SOCIAL-ECOLOGICAL NETWORK ANALYSIS

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OUTLINE OF THE WORKSHOP

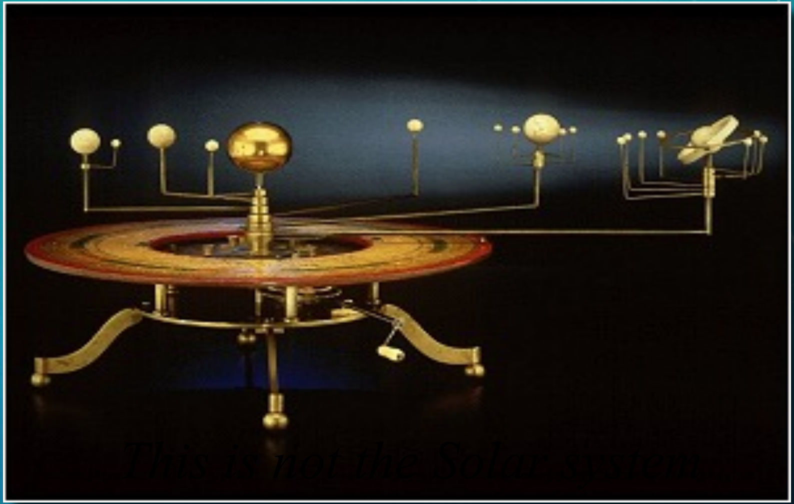
- Introductions
- Introduction to Networks: what are networks? From nodes to networks passing through motifs and graphlets
- Social Ecological Networks (SEN)
- Analyzing Networks two simple example (Alaska, and Pudget Sound)
- SEN Motifs in brief
- Break
- Hands On example (will distribute data) and breakout groups
- Report Back and conclusion

INTRODUCTIONS

- Quick introduction: Name, Institution, Interest in Networks, Expectations for this 2 hr workshop

WHAT ARE NETWORKS?

A MODEL…



and this is not a light ray

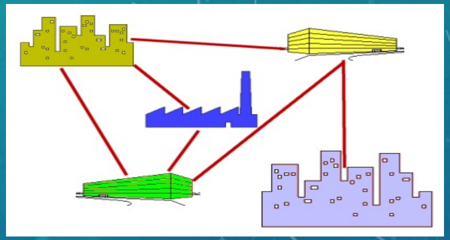
$$
\begin{cases}
\dfrac{\partial^2 \mathbf{E}}{\partial t^2} - c^2 \cdot \nabla^2 \mathbf{E} = 0 \\
\dfrac{\partial^2 \mathbf{H}}{\partial t^2} - c^2 \cdot \nabla^2 \mathbf{H} = 0
\end{cases}
$$

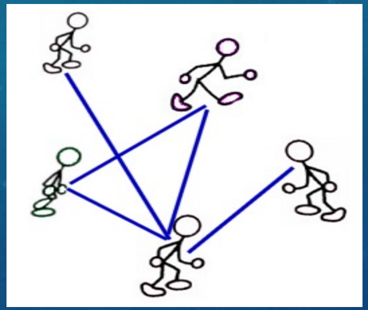
A pattern, plan, representation, or description designed to show the structure or workings of an object, system, or concept

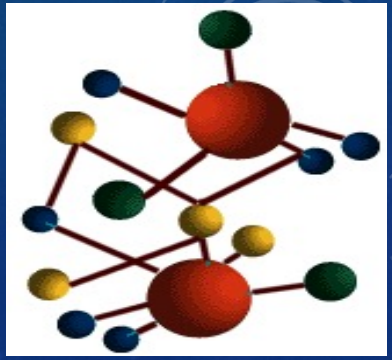
A **minimum** representation of a system that allows for investigation of the properties of the system and, in some cases, prediction of future outcomes

WHAT IS A NETWORK?

- **A Network is a ”model”!**
- A collection of individual or atomic entities
  - nodes or vertices
- Collection of links or edges between vertices
  - represent pairwise relationships
  - can have direction &/or weight
- Network: entire collection of nodes and links visualized as a graph → mathematical methods
- We are interested in properties of networks, often statistical properties of families of networks

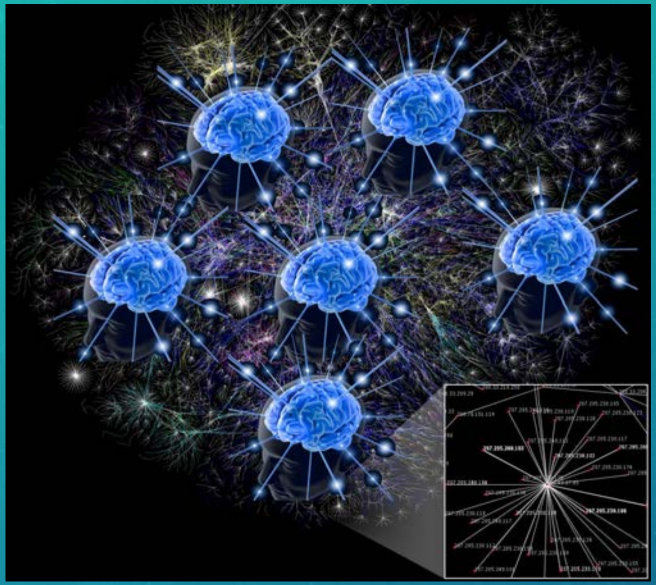


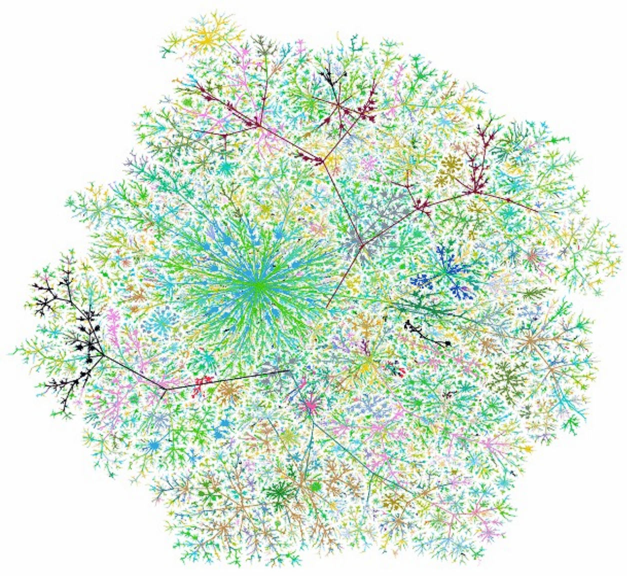


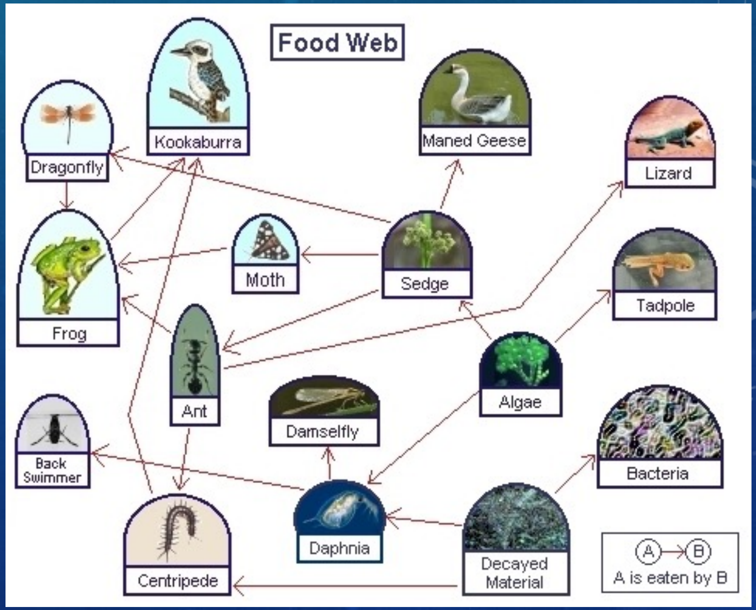


NETWORKS ARE USED…

- Everywhere, from brains to societies, from rivers to food webs to protein interactions, from trade to governance and management.

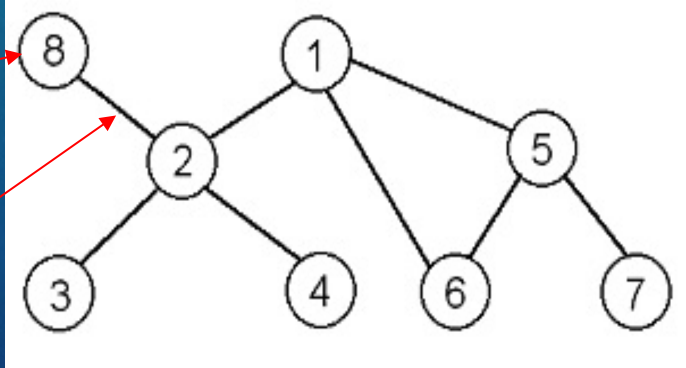






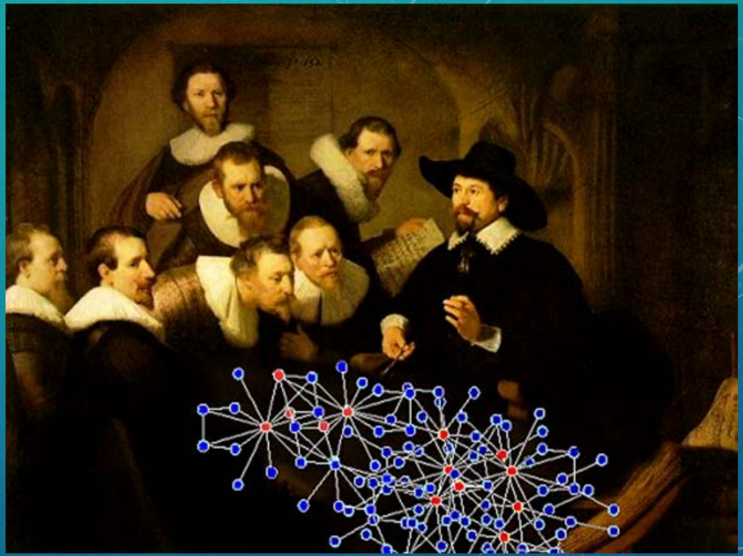
node, vertex, actor

link, edge, tie, arcs



WHY ARE NETWORKS IMPORTANT?

- Network metrics define network topology
- Topology of social networks affects the spread of information (and diseases), knowledge, strategy etc.
- Topology of ecological networks can affect species migration patterns, species extinction probability, potential for invasive species etc.

