Using network theory to evaluate the passage behaviors of Chinook salmon and Pacific lamprey at Bonneville Dam

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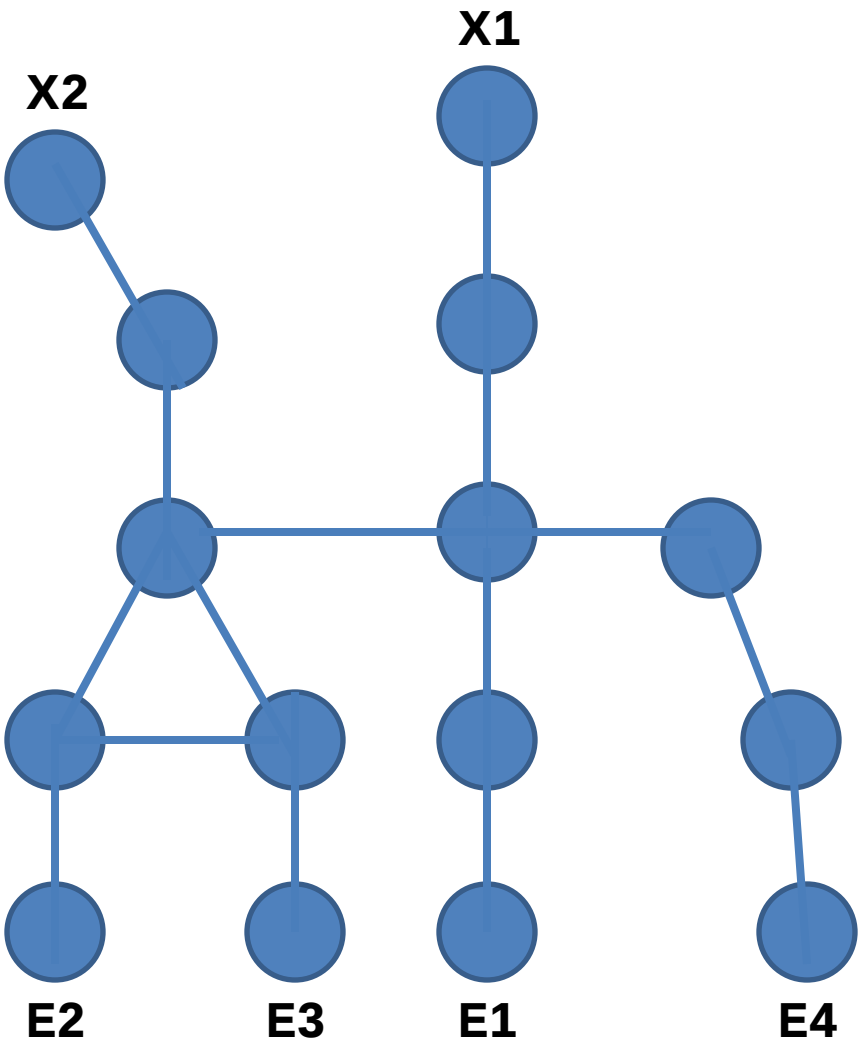
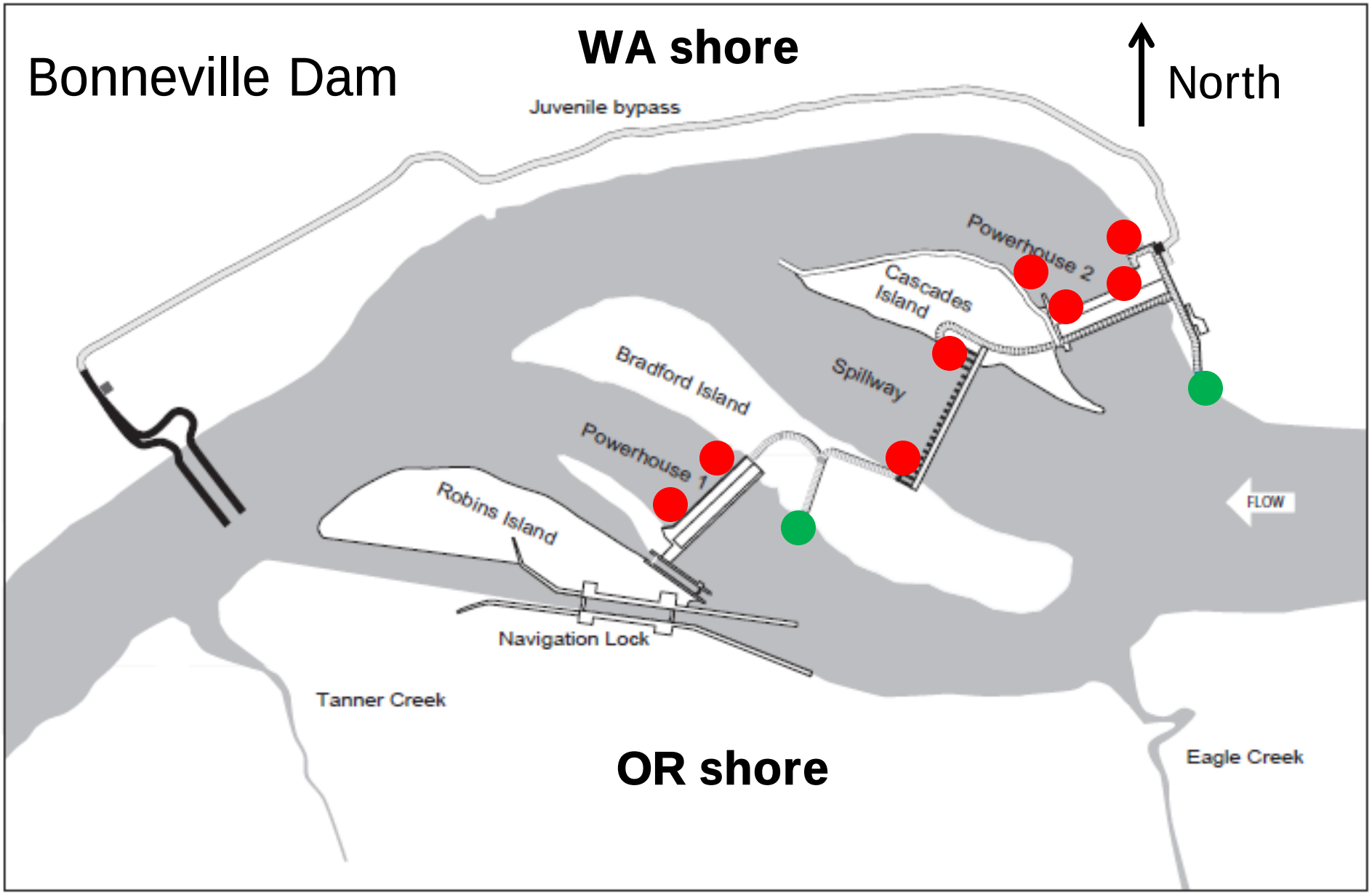
US Army Corps of Engineers®

