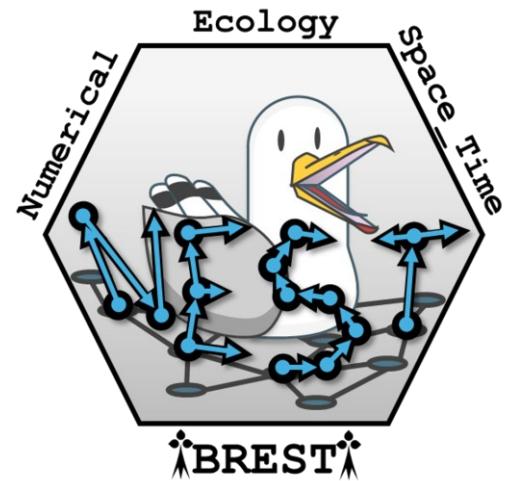


Network Tools for Ecology

David Cunillera-Montcusí

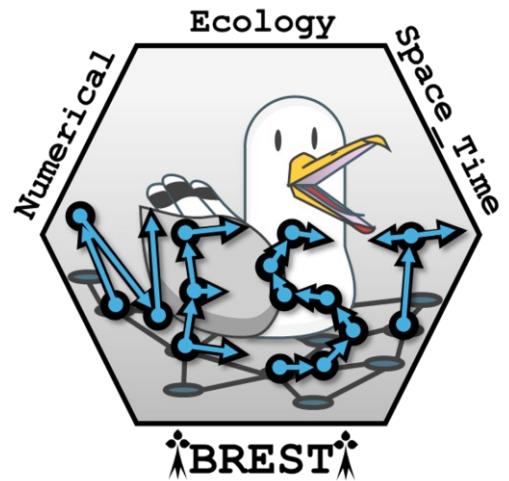
david.cunillera@dcm.cat



Network Tools for Ecology

David Cunillera-Montcusí

david.cunillera@dcm.cat



- First session (10:00-11:00)
 - Introduction to networks
 - Spatial networks and where to find them
 - R time through network examples
- Second session (11:30-12:30)
 - Connecting network structure with diversity
 - Coalescent runs and habitat loss

Introduction to networks

“A network is a set of items, which we will call **vertices** or sometimes **nodes**, with connections between them, called **edges**.

Systems taking the form of **networks** (also called “**graphs**” in much of the mathematical literature) around in the world.”

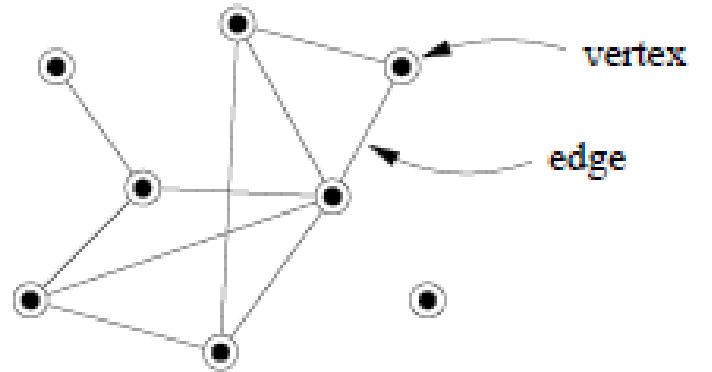


FIG. 1 A small example network with eight vertices and ten edges.

