Riverine Landscapes: Exploring Connectivity, Extinction Risk and Biogeography in an Alternative Geometry

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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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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 ...
Delicate Bifurcations?
Delicate Bifurcations?

…Maximum angle of repose
Adaptive Dispersal ?
Adaptive Dispersal?

... Experience with barriers to movement
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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Key features affecting connectivity:

- Directional biases
- Intrinsic effects of configuration
- Opportunities for ‘out of network’ movement
- Transient connectivity
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Connectivity is Critical for Species Persistence in Riverine Landscapes

Sonoran Desert Fishes Database

Fagan et al. 
Species with Fragmented Historical Distributions Are Predisposed to Extinction

\[ r^2 = 0.63 \]

\[ r^2 = 0.90 \]

Geometric Opportunities for Recolonization Facilitate Persistence

- **Catostomus insignis**
- **Gila intermedia**
- **Rhinichthys osculus**
- **Tiaroga cobitis**

**Network ‘Branchiness’**
- $T_1$
- $R_T$

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
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

Asymptotic Growth Rate, $\lambda$

Connectivity Differences from Bifurcating Network

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 population is growing, and its water supplies are not keeping pace. Can an ambitious scheme to connect up the country’s rivers slake the nation’s deepening thirst? Daemon Fairless investigates.
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

Grant et al. PLOS One. 2012.
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?
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)
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

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

Neutral model captures key aspects of:

**α diversity**

**β diversity**

Neutral model captures key aspects of:

**$\alpha$ diversity**

**$\beta$ diversity**

Geographic Range Size Distribution

Back to Indian Rivers: Alternative movement kernels fit to the Mississippi-Missouri River Basin (Muneepeerakul et al. 2008)
Long-term Impact of Interbasin Relinking

Alternative linkages
Krishna-Godavari

Long distance dispersal amplifies changes in local species richness

Common Species Become Even More Common After Relinking

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

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

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

Background (pre – linking) patterns of local richness

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

Analyses Using Real Species Distribution Data:

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.
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:

Collaborators:

• Wendell Minckley (Arizona State Univ.)
• Ignacio Rodriguez-Iturbe (Princeton)
• Andrea Rinaldo (Univ. Padova)
• Heather Lynch (SUNY-Stony Brook)
• Peter Unmack (NESCENT)
• Emma Goldberg (Univ. Illinois)
• Rachata Muneepeerakul (Arizona State Univ.)
• Enrico Bertuzzo (EPF Lausanne)
• Evan Grant (USGS)
• Mike Neubert (WHOI)

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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**