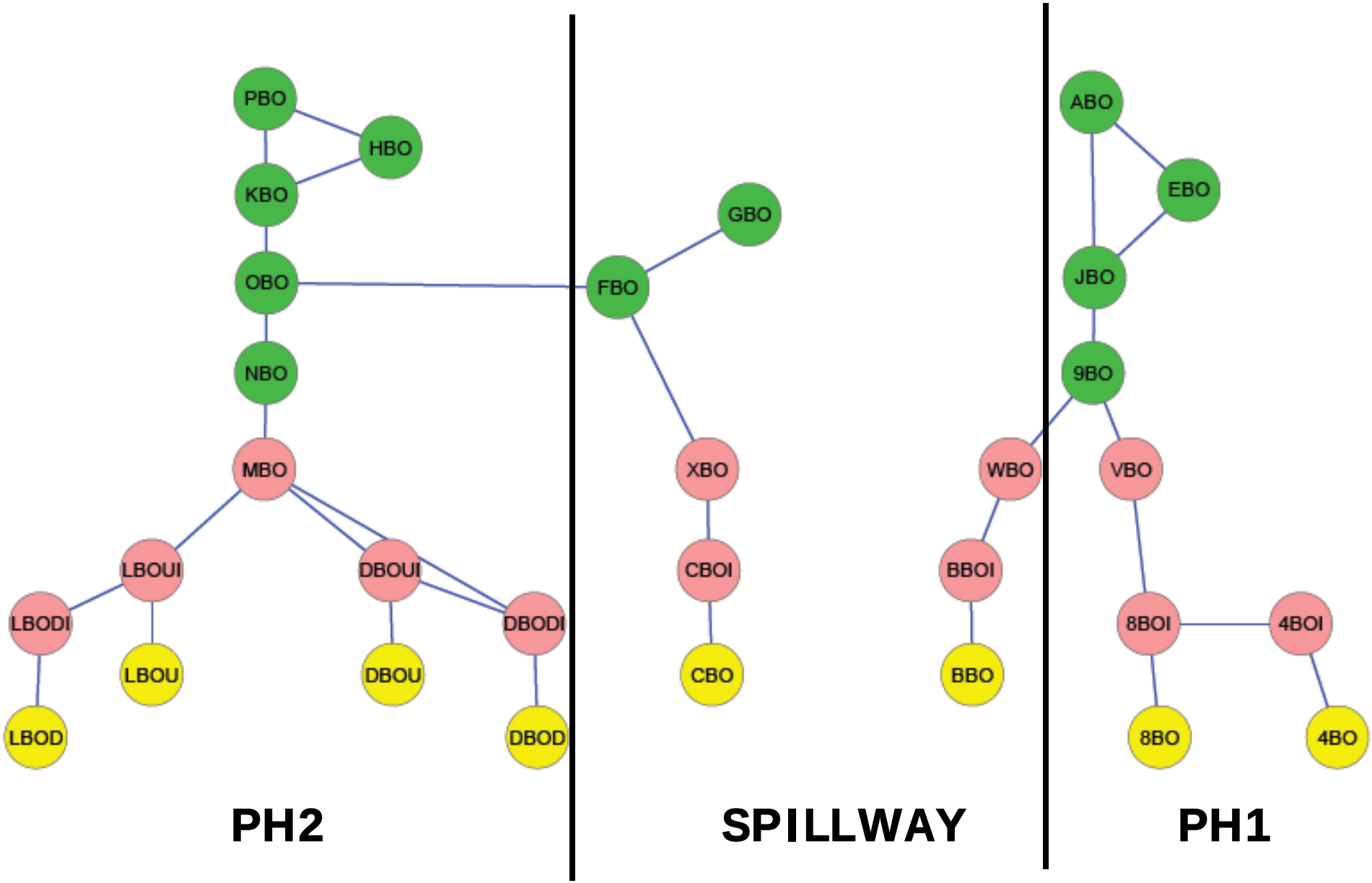
Spatial complexity of fish passage systems at hydropower dams

- Linear passage structures
  - Multiple entrances and exits
- Passage metrics such as ‘efficiency’ or ‘success’
  - May not capture true complexity of movements that fish exhibit




Bonneville Dam
WA shore
North
Juvenile bypass
Powerhouse 2
Cascades Island
Bradford Island
Spillway
Powerhouse 1
Robins Island
FLOW
Navigation Lock
Tanner Creek
OR shore
Eagle Creek

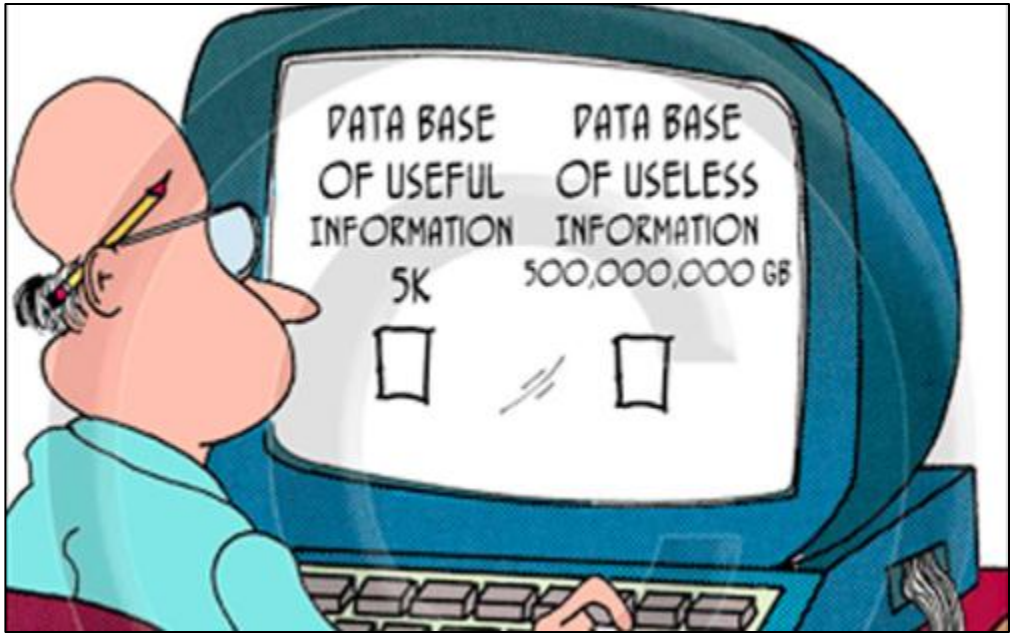
Top Down view of Bonneville Dam



Long-term radio-telemetry monitoring

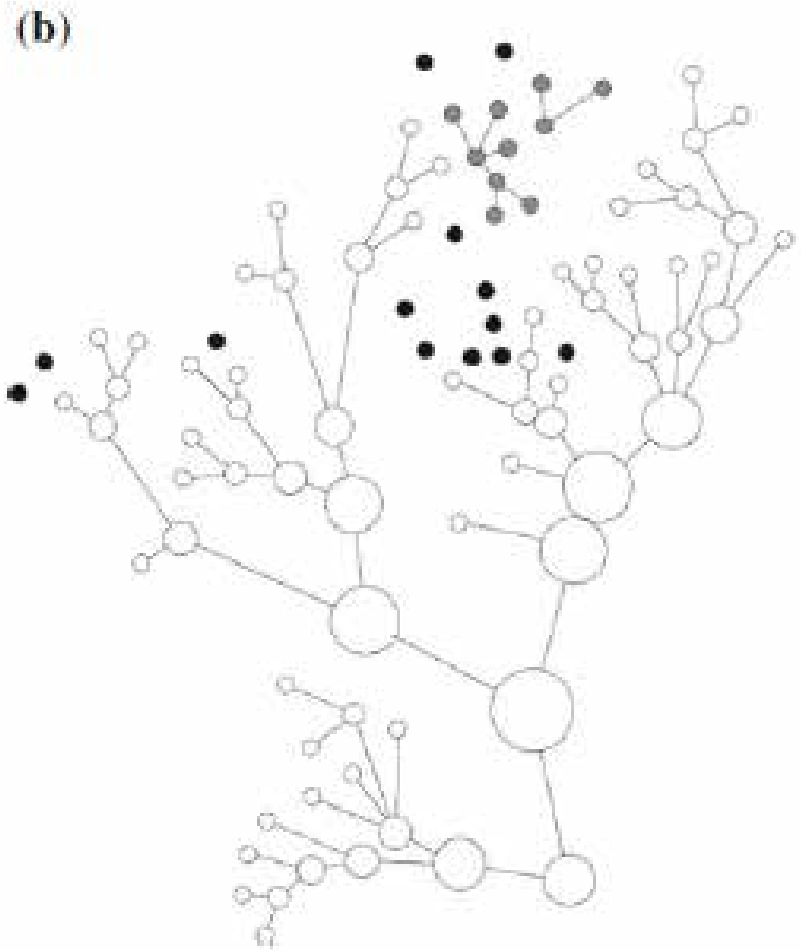
- Chinook Salmon and Pacific Lamprey
- Telemetry data = ~50,000 lines coded data