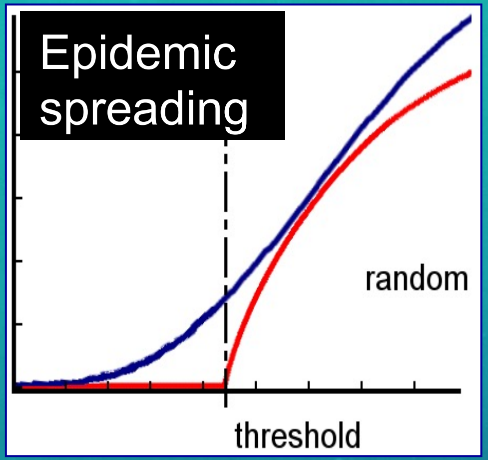


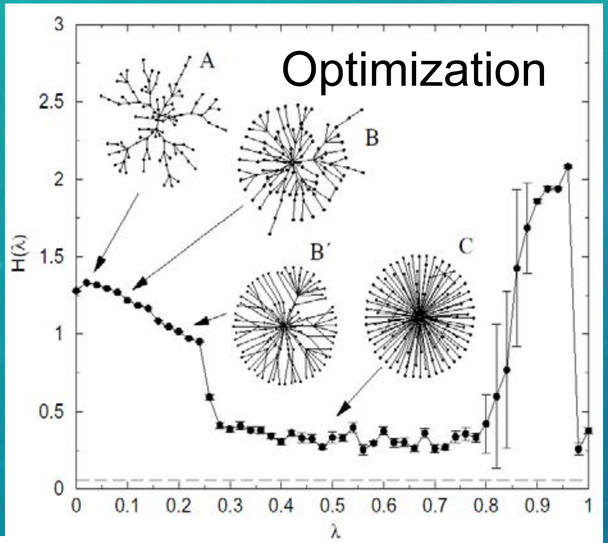
NETWORK structure

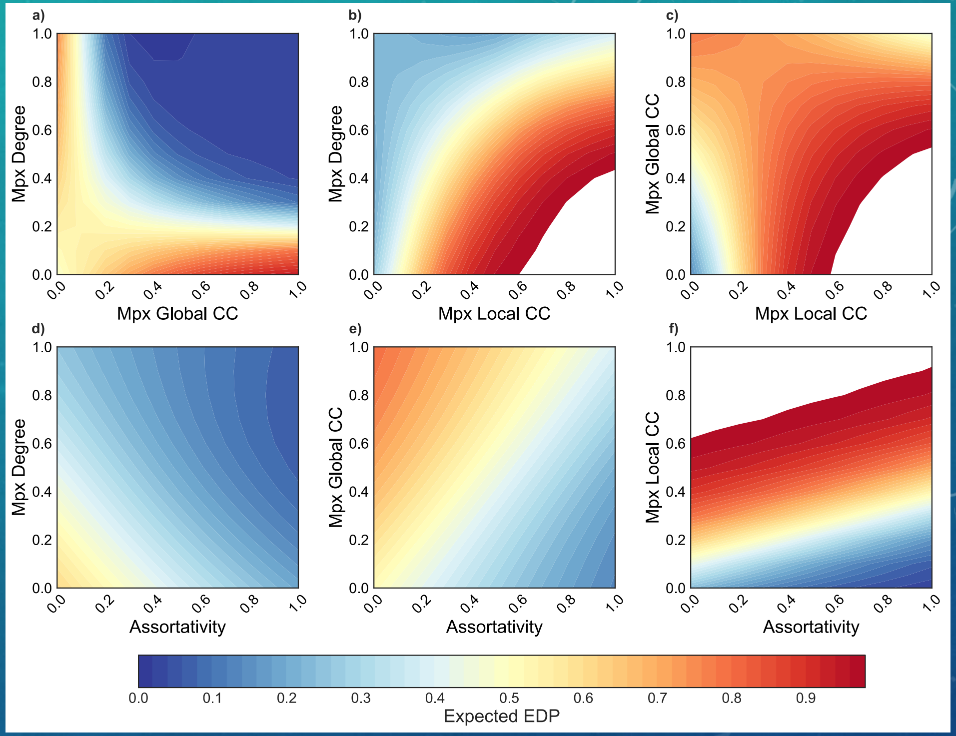
affects

function(s)

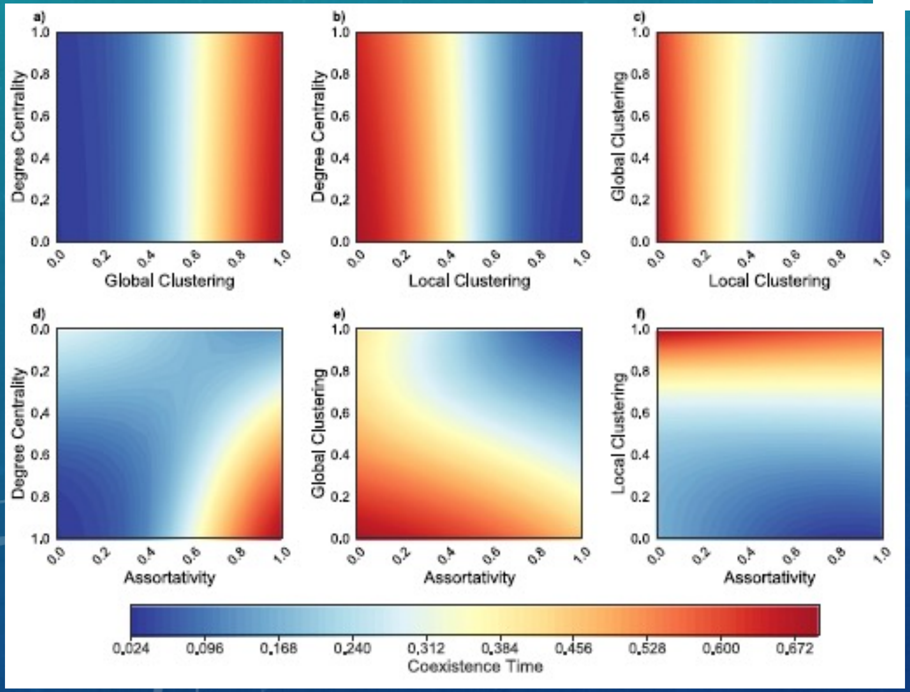
NETWORKS: STRUCTURES & PROCESSES







Baggio, J. A., & Hillis, V. (2018). Managing ecological disturbances: Learning and the structure of social-ecological networks. Environmental Modelling & Software, 109(August), 32–40. https://doi.org/10.1016/j.envsoft.2018.08.002

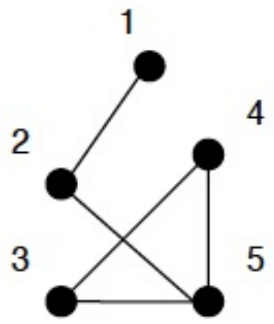


Baggio, J. A., Schoon, M. L., & Valury, S. (2019). Managing networked landscapes: conservation in a fragmented, regionally connected world. Regional Environmental Change, 19(8), 2551–2562. https://doi.org/10.1007/s10113-019-01567-8

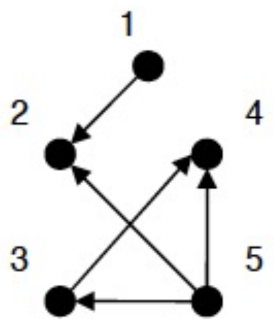
FROM FIGURES TO MATRICES…

NETWORK: MATHEMATICAL REPRESENTATION

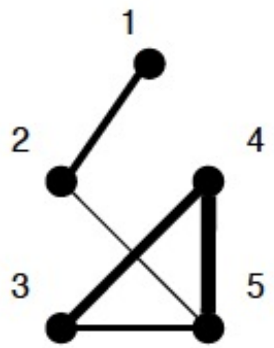
Network: G(V,E) $\begin{cases} V = \{v_1 \ldots v_n\} \\ E = \{e_1 \ldots e_n\} \end{cases}$



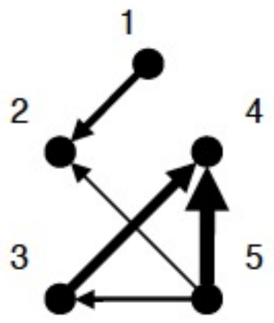
	1	2	3	4	5
1	0	1	0	0	0
2	1	0	0	0	1
3	0	0	0	1	1
4	0	0	1	0	1
5	0	1	1	1	0