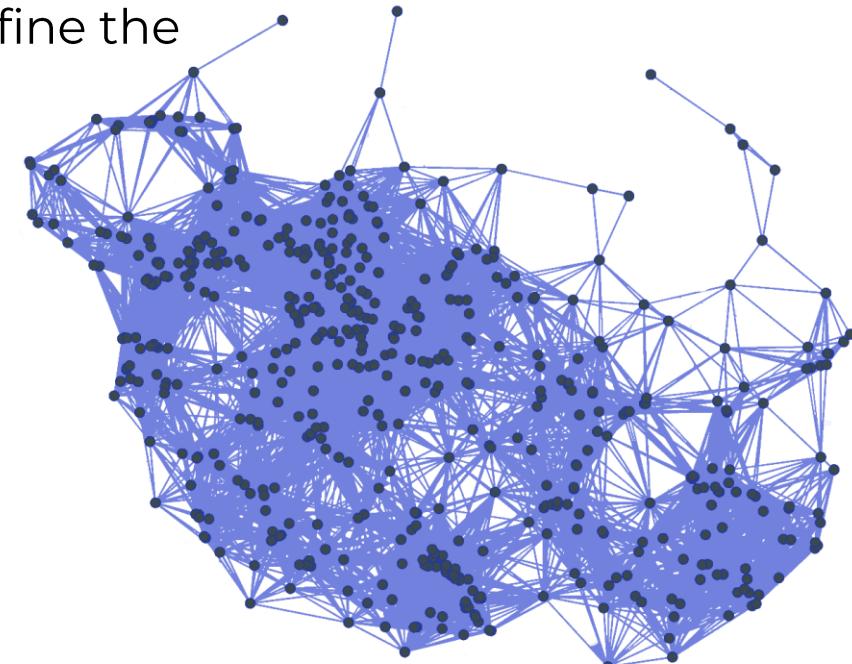
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What is a network? It is just a matrix...

How each pair of elements is connected in this matrix will define the nature of our networks.



Newman, M. E. J. 2003. *The structure and function of complex networks.*: 48.

Jordán, F. and Scheuring, I. 2004. Network ecology: topological constraints on ecosystem dynamics. - *Physics of Life Reviews* 1: 139–172.

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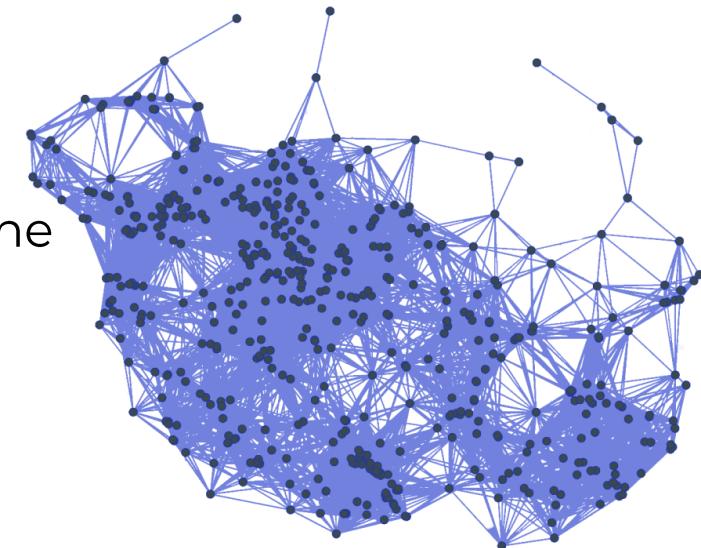
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What is a network? It is just a matrix...

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Distance between sites

	1	2	3	4	5	6	7
1	0.0000	2673.3805	171.1212	478.8186	495.7922	733.7658	687.7677
2	2673.3805	0.0000	2825.2894	2938.2897	2592.0787	2177.5616	2453.6054
3	171.1212	2825.2894	0.0000	346.5546	485.2156	809.3923	701.5861
4	478.8186	2938.2897	346.5546	0.0000	366.5456	788.6309	571.3328
5	495.7922	2592.0787	485.2156	366.5456	0.0000	424.5368	222.5385
6	733.7658	2177.5616	809.3923	788.6309	424.5368	0.0000	284.9015
7	687.7677	2453.6054	701.5861	571.3328	222.5385	284.9015	0.0000



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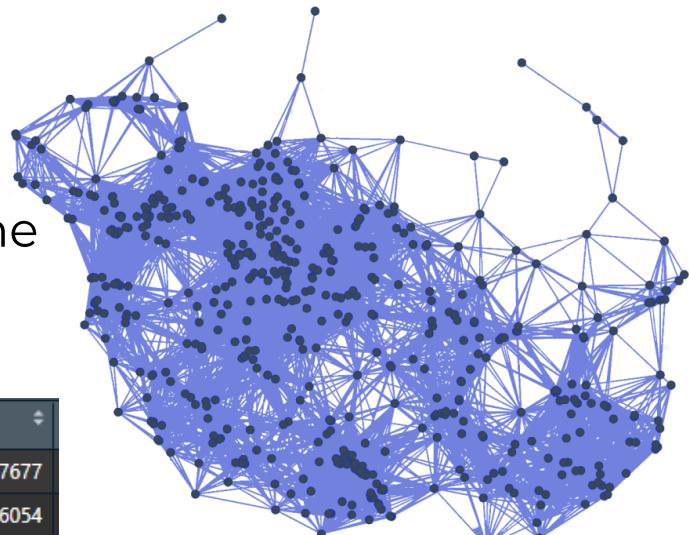
How each pair of elements is connected in this matrix will define the nature of our networks.