- Objective 1: Visualize patterns in the movements of Chinook salmon and Pacific lamprey at Bonneville.
  - Descriptive in nature

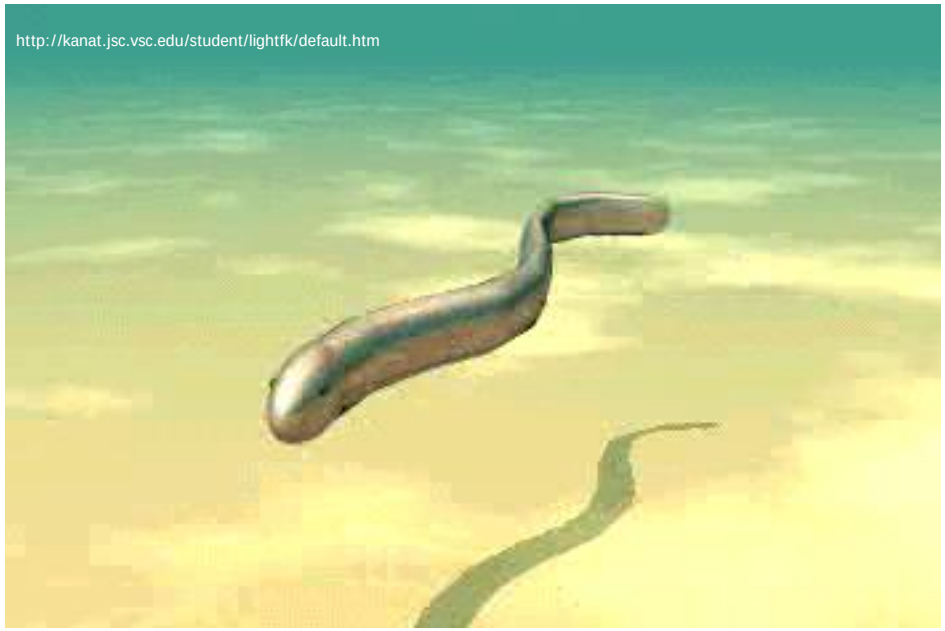


Applying network theory to telemetry data

- Describes connectivity and size of large, spatial systems
  - Visualization
  - Nodes and edges
- Era of big data
- Frequently applied for social network analyses
- Ecological applications
  - River connectivity



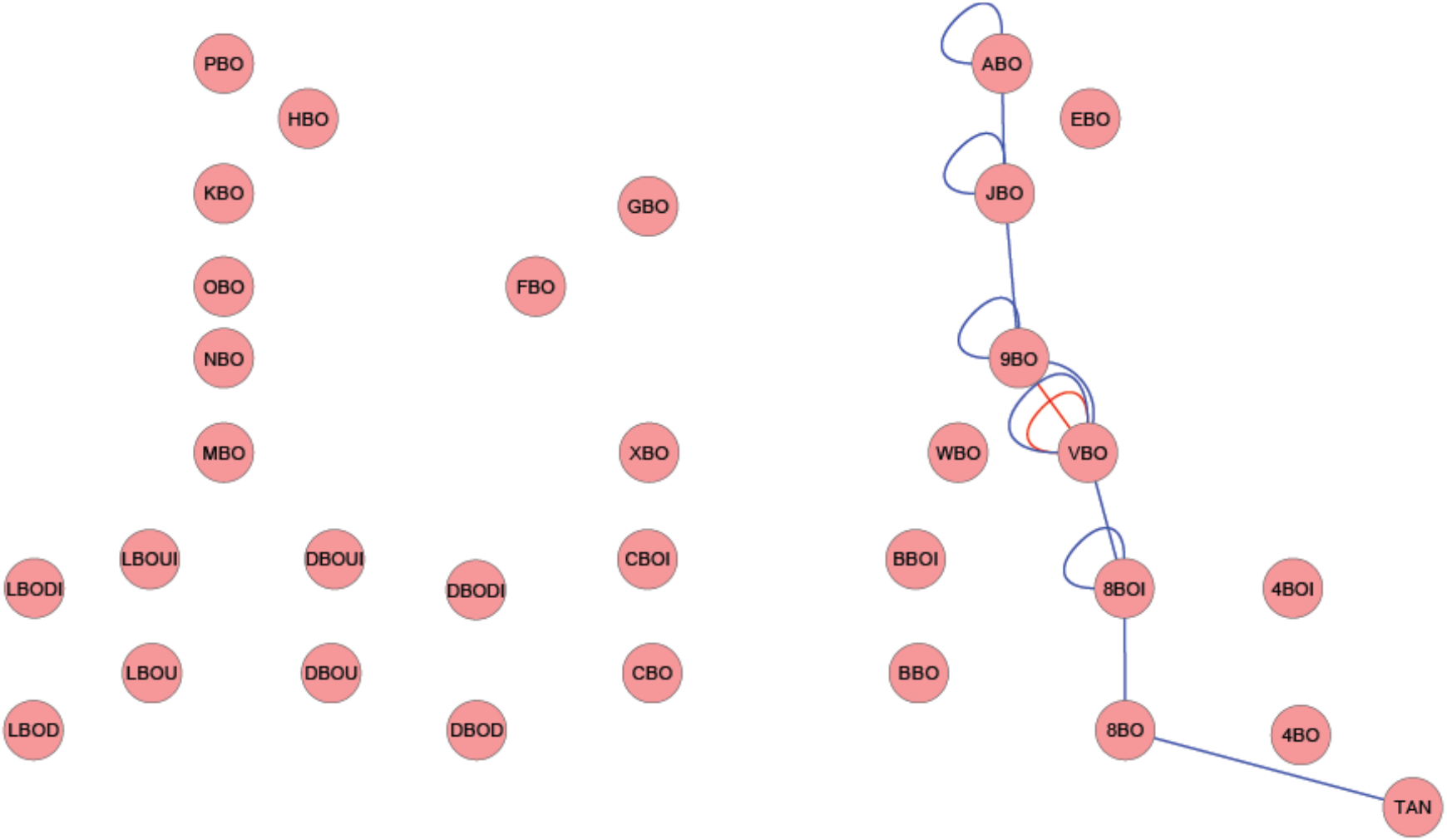
Eros et al. (2011)



- Passage success = 50% for lamprey and 95% for Chinook
- Potentially large variability in passage differences
  1. Motivation-related
     - Philopatric versus non-philopatric
  2. Performance-related
     - Overcoming high velocity zones
     - Structural impediments
- Novel opportunity to capture that variation