	1	2	3	4	5
1	0	1	0	0	0
2	0	0	0	0	0
3	0	0	0	1	0
4	0	0	0	0	0
5	0	1	1	1	0



	1	2	3	4	5
1	0	3	0	0	0
2	3	0	0	0	1
3	0	0	0	4	2
4	0	0	4	0	5
5	0	1	2	5	0

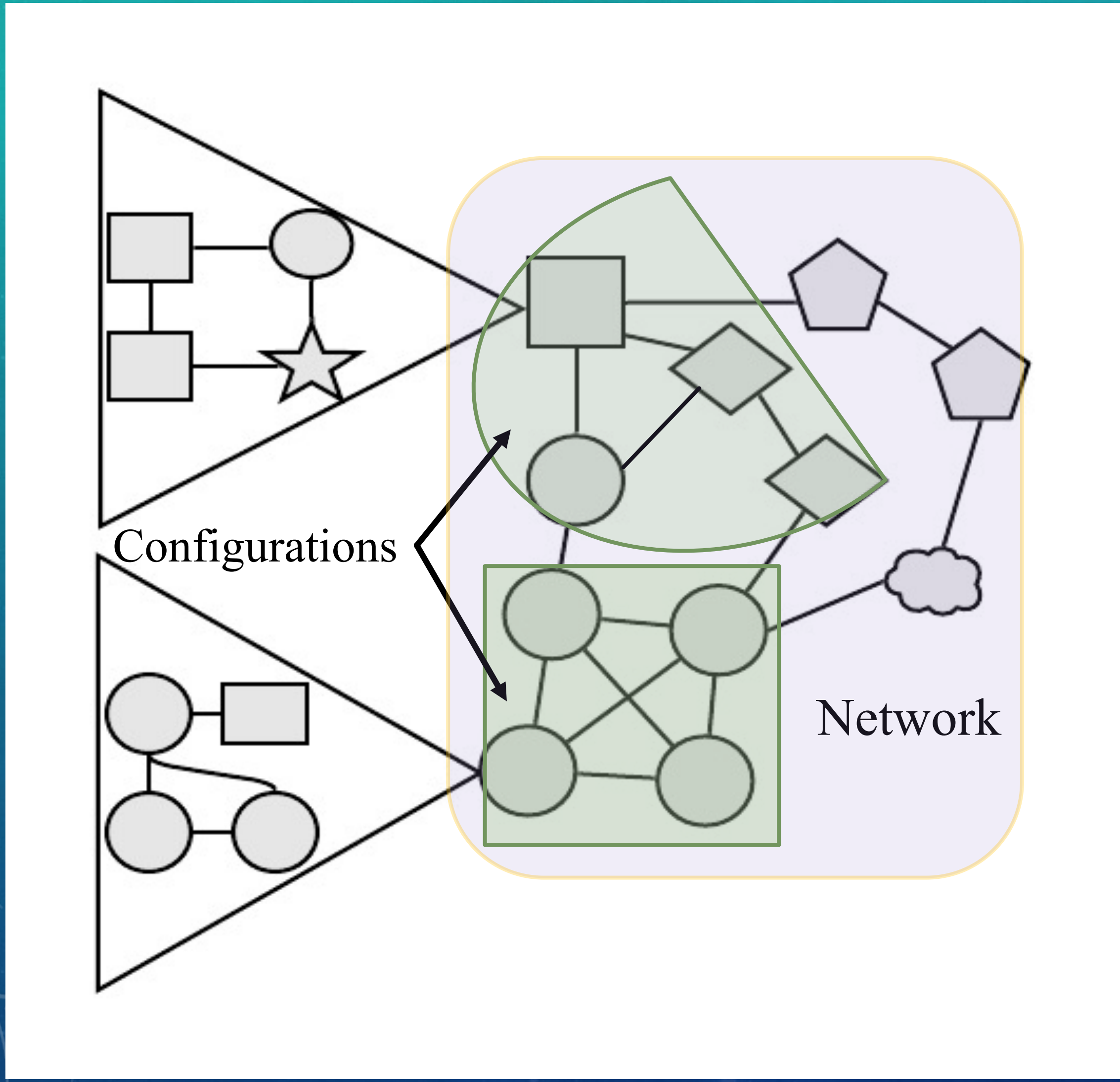


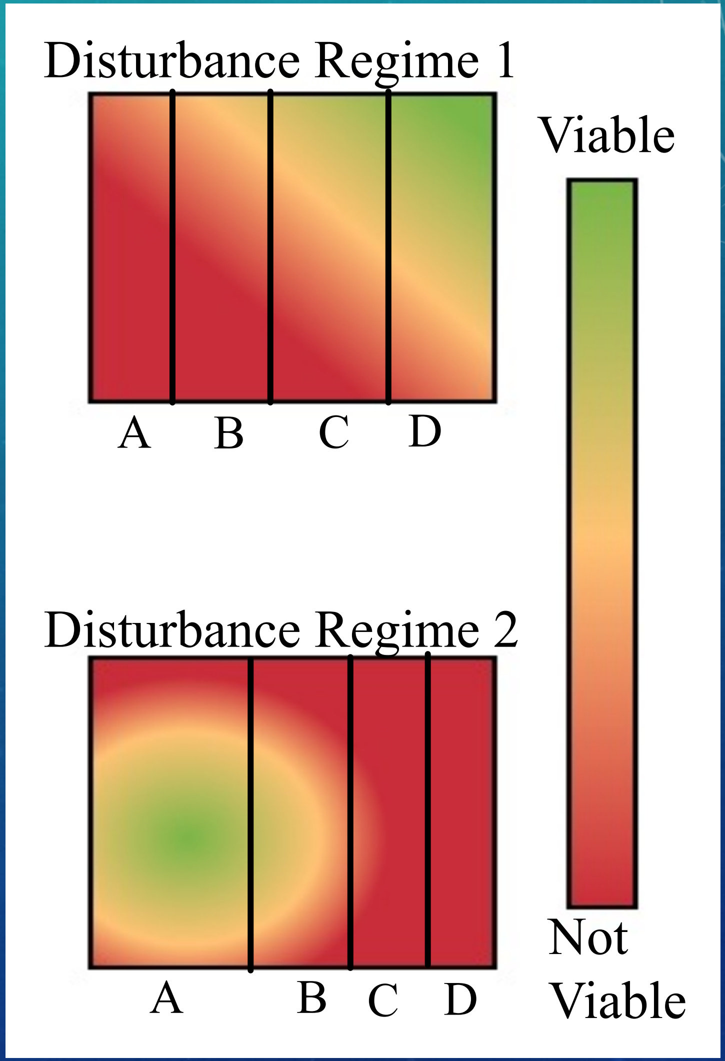
	1	2	3	4	5
1	0	3	0	0	0
2	0	0	0	0	0
3	0	0	0	4	0
4	0	0	0	0	0
5	0	1	2	5	0

Networks can be:

- Undirected-unweighted (upper-left)
- Directed-unweighted (upper-right)
- Undirected-weighted (lower-left)
- Directed-weighted (lower-right)

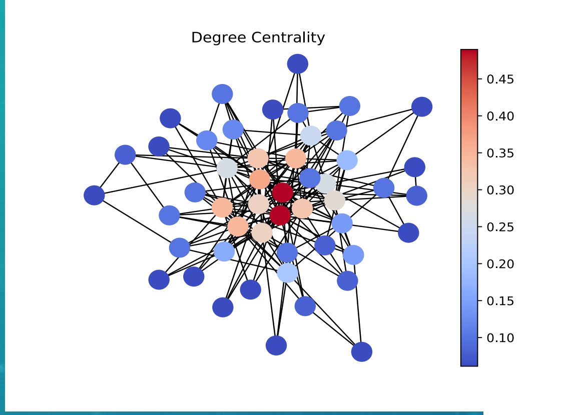
NODES ⟺ CONFIGURATIONS MOTIFS/GRAPHLETS ⟺ NETWORKS ⟺ ROBUSTNESS/ RESILIENCE

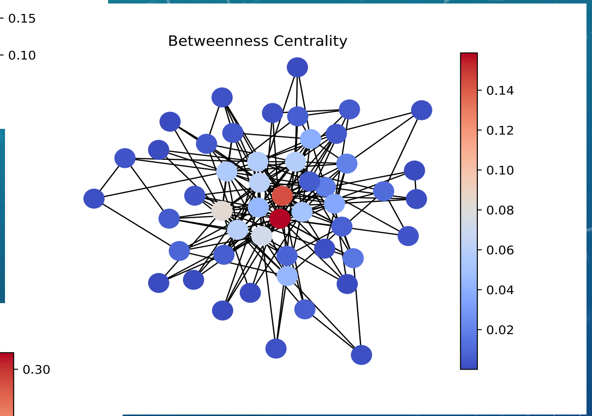


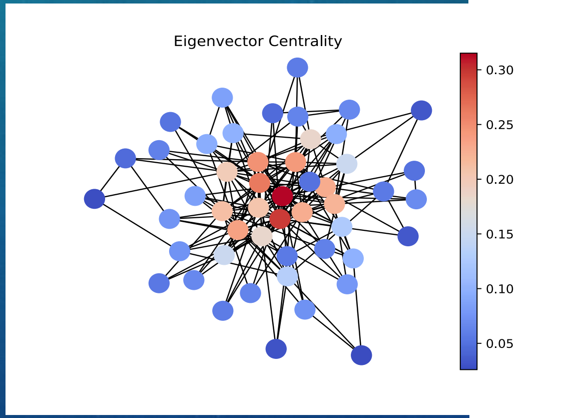


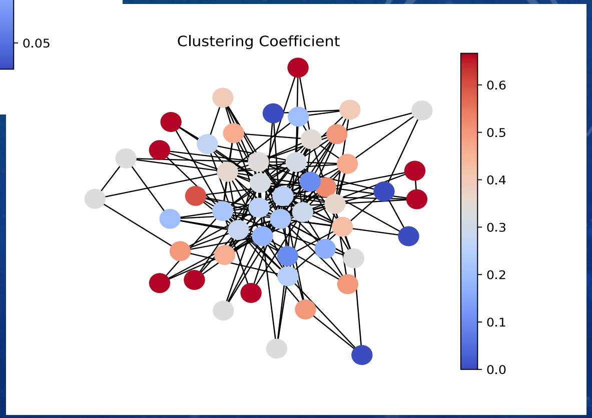
NODAL METRICS

- Degree Centrality:
  - Measures how many connections a node has
  - Degree centrality can be used to assess how central patches on a landscape or popular individuals or individuals that are more able to diffuse information quickly.
- Betweenness Centrality:
  - Measures how many shortest paths pass by a specific node
  - High betweenness centrality can indicate nodes that are more likely to “control” the flow of information (from landscape patches that are central in favoring migration of species to individuals that can act as gatekeepers or brokers
- Eigen vector Centrality
  - Similar to degree centrality, BUT it takes also into account how connected neighboring nodes are (so not only how many connection I have, but how many connection the ones connected to me have)
  - High eigen-centrality can identify nodes that are important in affecting the overall network
- Clustering Coefficient
  - How many of my friends are friends with each other? Or.. How many neighbors of node I are also connected to each others?