No weights between sites

1	2	3	4	5	6	7	8	9	10	11	12	13
1	0	1	1	1	1	1	1	1	1	0	1	0
2	1	0	0	0	1	1	1	1	1	1	1	1
3	1	0	0	1	1	1	1	1	1	0	1	0
4	1	0	1	0	1	1	1	1	1	0	1	0
5	1	1	1	1	0	1	1	1	1	0	1	0
6	1	1	1	1	1	0	1	1	1	1	1	1
7	1	1	1	1	1	1	0	1	1	1	0	1
8	1	1	1	1	1	1	0	1	1	0	1	0
9	1	1	1	1	1	1	1	0	1	1	1	1
10	1	1	1	1	1	1	1	1	0	0	1	0

Weights between sites

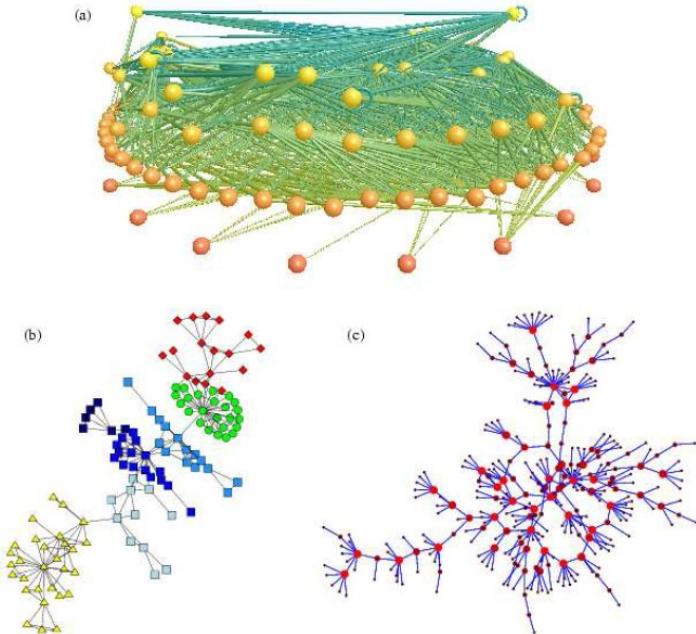
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Introduction to networks

Networks can be used for multiple meanings like trophic networks, co-occurrence networks, biotic-abiotic networks

...



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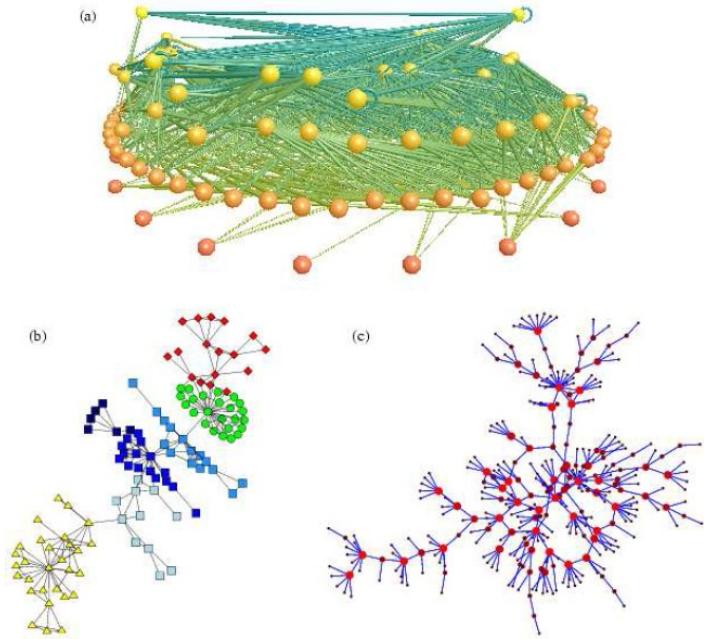
Galiana, N., Arnoldi, J.-F., Mestre, F., Rozenfeld, A. and Araújo, M. B. 2023. Power laws in species' biotic interaction networks can be inferred from co-occurrence data. - *Nat Ecol Evol*: 1–9.