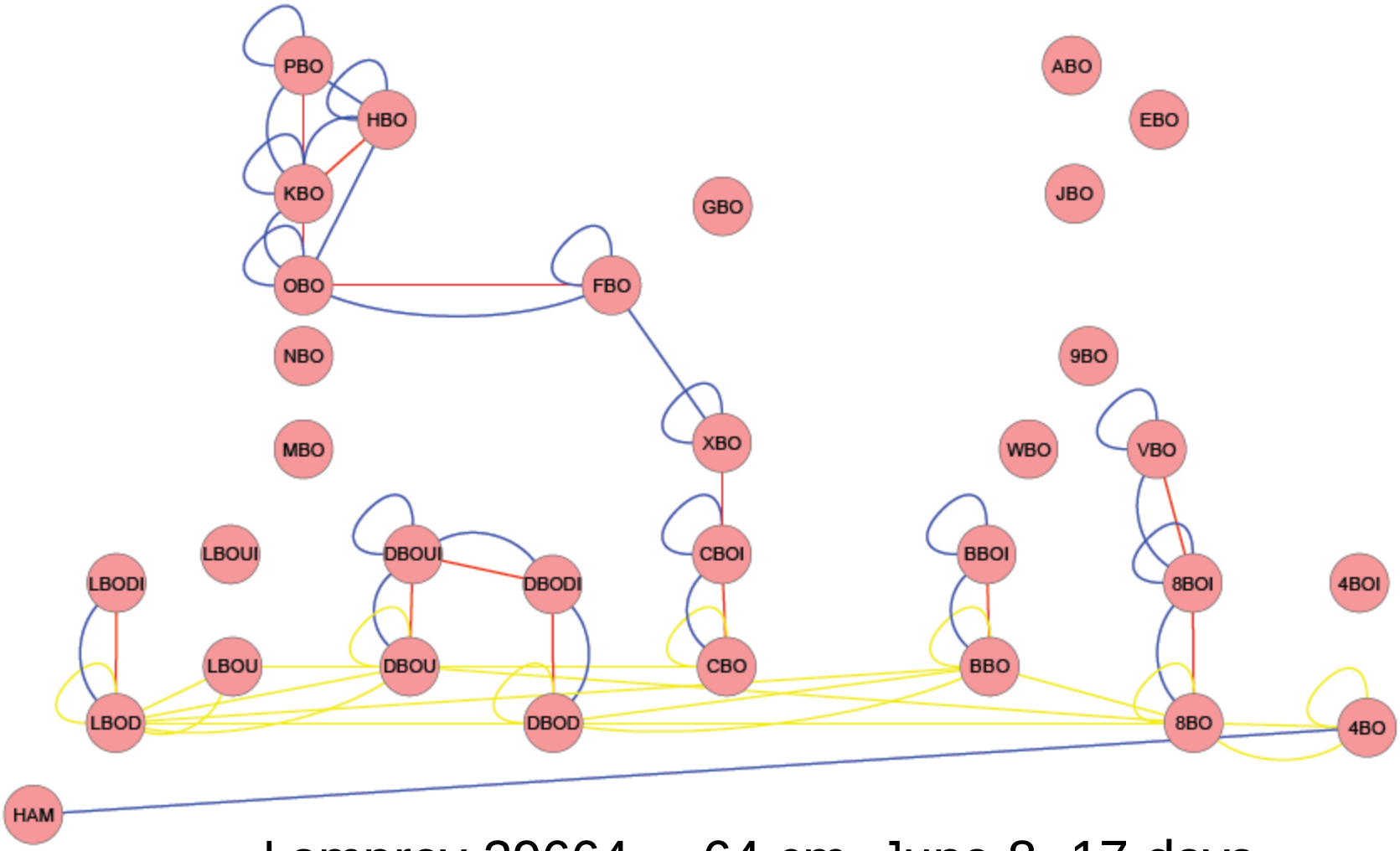
Constructing networks (Cytoscape v2.8.3)

A) Lamprey 39664



Significant individual variability for lamprey

B) Lamprey 39689

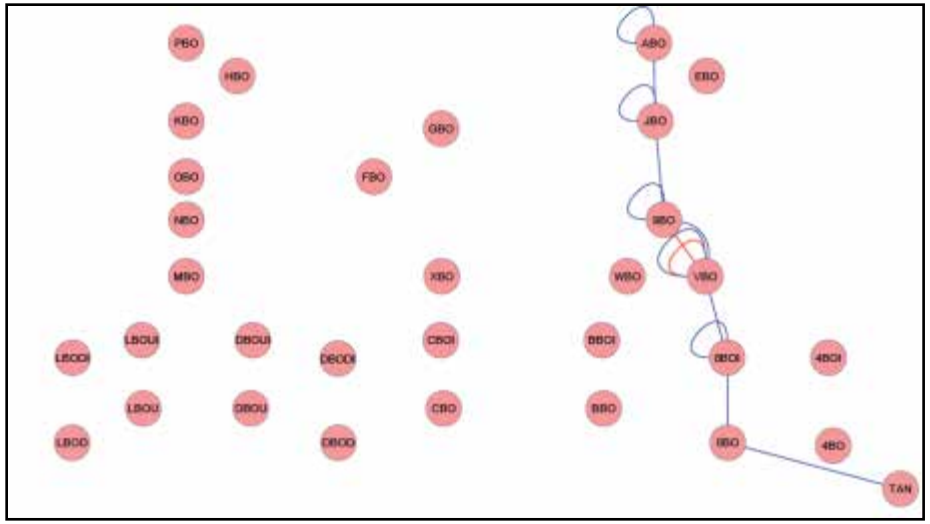


Lamprey 39664 = 64 cm, June 8, 17 days
Lamprey 39689 = 69 cm, June 9, 17 days

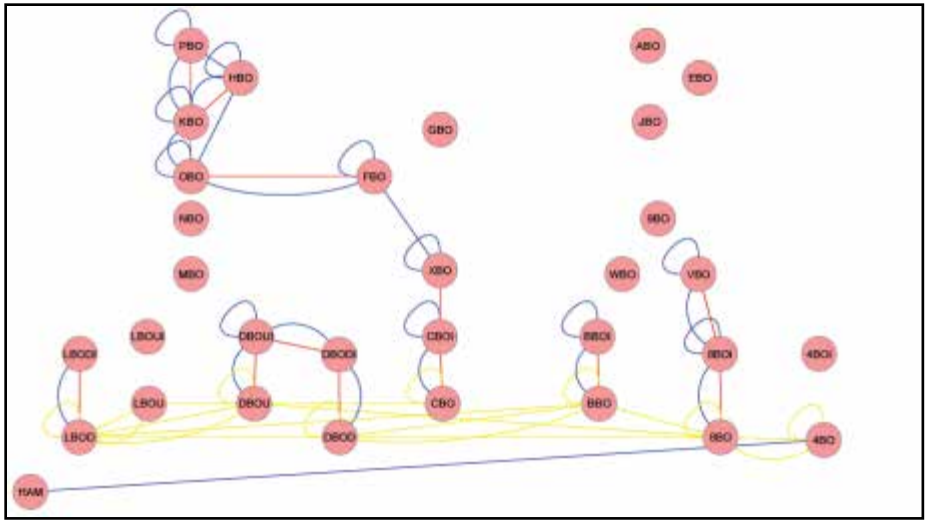
Characterizing individual network structure (5 connectivity metrics)

- <u>Number of edges:</u> # of connections (e.g., movements)

14



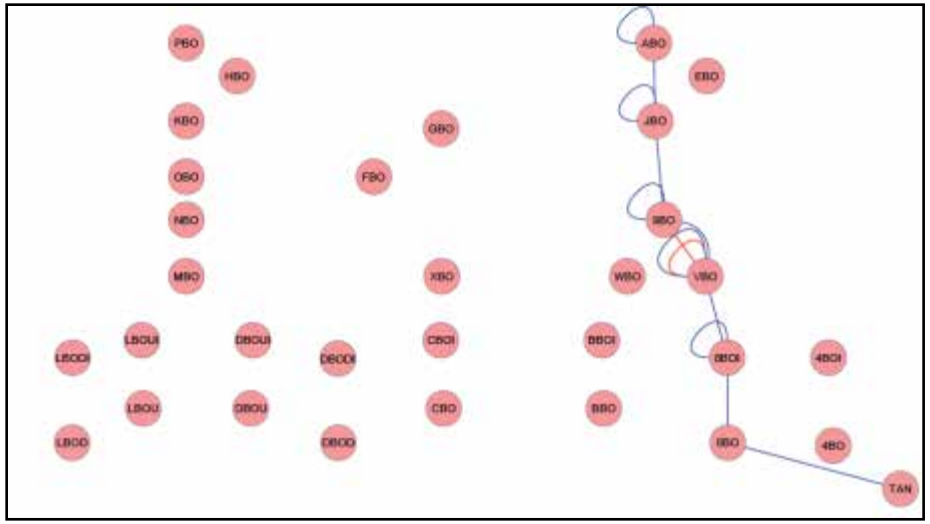
64



Characterizing individual network structure (5 connectivity metrics)

