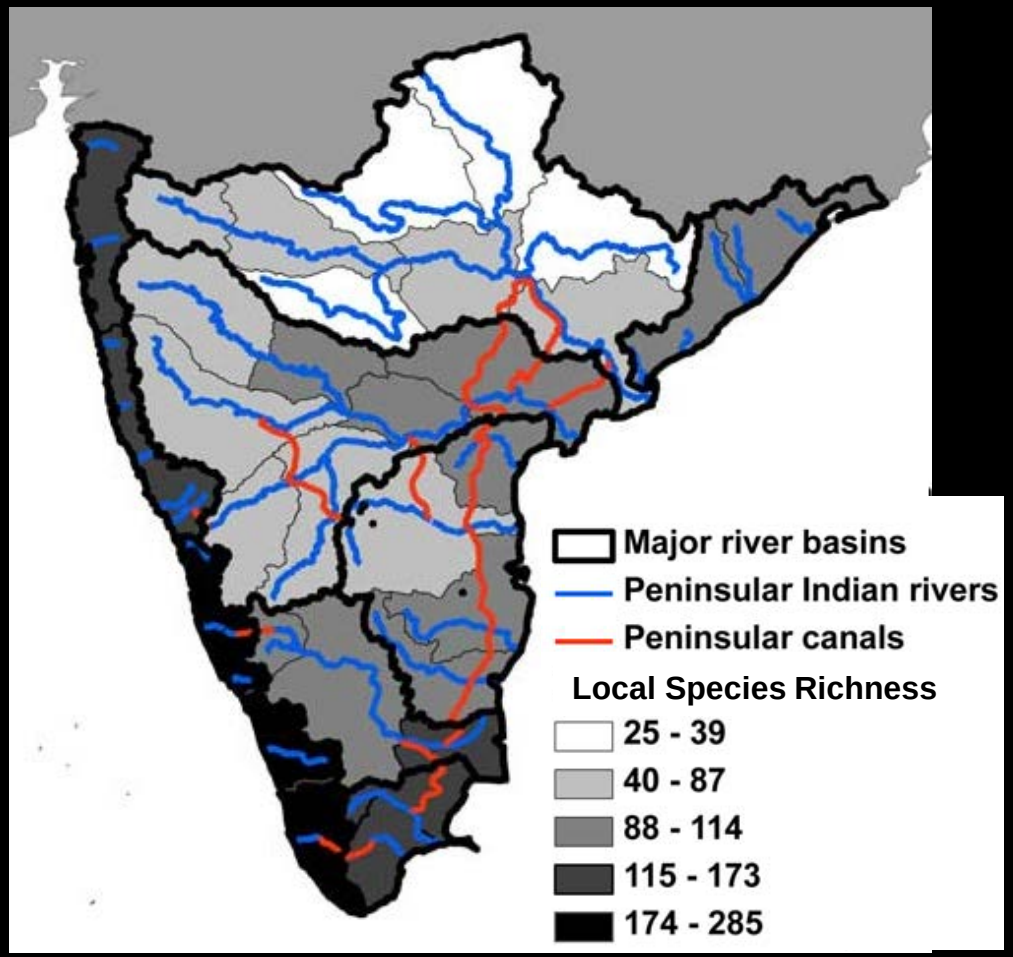
All Links

Background (pre – linking) patterns of local richness



Lynch et al. Water Resources Research. 2011.

Analyses Using Real Species Distribution Data:

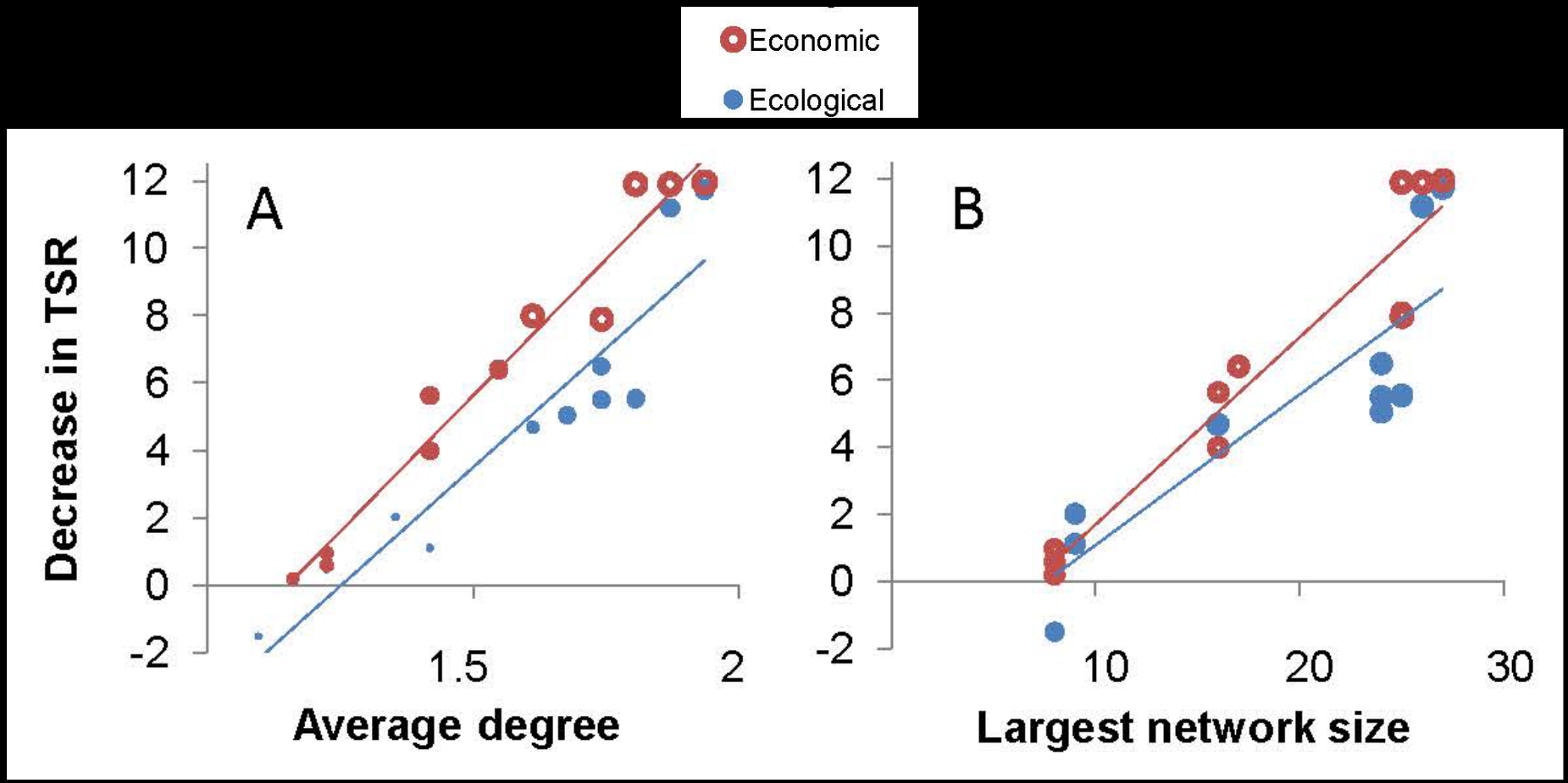


Assembled a database of freshwater fish biodiversity on the Indian Peninsula

- **Developed a model to estimate species richness along each river reach**
- **Examined *near-term* biological turnover due to canal implementation**