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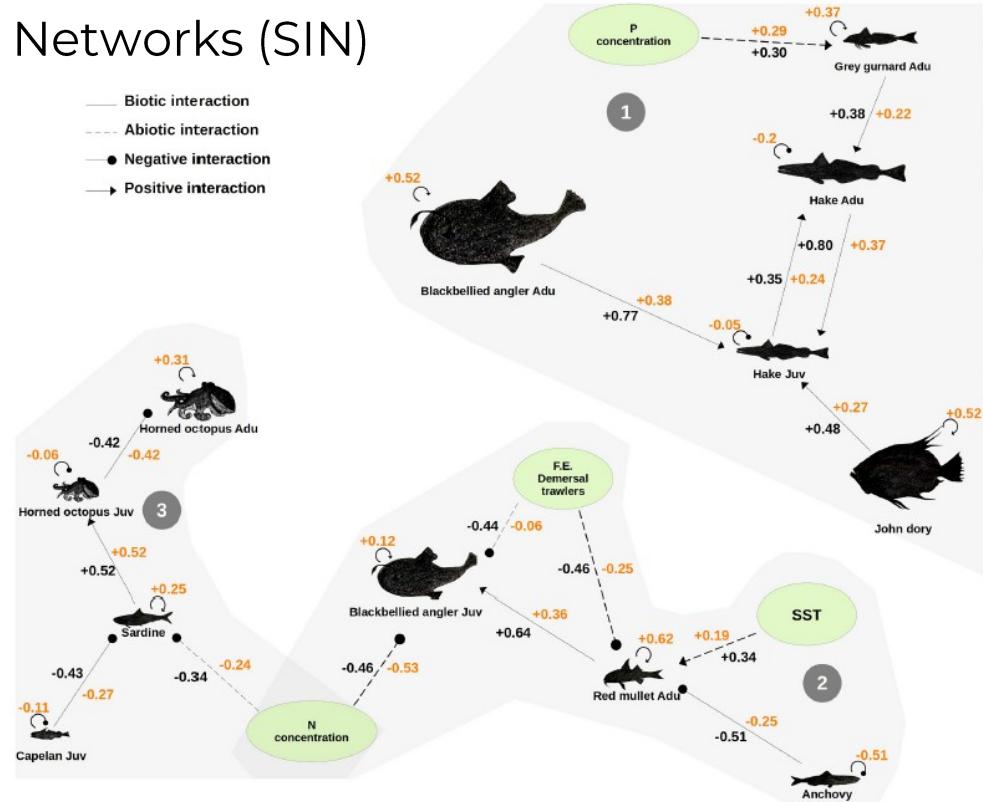
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Statistical interaction Networks (SIN)



Newman, M. E. J. 2003. *The structure and function of complex networks.*: 48.

Hernández-Carrasco et al 2023. Ecological restoration promotes zooplankton network complexity in Mediterranean coastal lagoons. - *Restoration Ecology* 31: e13920.

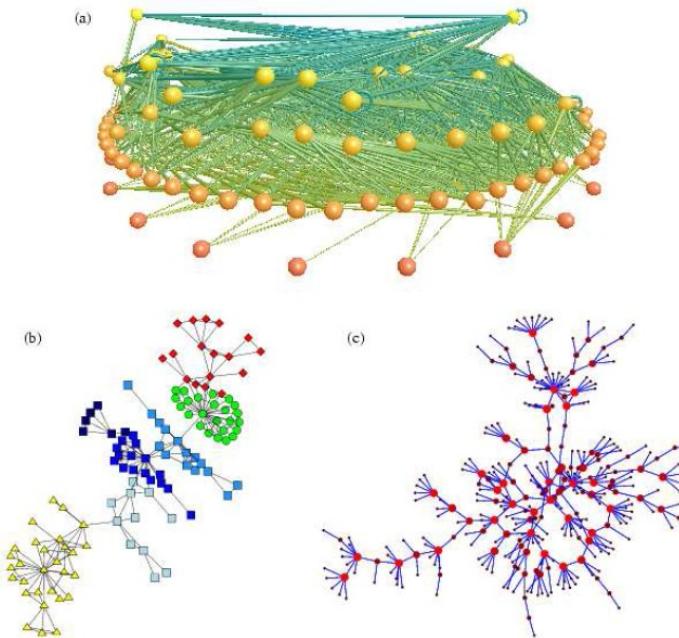
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Introduction to networks