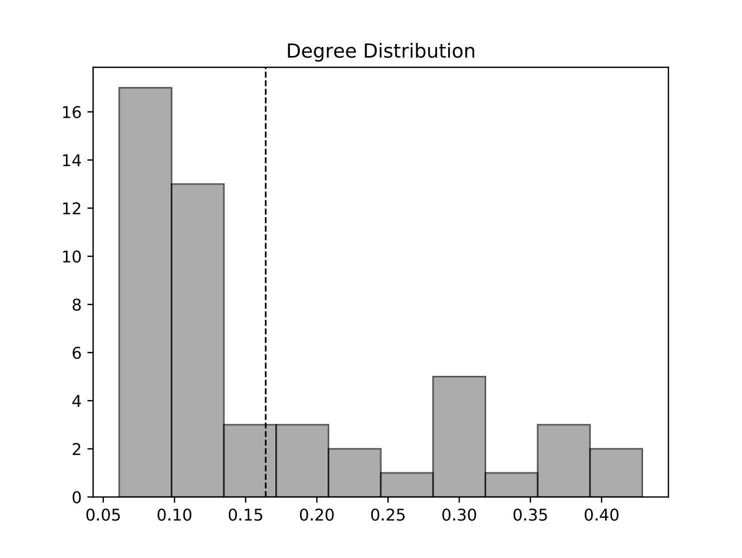


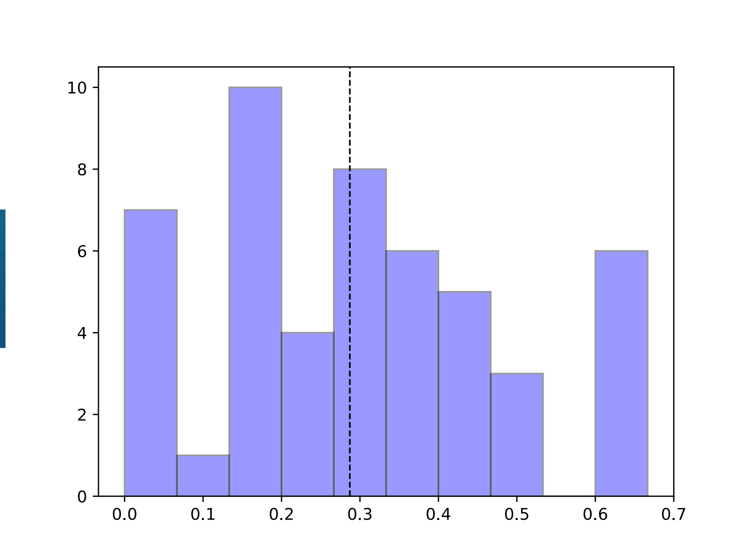


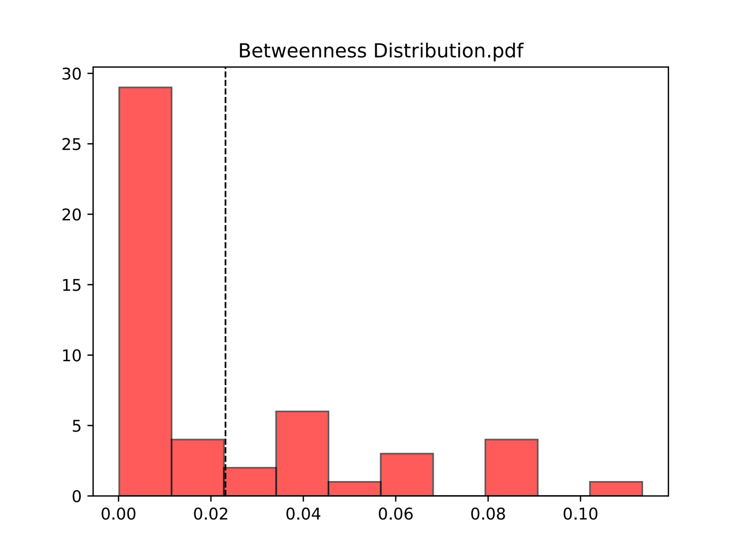


NETWORK METRICS

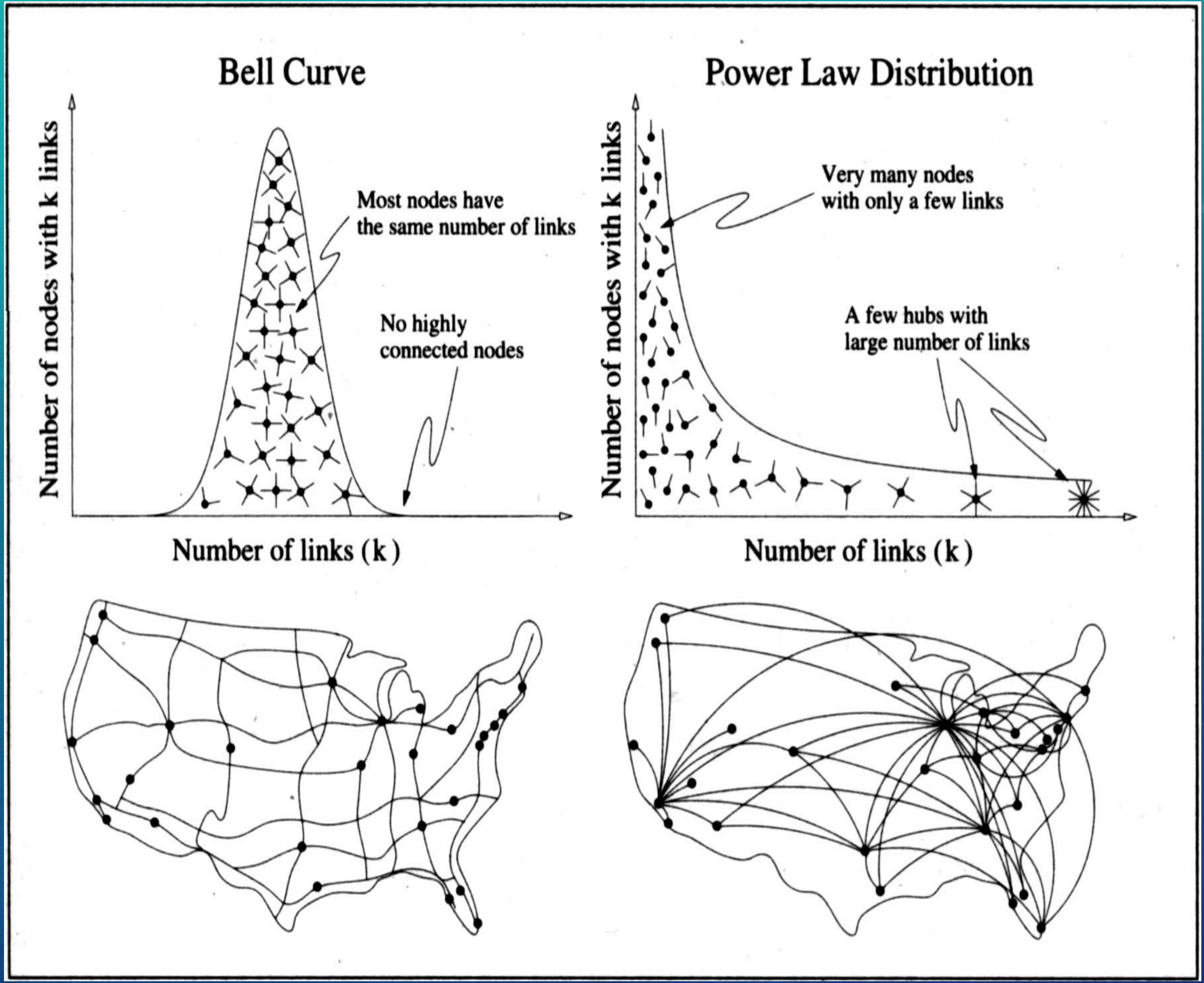
- Average metrics (average degree, average betwenness, average shortest path length, average clustering coefficient, global efficiency etc.)
- Distributions: (i.e. Degree distribution, Betweeness centrality distribution, Clustering distribution etc..)





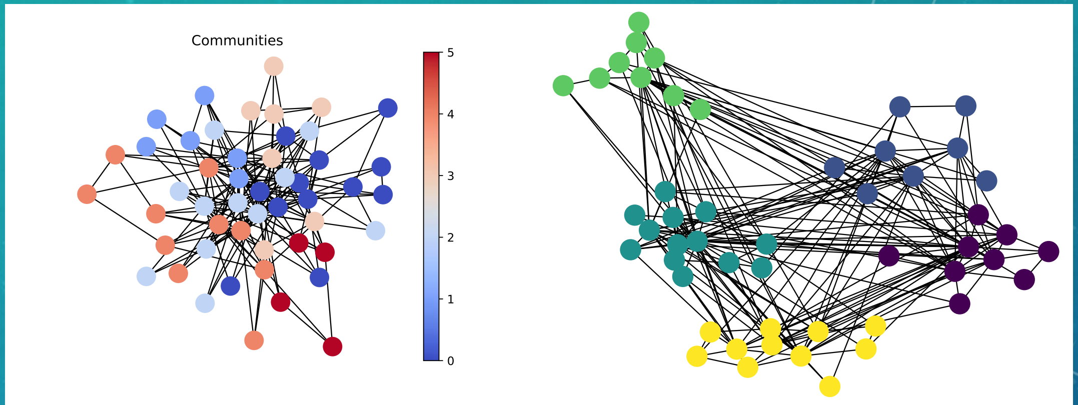


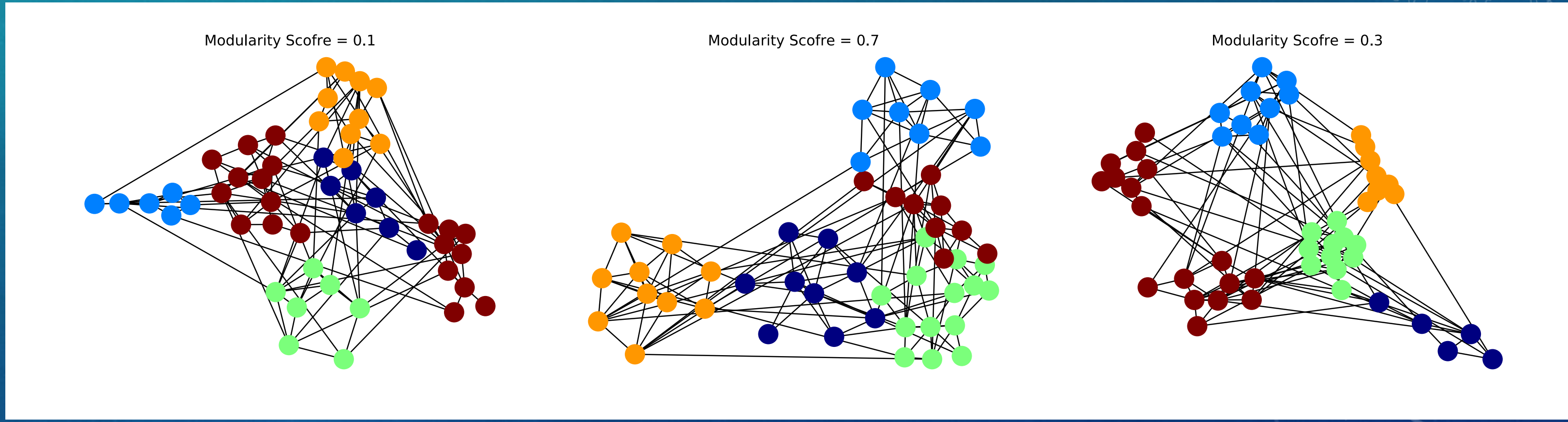
DEGREE DISTRIBUTION, SIMPLE IMPLICATIONS



MODULARITY, COMMUNITIES AND PARTICIPATION COEFFICIENT

- Communties are not easily found, but generally they refer to parts of the network that are densely connected while loosely connected to other parts of the network
- Modularity is a measure that assesses how “divided” a network is into different communities.
- Participation coefficient indicates how the degree of a node is “distributed” across communities (P = 0 if all edges are connecting nodes within the same community, 1 when edges are equally distributed across all communities.

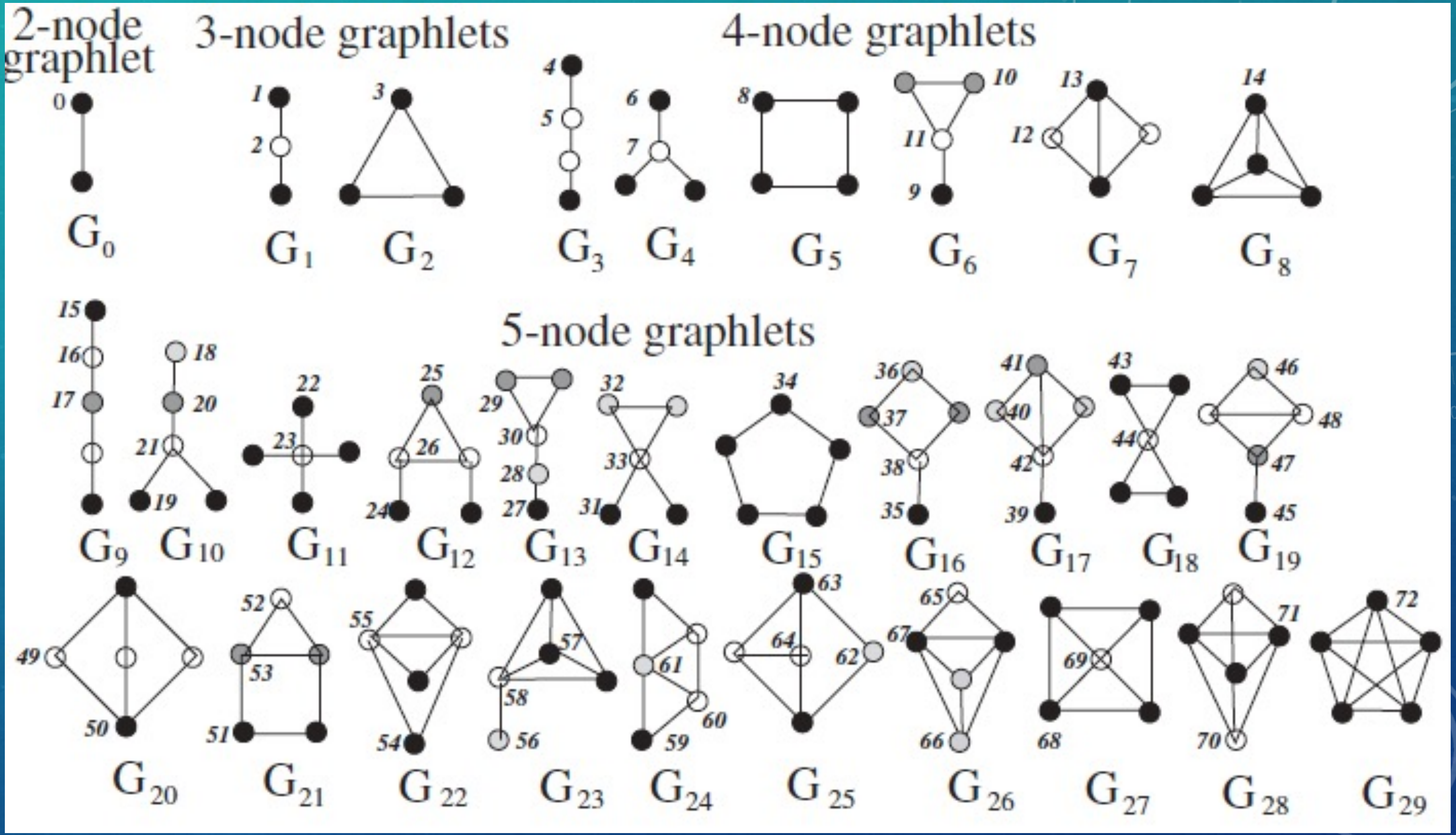




Modularity network generator adapted from:
Sah, Pratha*, Lisa O. Singh, Aaron Clauset, and Shweta Bansal. "Exploring community structure in biological networks with random graphs." BMC Bioinformatics 2014, 15:220. doi:10.1186/1471-2105-15-220

CONFIGURATIONS: GRAPHLETS AND MOTIFS

- A graphlet is a subgraph of N nodes. As such, graphlets contain all edges of a specific subgraph.
- Motifs are specific patterns within a network, a motif can contain only some edges of a graphlet of the same size.
- Motifs need to be assessed vs a baseline model (that can retain basic properties, such as number of nodes, edges, degree distribution, clustering, etc.).
- Assessment of motifs leads to calculate significance and over/under-representation vs baseline.