- Number of edges: # of connections (e.g., movements)
- Network diameter: farthest distance between two nodes in the network (e.g., path length)

7



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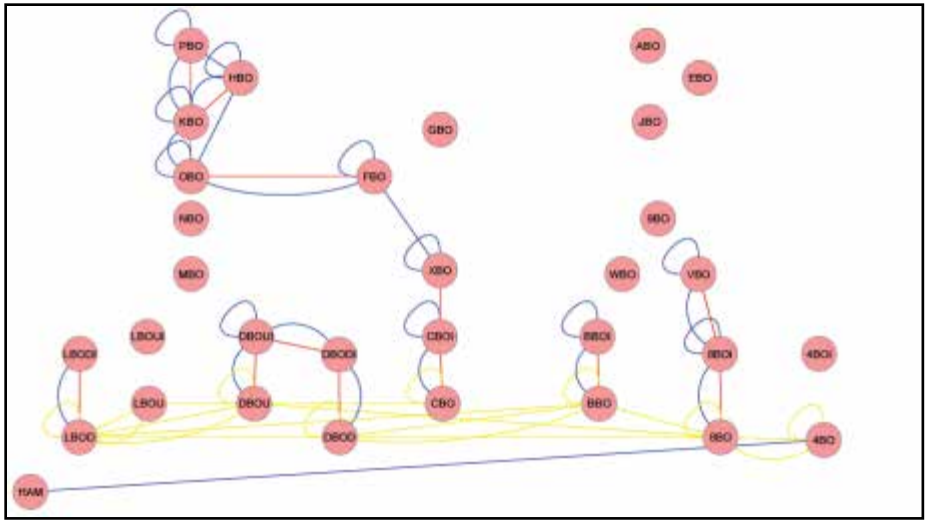
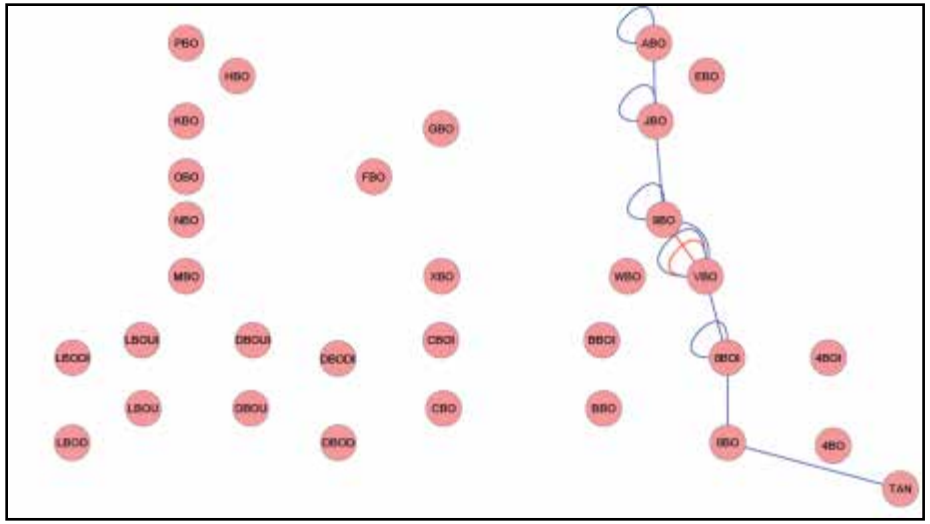


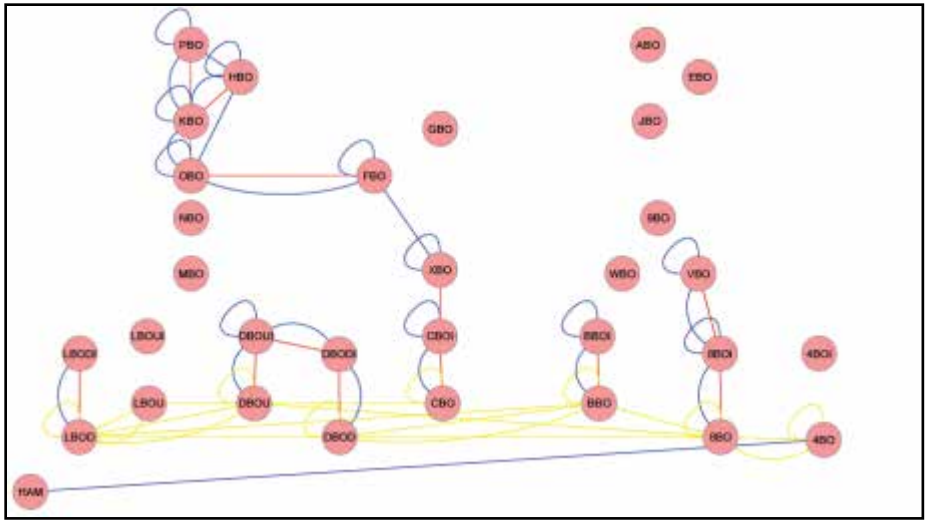
Characterizing individual network structure (5 connectivity metrics)

- Number of edges: # of connections (e.g., movements)
- Network diameter: farthest distance between two nodes in the network (e.g., path length)
- Average number neighbors: # of edges for each node divided by the total number of nodes (e.g., movements between sites)

0.485



1.515



Characterizing individual network structure (5 connectivity metrics)

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- Network diameter: farthest distance between two nodes in the network (e.g., path length)
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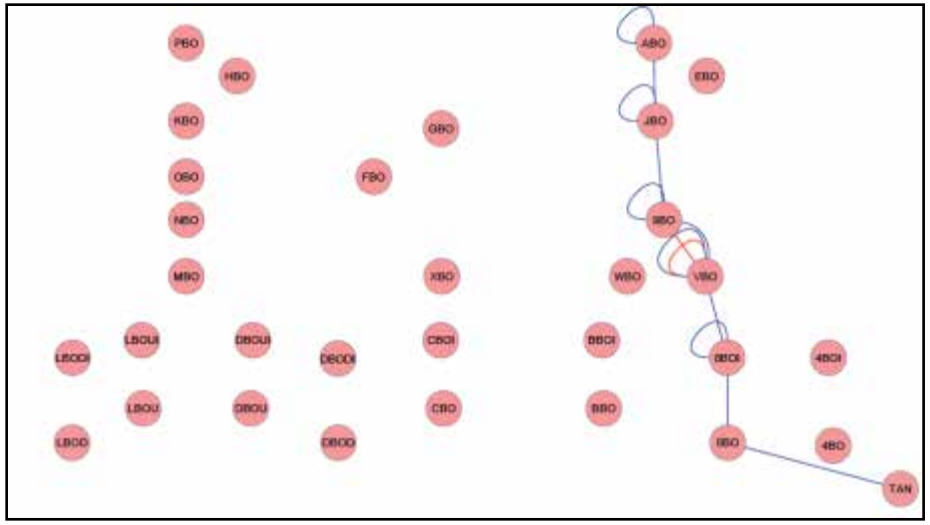
- Multi-edge nodes: # of node pairs sharing more than one edge (e.g., milling behaviors between sites)