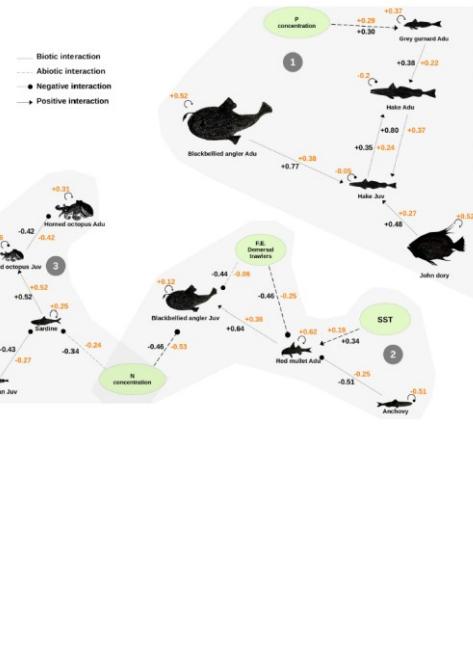


Networks can be used for multiple meanings like trophic networks, co-occurrence networks, biotic-abiotic networks

3

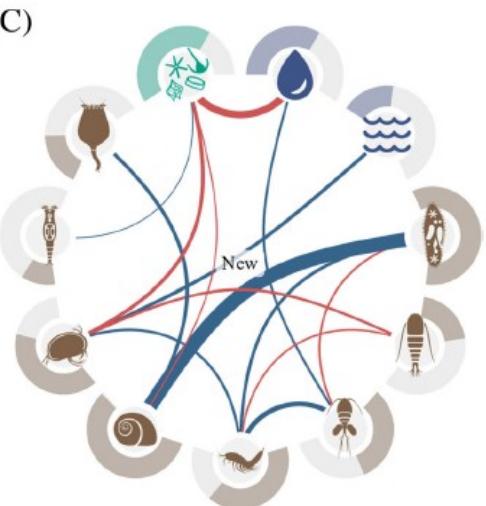
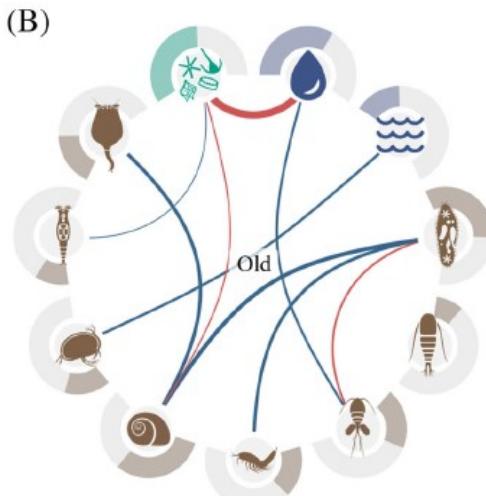


Statistical interaction Networks (SIN)



Biotic-Abiotic Interaction Networks (BAINs)

Temporal co-occurrence (LASSO)



Introduction to networks

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...

Co-occurrence



Biotic interaction



Borthagaray et al 2014. Inferring species roles in metacommunity structure from species co-occurrence networks. - *Proceedings of The Royal Society. Biological sciences* 281: 20141425.