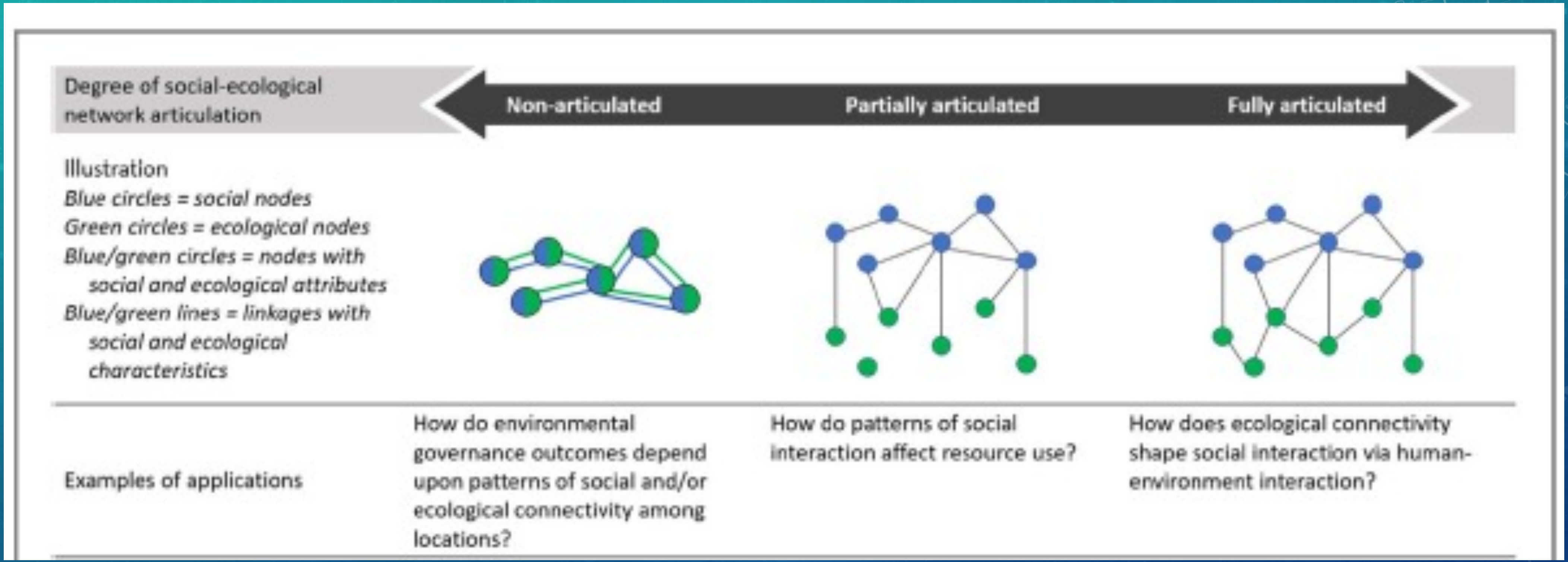


Pržulj, N. (2007). Biological network comparison using graphlet degree distribution. *Bioinformatics*, *23*(2), 177–183. https://doi.org/10.1093/bioinformatics/btl301

Milo, R., Shen-Orr, S., Itzkovitz, S., Kashtan, N., Chklovskii, D., & Alon, U. (2002). Network motifs: Simpl building blocks of complex networks. Science, 298(5594), 824–827. https://doi.org/10.1126/science.298.5594.824

SOCIAL-ECOLOGICAL NETWORKS

SOCIAL-ECOLOGICAL NETWORK "TYPES"



Degree of social-ecological network articulation	Non-articulated	Partially articulated	Fully articulated
Illustration *Blue circles = social nodes* *Green circles = ecological nodes* *Blue/green circles = nodes with social and ecological attributes* *Blue/green lines = linkages with social and ecological characteristics*			
Examples of applications	How do environmental governance outcomes depend upon patterns of social and/or ecological connectivity among locations?	How do patterns of social interaction affect resource use?	How does ecological connectivity shape social interaction via human-environment interaction?

Sayles, J., Mancilla Garcia, M., Hamilton, M., Alexander, S., Baggio, J., Fischer, A. P., … Pittman, J. (2019). Social-ecological network analysis for sustainability sciences: a systematic review and innovative research agenda for the future. Environmental Research Letters, 1–5. https://doi.org/10.1088/1748-9326/ab2619

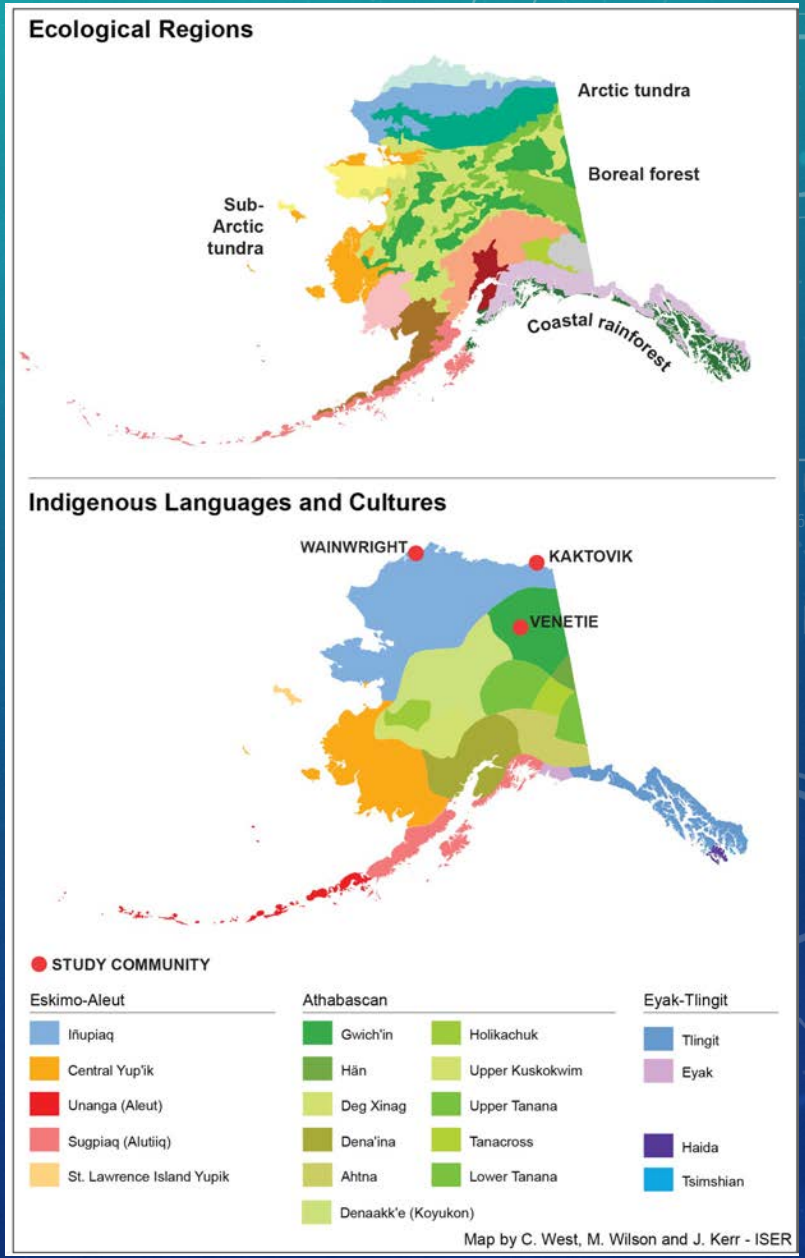
IMAGINE

- You want to assess how food sharing may be affected by changes in the social as well as in the biophysical domain
- You need to take into account:
    - biophysical elements (i.e. species hunted or harvested)
    - social (i.e. cooperation, helping or simply sharing with those in need, contributions etc…)
- Single ("monoplex") networks fall short as they would not be able to characterize the system properly …(i.e. not an adequate model representation)

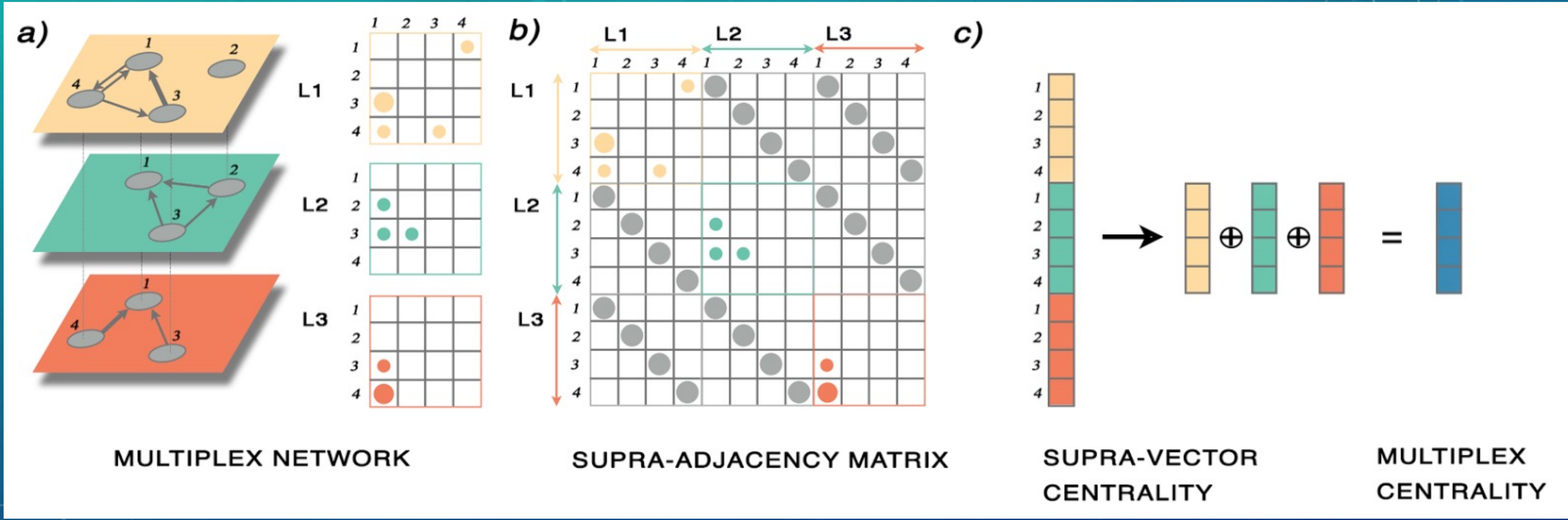
Community Robustness and Social-Ecological Networks

Baggio, J. A., Burnsilver, S. B., Arenas, A., Magdanz, J. S., Kofinas, G. P., & De Domenico, M. (2016). Multiplex social ecological network analysis reveals how social changes affect community robustness more than resource depletion. PNAS, 113(48), 13708–13713. https://doi.org/10.1073/pnas.1604401113

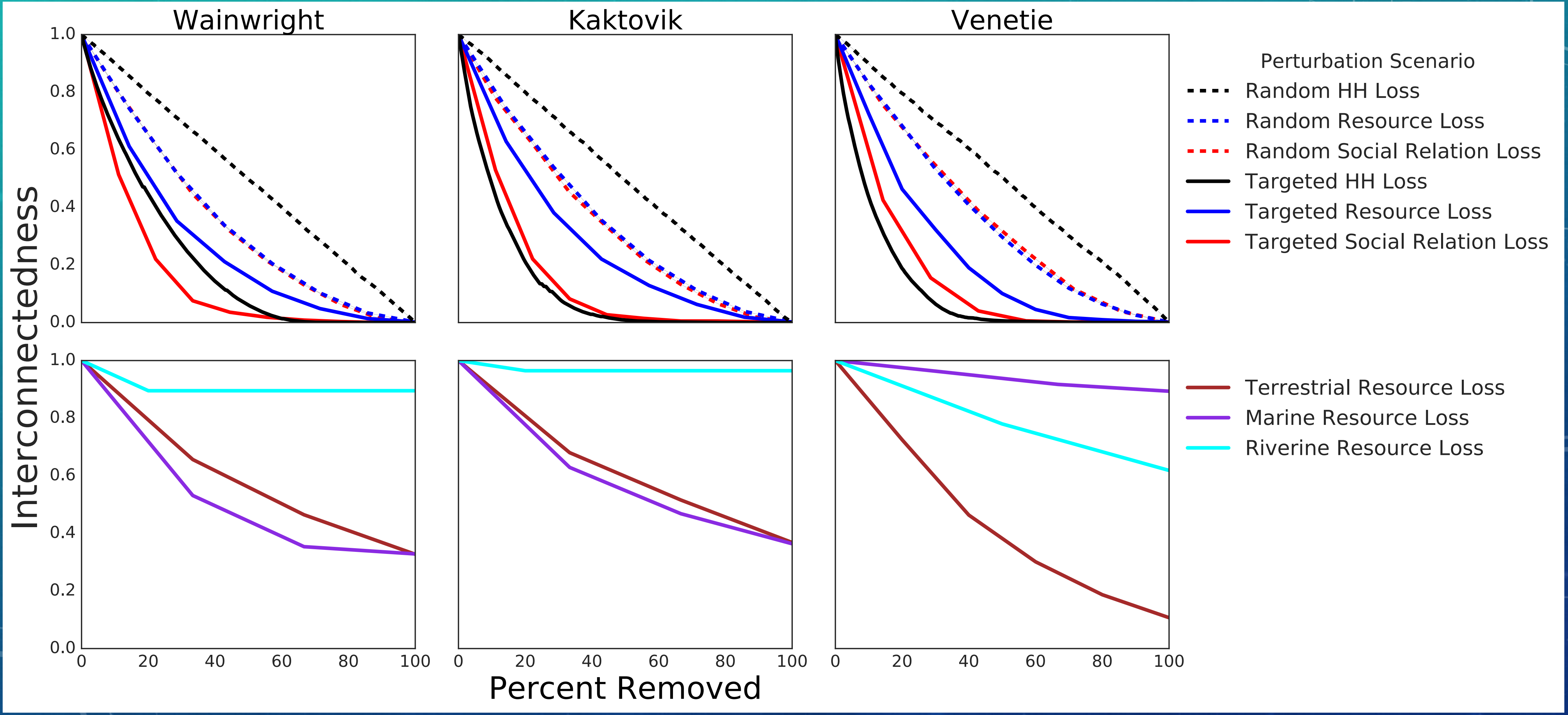
- Mixed subsistence-cash economies
- Plausible future social changes relate to migration, job creation/dissolution, market integration
- Plausible future ecological changes relate to ice cover, air and water temperature that influence species abundance
- Cultural norms related to sharing are key for food security, group identity, well being.
- Analysis of subsistence food flows between HH depending on resource type and specific social relation