1



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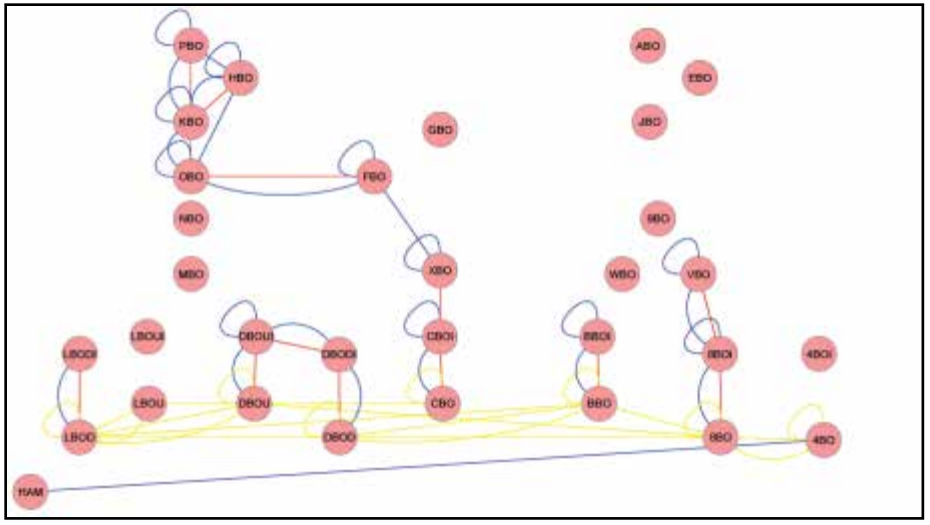

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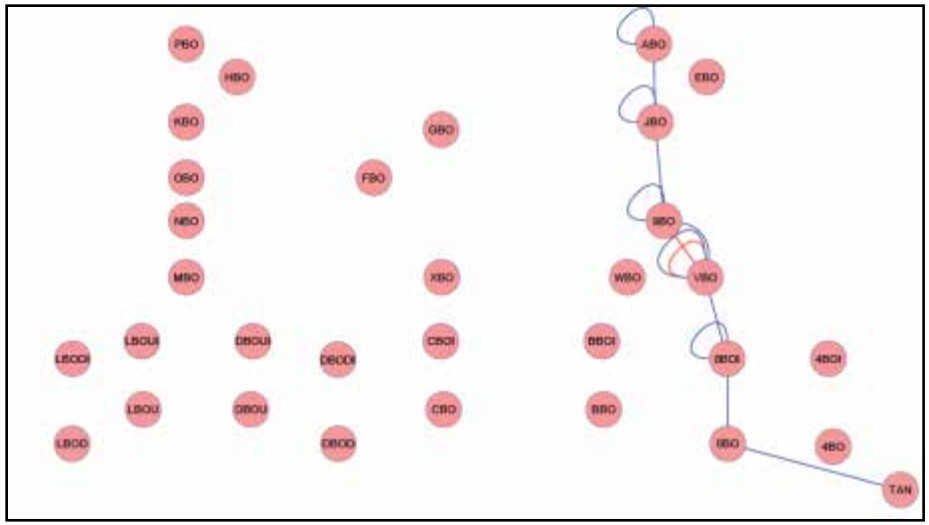
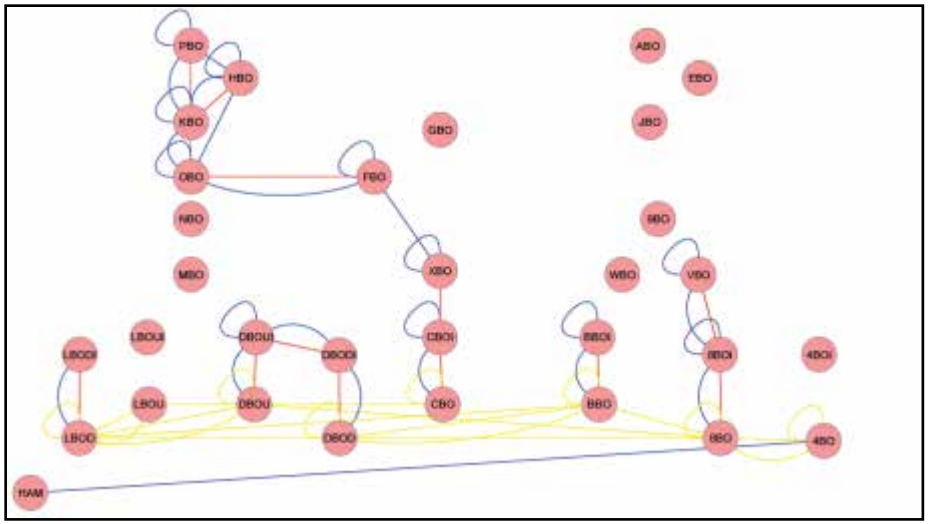
- Edge: diameter ratio: # edges in network divided by diameter (e.g., passage routes of more milling and exploring)

2.00

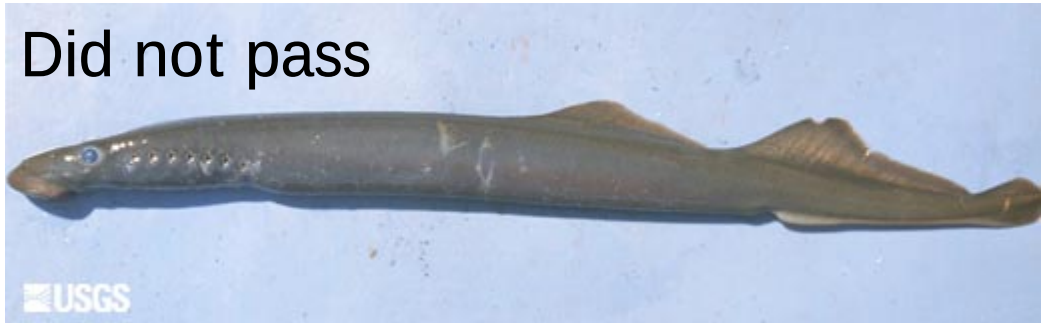


4.92



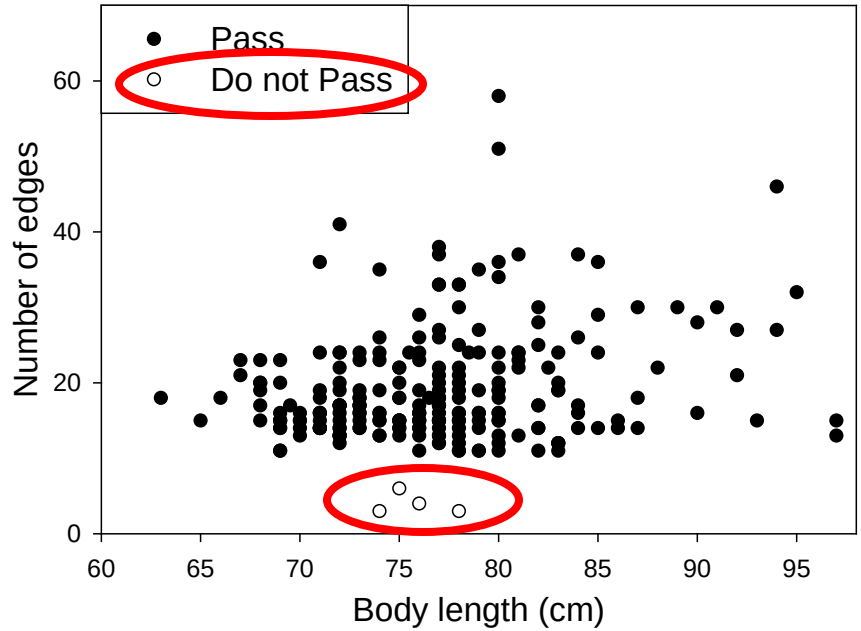
Objective 2: Test for differences in movement and behavior both between and within Pacific lamprey and Chinook salmon.