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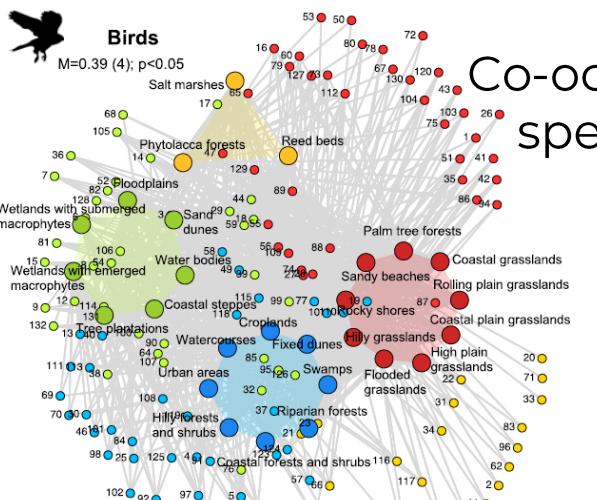
Co-occurrence



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Modularity analysis
Nodes groups/roles within network



Co-occurrence
species-habitat

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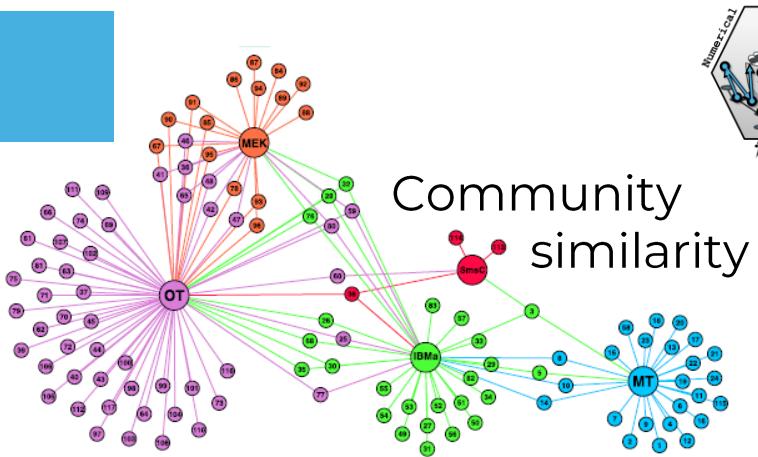
Co-occurrence



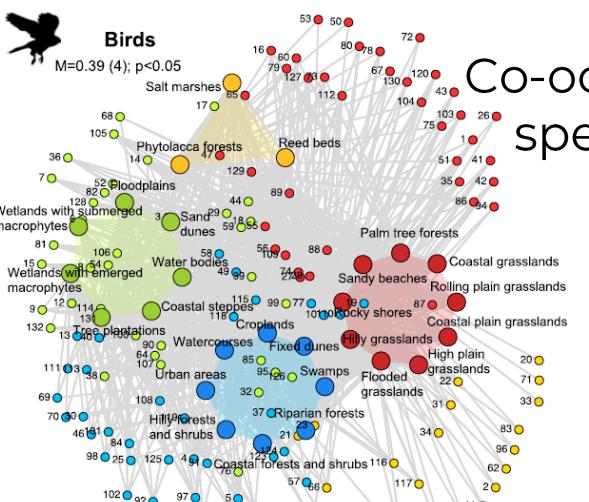
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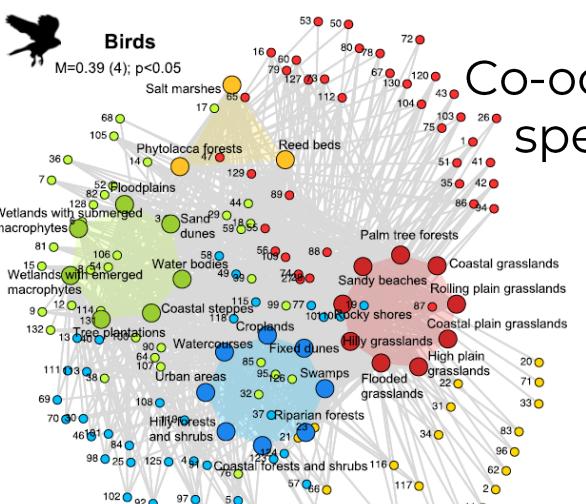
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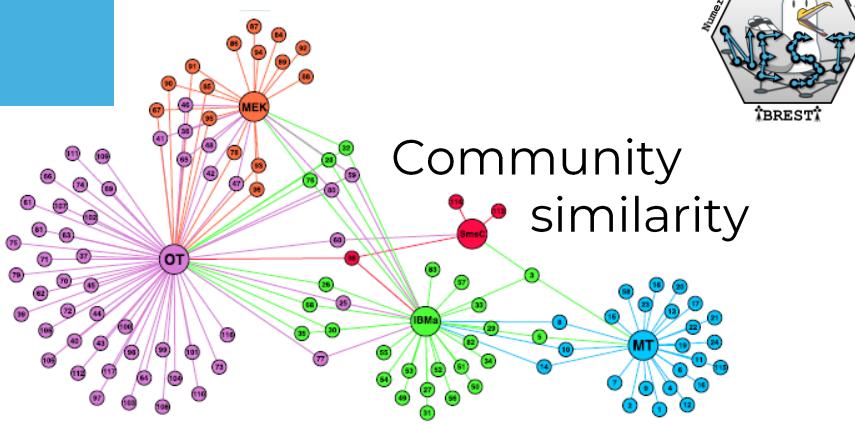
Biotic interaction