MULTIPLEX NETWORKS



ROBUSTNESS ANALYSIS

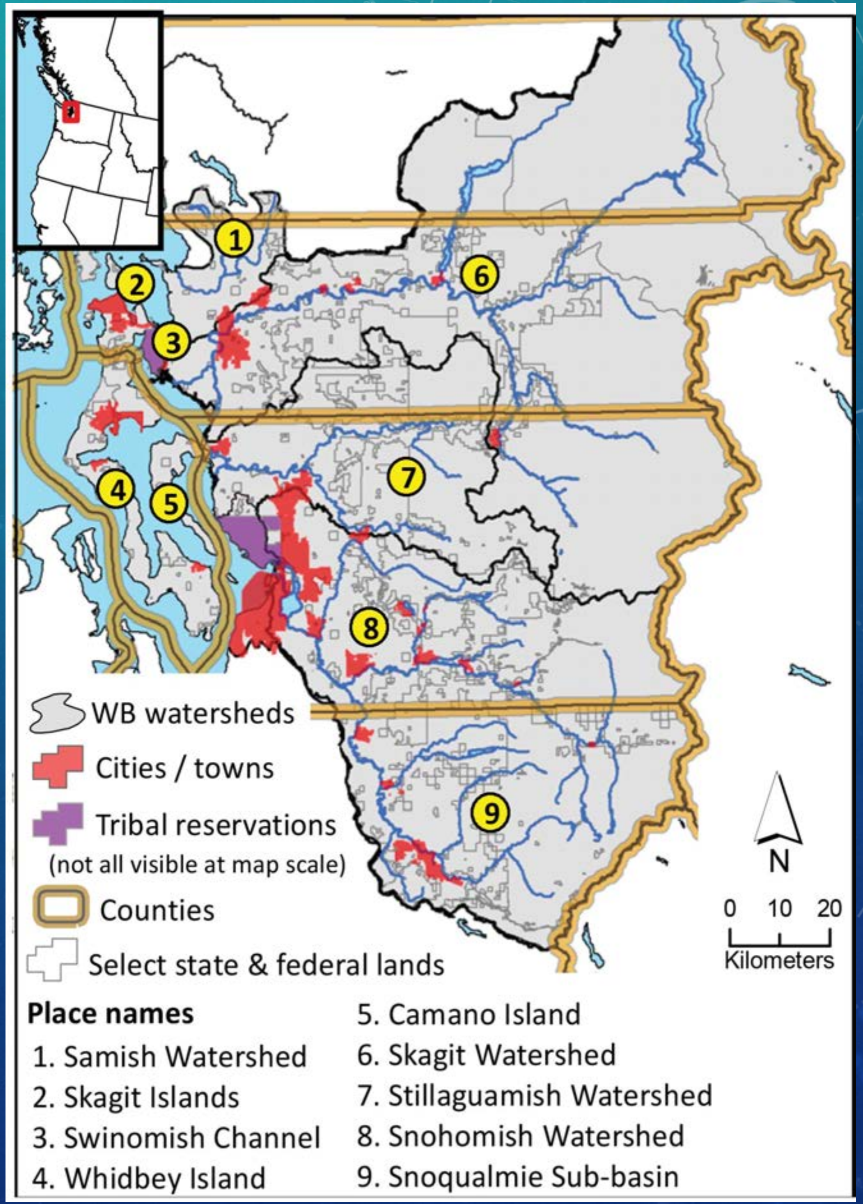


IMAGINE

- You want to assess water governance in an estuary region
- You need to take into account:
  - biophysical elements (water flows, biota)
  - social (water management associations, local and regional governing bodies, private actors, NGO, etc.)
- Single (“monoplex”) networks fall short as they would not be able to characterize the system properly …(i.e. not an adequate model representation)

RESTORATION AND SOCIAL-ECOLOGICAL NETWORKS

- Fragmented Governance in Bio-physically connected regions
- Considering governance capacity with ecological conditions may help policy makers allocate resources
- Assess scale mismatches and effects on ecological habitat
- Use of Network Science as a diagnostic tool

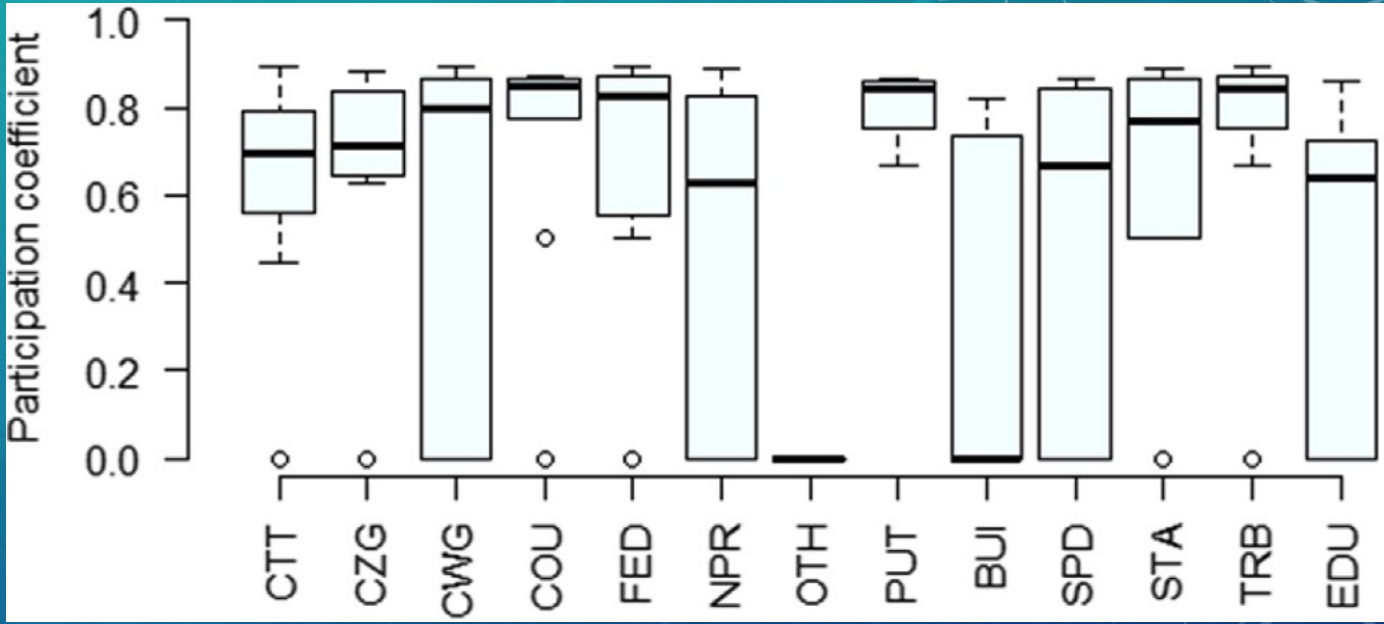


Sayles, J. S., & Baggio, J. A. (2017). Who collaborates and why: Assessment and diagnostic of governance network integration for salmon restoration in Puget Sound, USA. Journal of Environmental Management, 186, 64–78. https://doi.org/10.1016/j.jenvman.2016.09.085

Sayles, J. S., & Baggio, J. A. (2017). Social–ecological network analysis of scale mismatches in estuary watershed restoration. PNAS, 114(10), E1776–E1785. https://doi.org/10.1073/pnas.1604405114

WHO WORKS WITH WHOM?

Organization Type	Abbreviation
City & town Citizen group	CTT
Coordinating & watershed groups	CZG
County	COU
Federal	FED
Nonprofit	NPR
Other	OTH
Public utility	PUT
Business	BUI
Special districts	SPD
State	STA
Tribe	TRB
Education	EDU