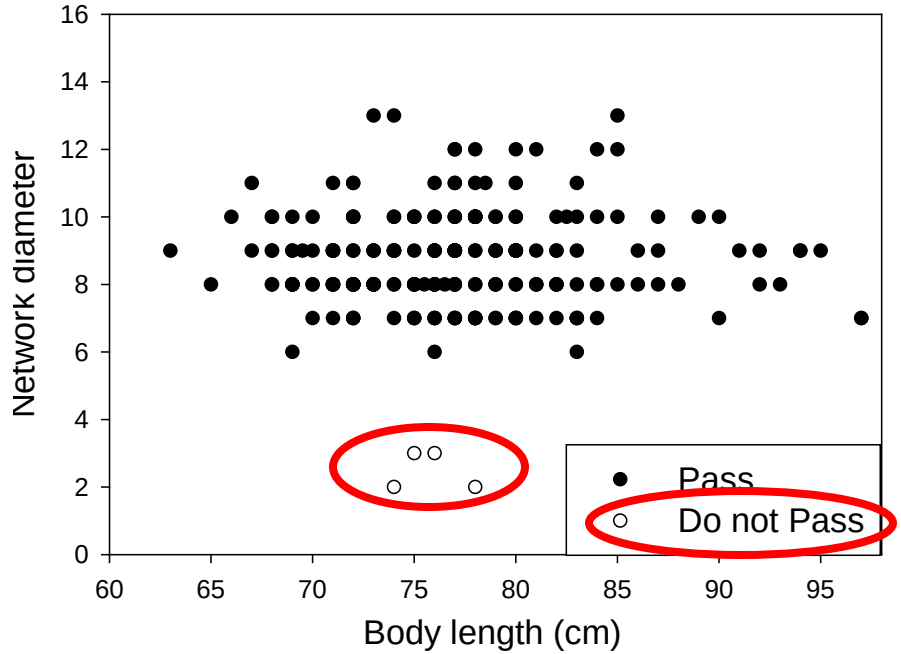
- Application of network methods for movement
  - Individual-level
  - Population level inferences
  - Hypothesis testing



- Q1: How do movement patterns differ between lamprey and salmon?
- Q2: How do movement patterns differ between fish that pass and those that do not pass the dam?

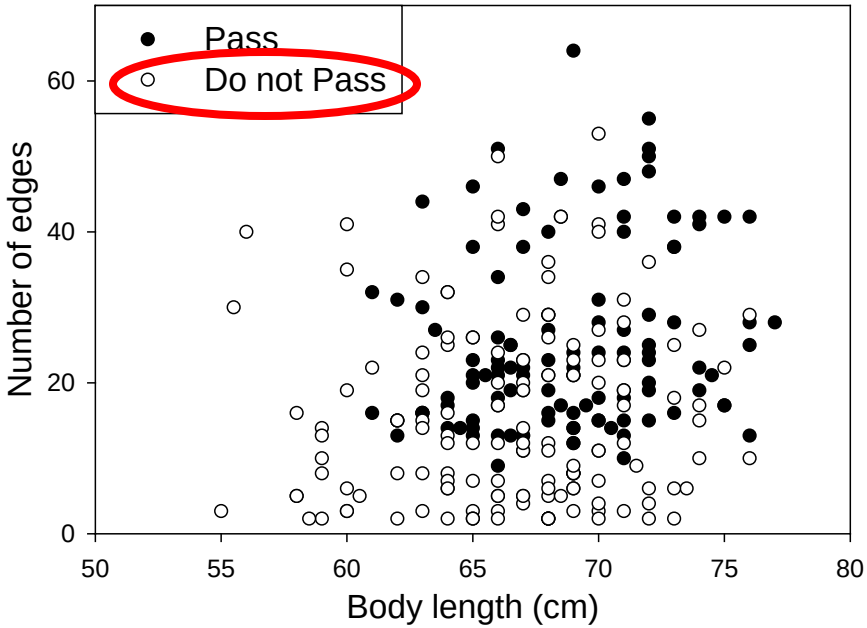
Salmon
(n = 240)

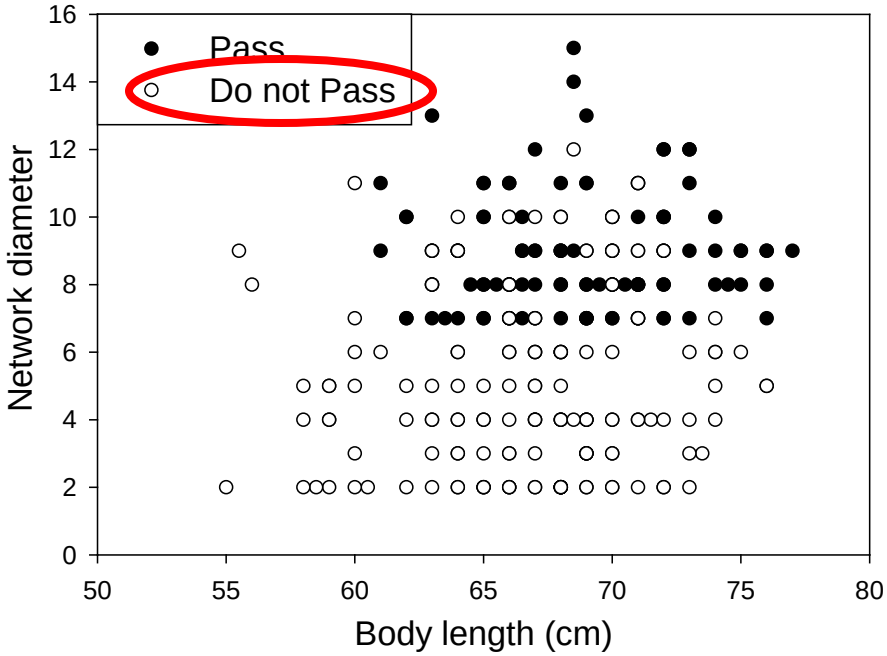




Only four salmon did not pass

Lamprey
(n = 255)



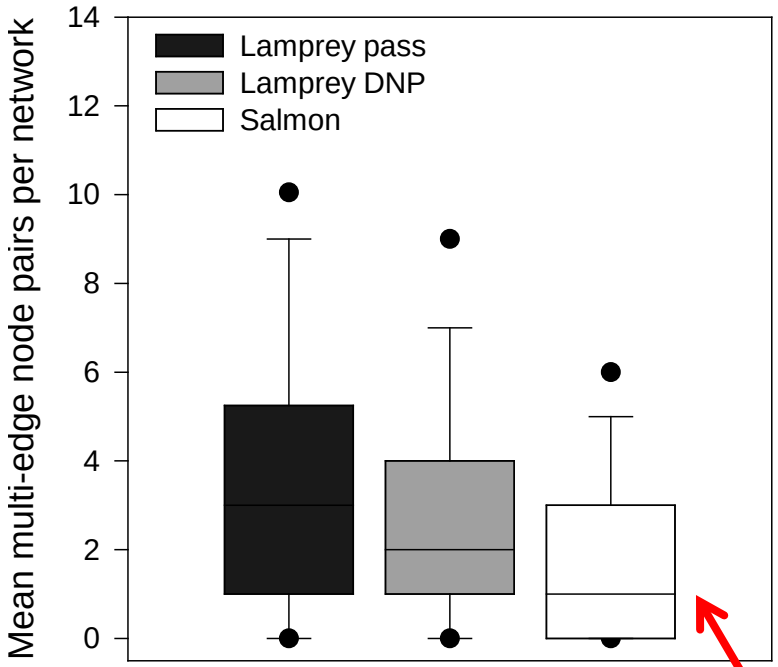


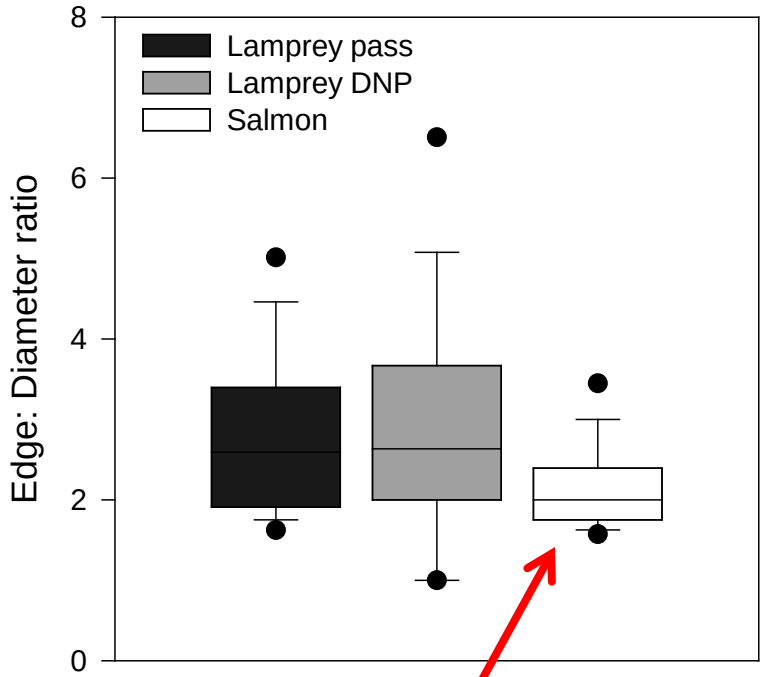
Network metrics showed no relationships with body size

Size-selective Passage!