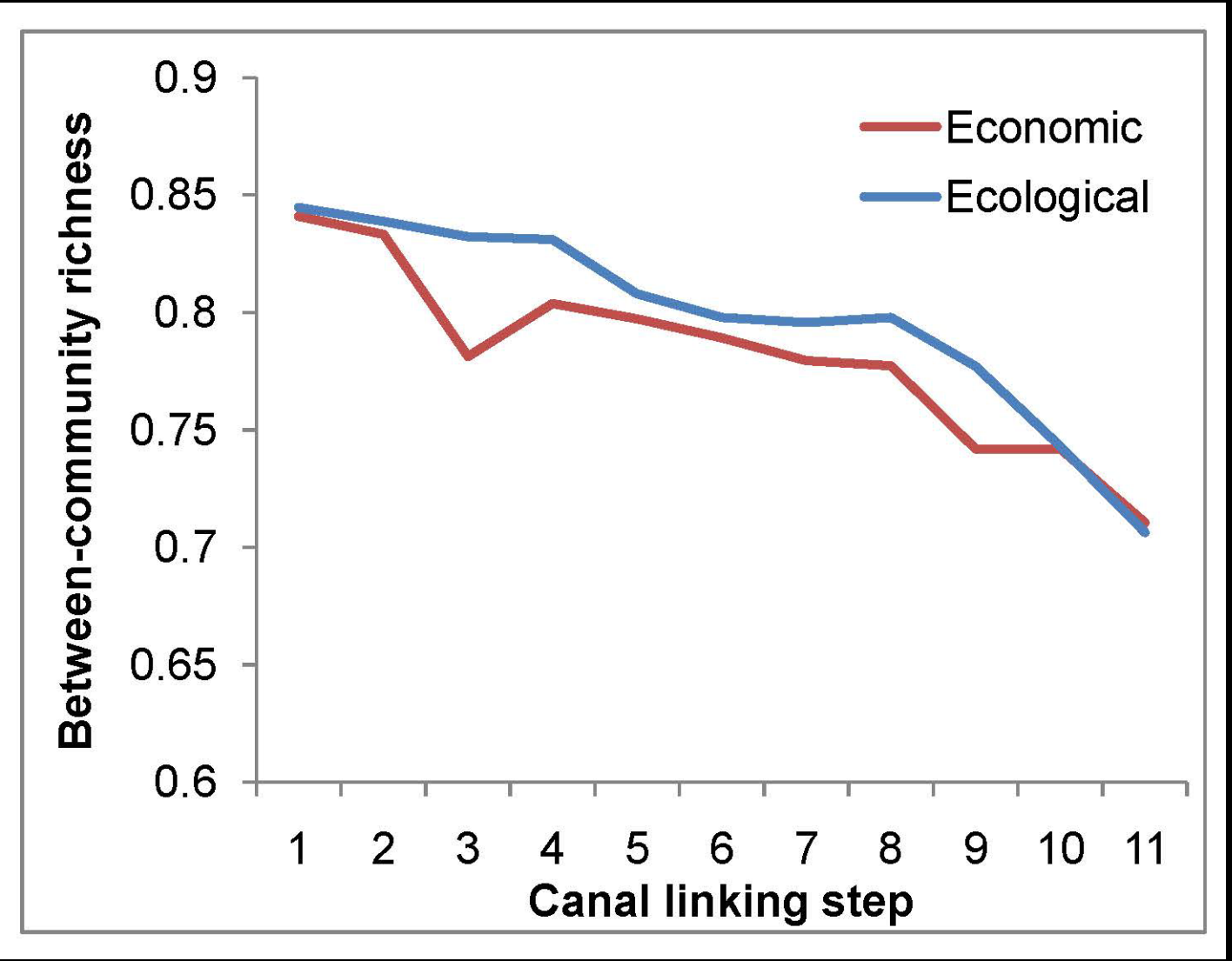
Grant et al. PLOS One. 2012.

Changes to Riverine Geometry Drive Changes in Species Richness Patterns, but the Sequence of Linkages Determines the Magnitude of Impacts



Grant et al. PLOS One. 2012.

Canal sequencing determines whether loss of locally unique biodiversity happens early or late



Grant et al. PLOS One. 2012.

Conclusions:

Connectivity in Riverine Landscapes:

- **Intrinsic effects of configuration**
- **Opportunities for 'out of network' movement**

Results share some similarities with classical 2-D landscapes

- **Increased fragmentation → Increased extinction risk**
- **Increased connectivity → Increased homogeneity**

But geometry drives outcomes in dendritic systems

Conclusions:

Connectivity in Riverine Landscapes:

- Directional biases
- Intrinsic effects of configuration
- Opportunities for ‘out of network’ movement
- → Transient connectivity

Ecology of Riverine Systems:

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- Evan Grant (USGS)
- Mike Neubert (WHOI)

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- James S. McDonnell Foundation

Conclusions

- **Adding connections to a river network tends to increase local species richness and exaggerate relative abundance distributions.**
- **Impacts decline with distance from the points of connection**
- **Impacts are sensitive to the movement kernel: opportunities for long-distance travel will lead to larger network-wide changes than will scenarios where movement is constrained.**
- **Interbasin linking is fundamentally different from intrabasin linking**