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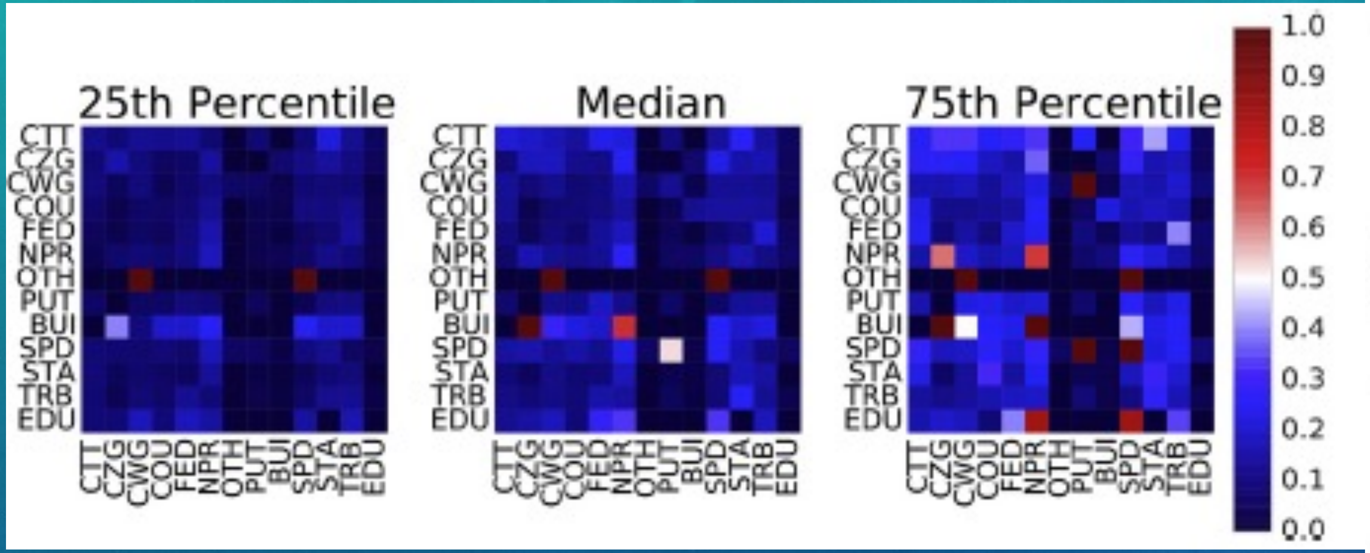
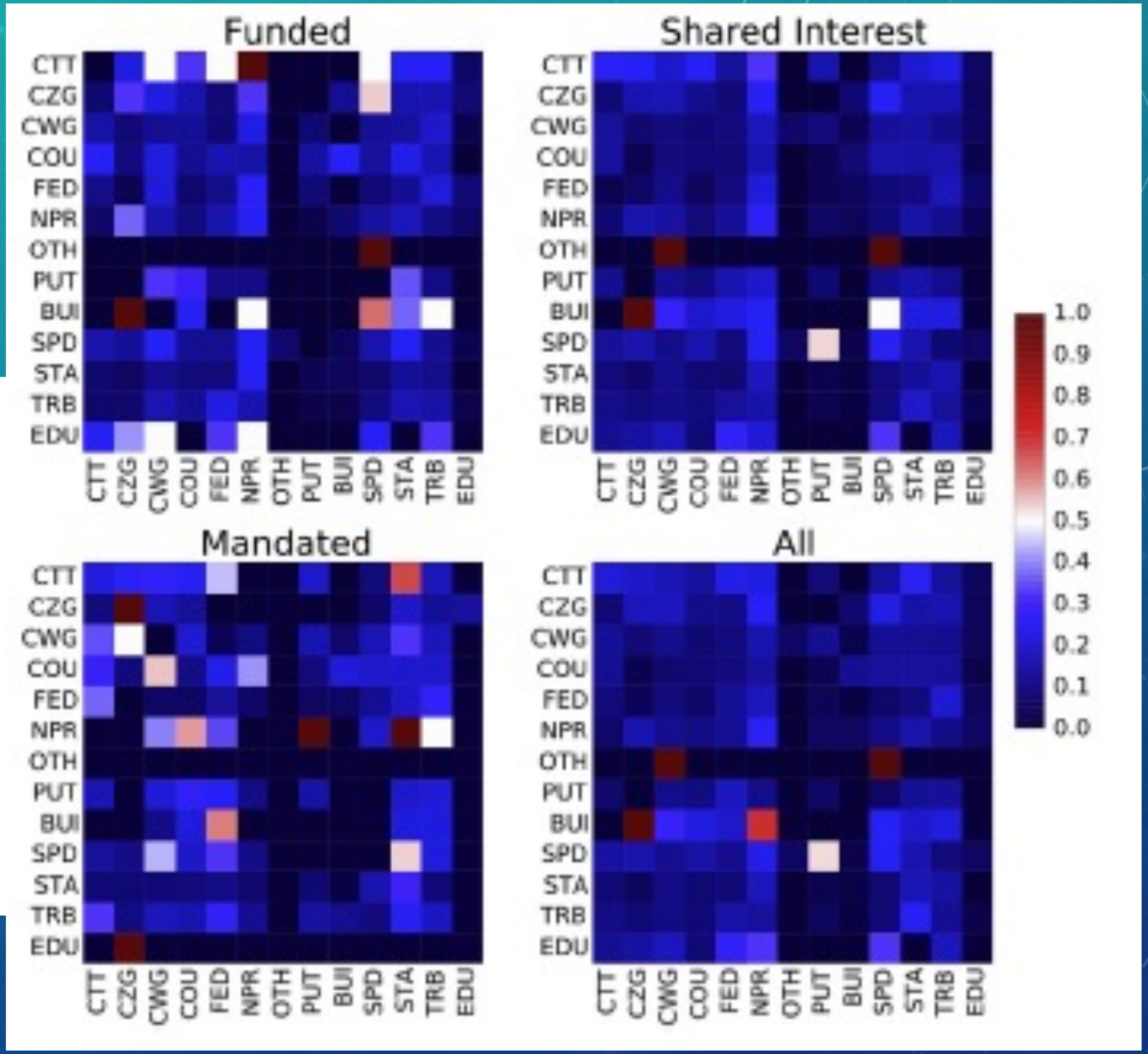
BREAKING DOWN: WHO WORKS WITH WHOM

Colors indicate PM score. Data should be read across rows; for example, top row represents PM scores from cities/towns (CTT) to other organization types.



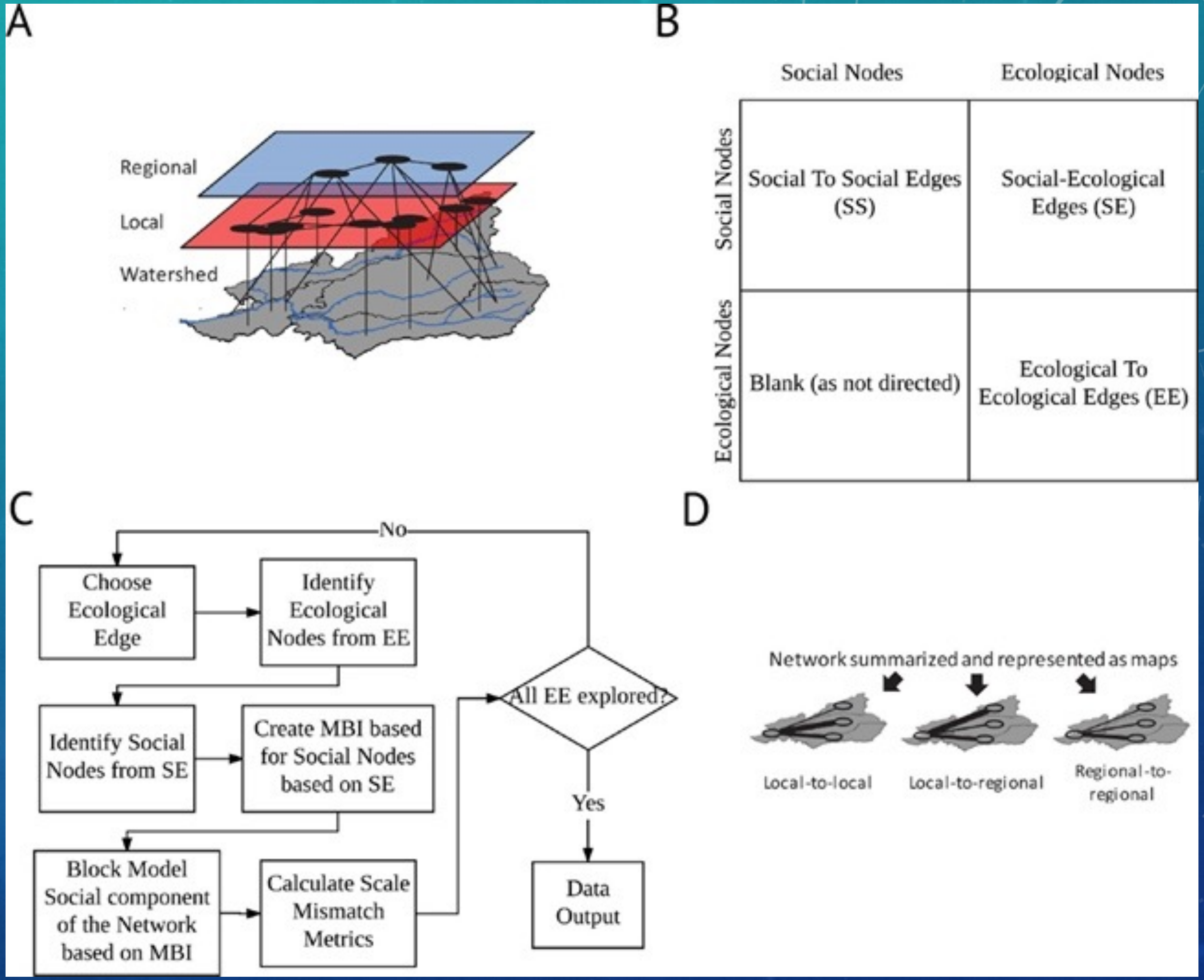
Median, 25th, and 75th percentile module-to-module participation (PM) scores among different group types in the salmon restoration network



Module to module participation score (PM) based on whether collaboration were mandated, funded or born out of shared interest

BUILDING SOCIAL-ECOLOGICAL NETWORKS

- Two types of Social Nodes
  - Local and Regional
- Where do organizations work?
  - GIS Integration of organizations and ecological patches
- Mapp social edge metrics on ecological network
  - Thickness indicates value of a specific network metric used



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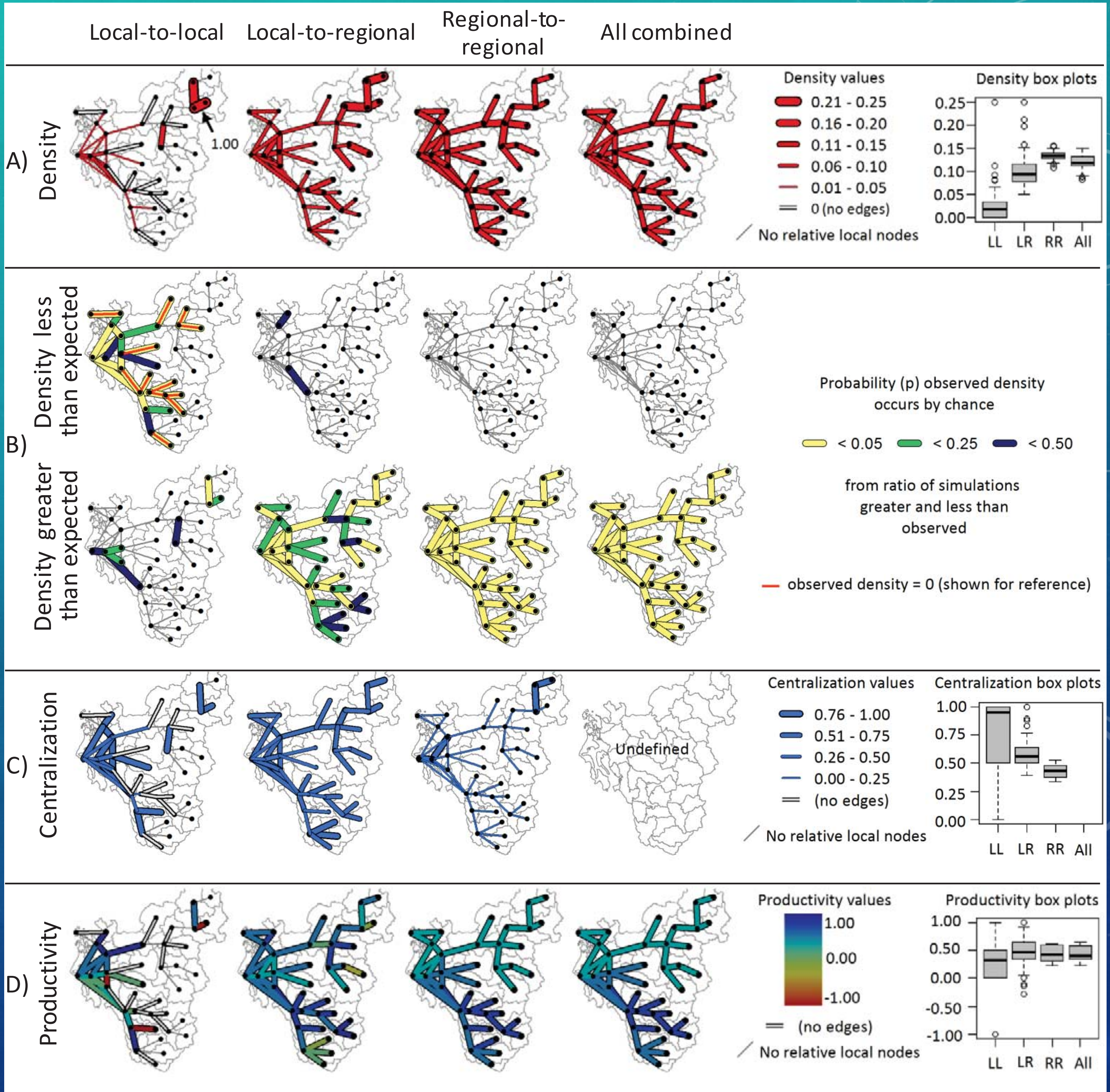
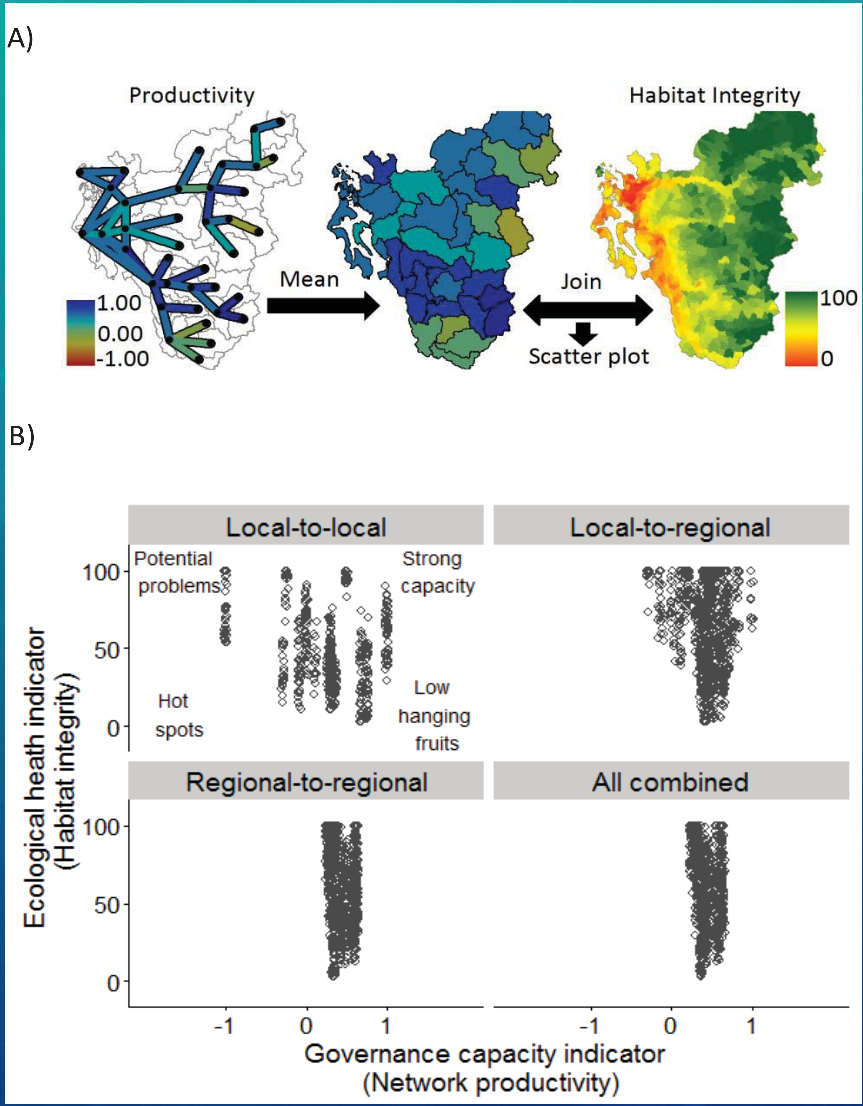
STRUCTURES OF COLLABORATION IN BIOPHYSICAL CONTEXT