Keefer et al. 2009

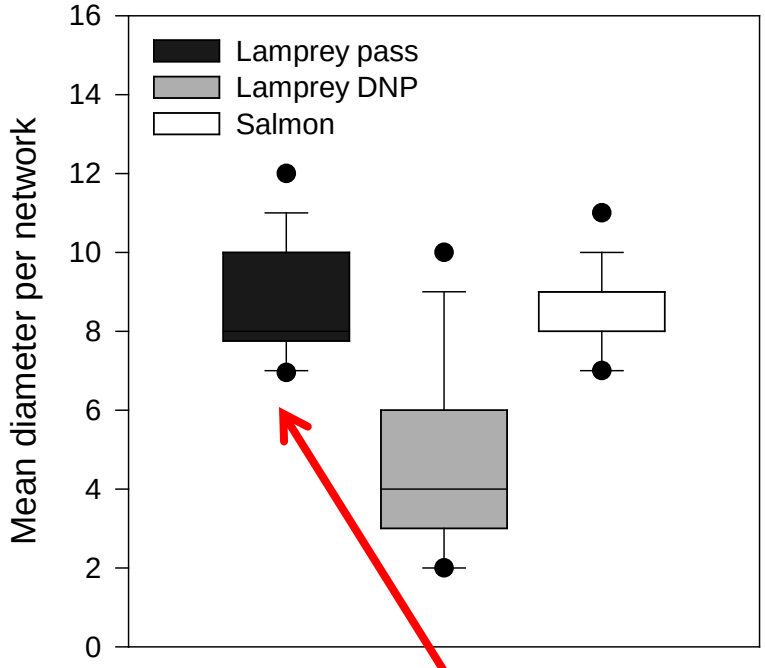
Salmon and lamprey population differences

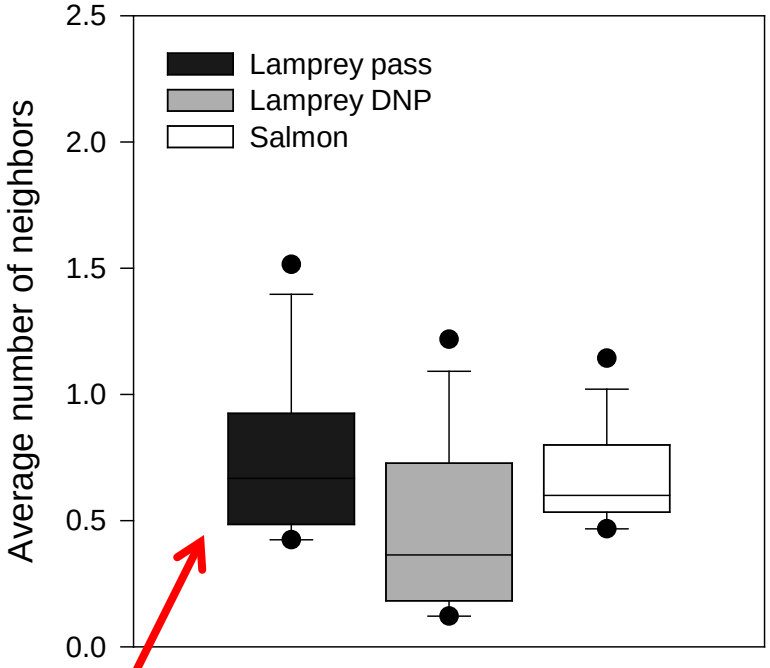




Salmon less milling and exploring between sites

Lamprey population differences

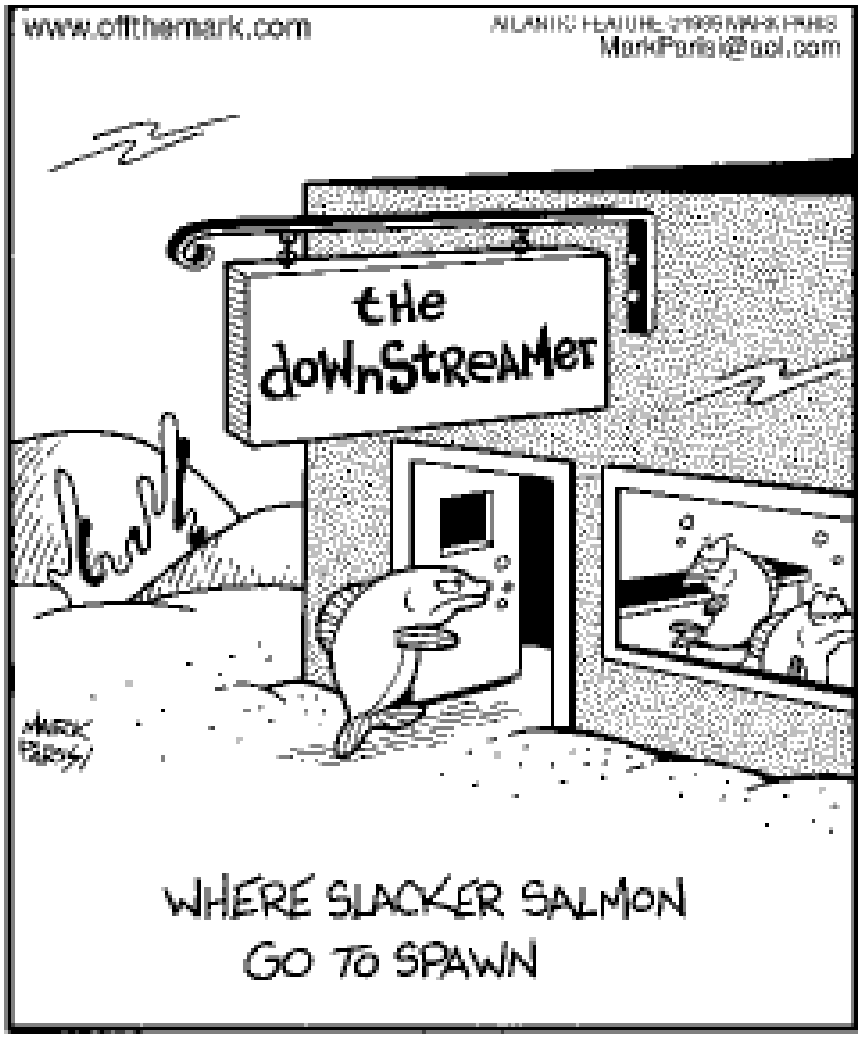




Lamprey that pass had higher connectivity

Conclusions about lamprey and salmon behavior

- Salmon had less milling and consistent route structures
- Individual variation in network metrics of lamprey
  - Variation unlikely attributed entirely to Performance-related failures
- No relationships with lamprey body size
- Potential differences in some “giving-up” threshold between lamprey and salmon



Broader Passage Implications

- New perspective for visualizing movements and passage history of individual fish.
  - Non-linear passage
- Provided novel metrics for describing elements of passage behavior
- Additional tool for monitoring movements
  - Wide application potential