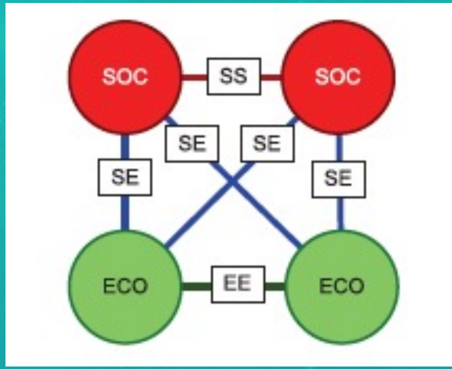
- Density
  - Is scale mismatch being overcome?
  - Controlling for the confounding effect of network size
- Centralization
  - Asymmetry of power or efficiency?
- Productivity

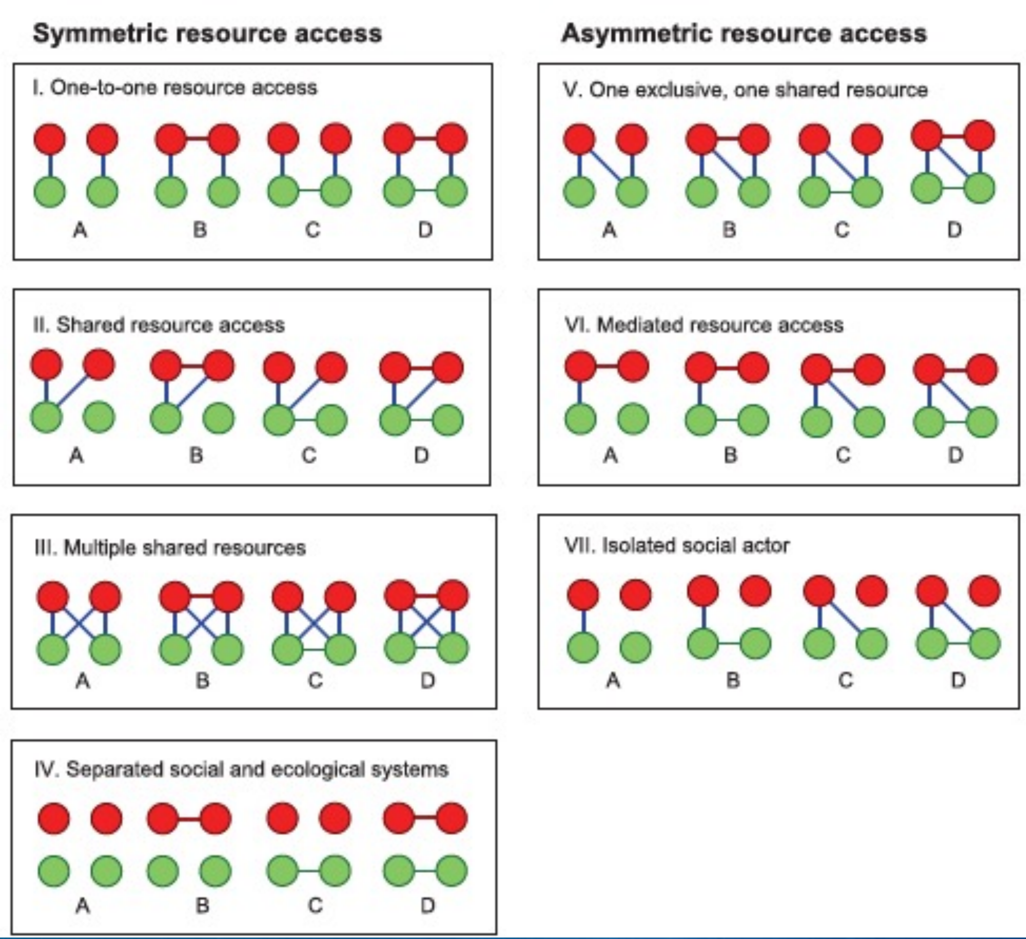


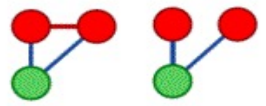
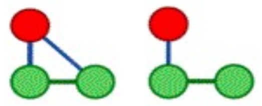
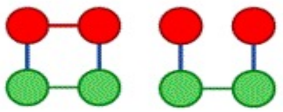
INTEGRATING NETWORKS AND ECOLOGICAL INDICATORS



NETWORK MOTIFS: ANALYZING SOCIAL ECOLOGICAL NETWORKS





Social-ecological building block	Governance challenge
Common-pool resource management	
Resource sharing with and without a social tie (closed and open common pool triangle) 	If two (or more) noncooperating actors share a resource (right), there may be a strong incentive for these actors to overharvest the resource. This governance challenge can, however, be addressed if the actors collaborate and agree on some common resource regulations (Ostrom 1990). This implies that the two actors need to be socially tied (left). Note that this does not imply that actors being tied to other actors is good in general, rather it emphasizes that collaboration is beneficial for actors sharing common ecological resources (Bodin et al. 2014).
Social-ecological fit and alignment	
Managing an ecosystem versus managing a subcomponent (closed and open ecosystem triangles) 	If an interconnected ecological resource is managed as separate entity (right), the governing structure is not well aligned with the structure of the ecosystems (Cumming et al. 2006, Bodin et al. 2014). This governance challenge resembles the notion of social-ecological misfit implying that the effect of management activities can, through ecological interdependency, spread to other resources beyond the realm of managing actor. Thus, a closed triangle (left) hypothetically suggests a better fitting building block because ecological costs and benefits occurring beyond the managed resource are internalized (Bodin et al. 2014).
Two actors managing interconnected resources being socially connected or disconnected (closed and open four-cycle) 	A lack of collaboration between two actors managing interconnected ecological resources (right) represents a similar type of governance challenge as above because the extent of the interconnected ecological resources is not aligned with the extent of the governance structure (social-ecological scale mismatch; Cumming et al. 2006). If the actors are socially tied (left), a better social-ecological scale alignment (fit) is accomplished (Bodin and Tengö 2012).

Bodin, Ö., Robins, G., McAllister, R. R. J., Guerrero, A. M., Crona, B., Tengö, M., & Lubell, M. (2016). Theorizing benefits and constraints in collaborative environmental governance: A transdisciplinary social-ecological network approach for empirical investigations. Ecology and Society, 21(1), 40. https://doi.org/10.5751/ES-08368-210140

Bodin, Ö., & Tengö, M. (2012). Disentangling intangible social-ecological systems. Global Environmental Change, 22(2), 430–439. https://doi.org/10.1016/j.gloenvcha.2012.01.005

SOFTWARE: NO ANALYSIS WITHOUT GOOD SOFTWARE

- Matlab, Python and R: allow to write your own scripts and routines, but steeper curve to learn.
- Gephi, Pajek, Cytoscape, UCINET: easier interface, plugins allow flexibility, but harder to write your own scripts/routines.
- Basic Network Packages for Python and R
  - Python: and networkx and igraph, pymnet
  - R: sna, igraph, statnet, MuxViz
- No “ideal” solution
  - Typically need to use a combination of softwares
  - Often different algorithms (or implementations) → different outcomes
  - Often need to code own routines

HANDS ON!
LET’S PUT INTO PRACTICE WHAT WE HAVE SEEN SO FAR!

SOME BACKGROUND

- Water governance implies institutions and organizations involved in the development and management of water resources. Water resources are, often, considered common pool resources, especially when no single individual holds specific rights to water.
- This implies that water, within individual accessing it, is a non-excludable (I can not exclude another to access it) but rivalrous (the more I access/pollute, the less you can use the water)

… ONCE UPON A TIME… IN AN UNDISCLOSED LOCATION…

- There where 40 different organizations able to access and affect water flows among four different rivers within a watershed.
- Some of these organizations were able to establish collaborations to co-manage access and water resources, however, not all organizations were able to collaborate with everyone else.
- To assess collaboration and potential issues with respect to the water common pool resource system, researchers mapped the collaboration between the 40 organizations and also where these organizations were located and to which “part” of the river system they had access too (and thus could either withdraw resources or pollute or try to preserve it for other uses (i.e. fishing, tourism etc..).

A NETWORK STUDY ON COLLABORATION AND RIVER SYSTEM

- Given the brief description of the scenario above:
- What type of network would you build? – not articulated, semi articulated or fully articulated SEN?
- How would you construct the social-ecological network? (define nodes and edges in both ,the social and the biophysical system and how they link to each other)
- What metrics and what structural properties you think would be important to assess to elicit whether the overall common pool resource system may incur in governance issues?
- Is it possible to define key actors (actors that are more likely to control the flow of information within the collaborative network or that are key to "bridge" the different organizations?)
- What role could motifs play in such network?

HANDS ON! LET'S PUT INTO PRACTICE WHAT WE HAVE SEEN SO FAR!

- Download the following files from github
  - SENAWk,
  - Snet (the social/organization collaboration network)
  - Bnet (the biophysical / river network)
  - Sbnet (dictionary indicating what river part is affected by which organization)
- The SENAWk contains a Jupiter notebook (similar to the one you have seen so far) to play and use it you can:
- IF you have python installed and jupiter notebooks, open it directly with jupiter notebooks
- OR you can open it via google colaboratory, without the need to install Jupiter notebook or python (I hope…)


"That's all Folks!"