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Nodes groups/roles within network

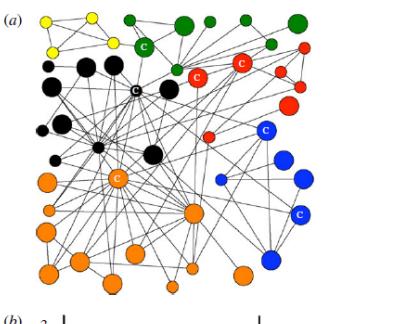


Co-occurrence
species-habitat



Community
similarity

Co-occurrence



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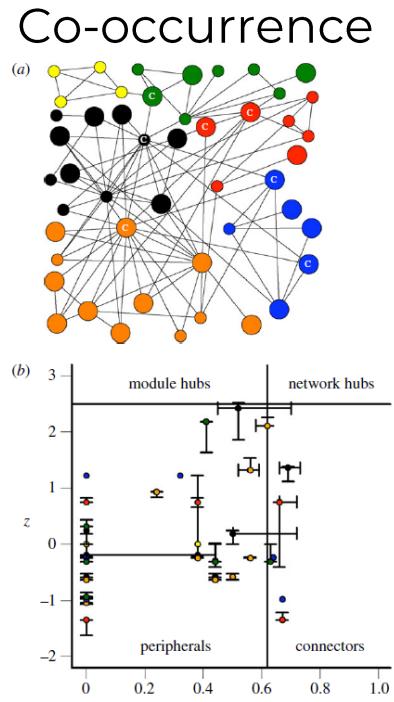
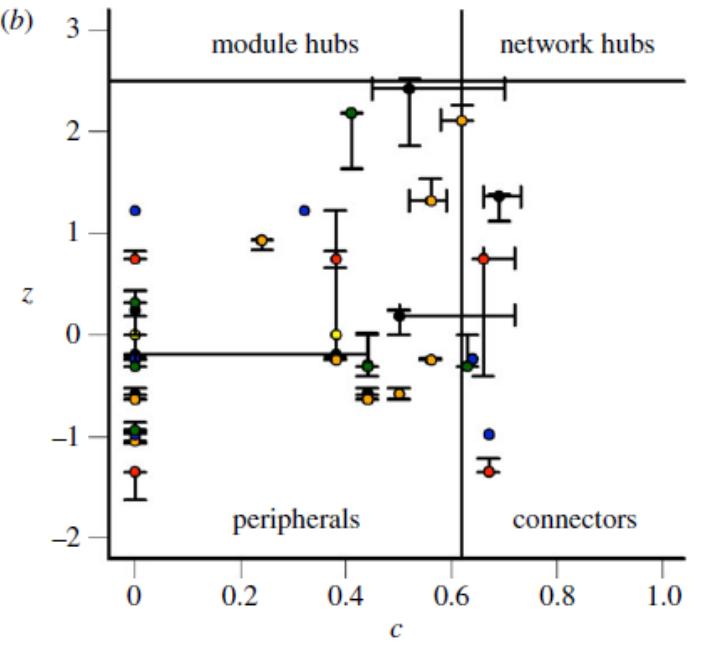
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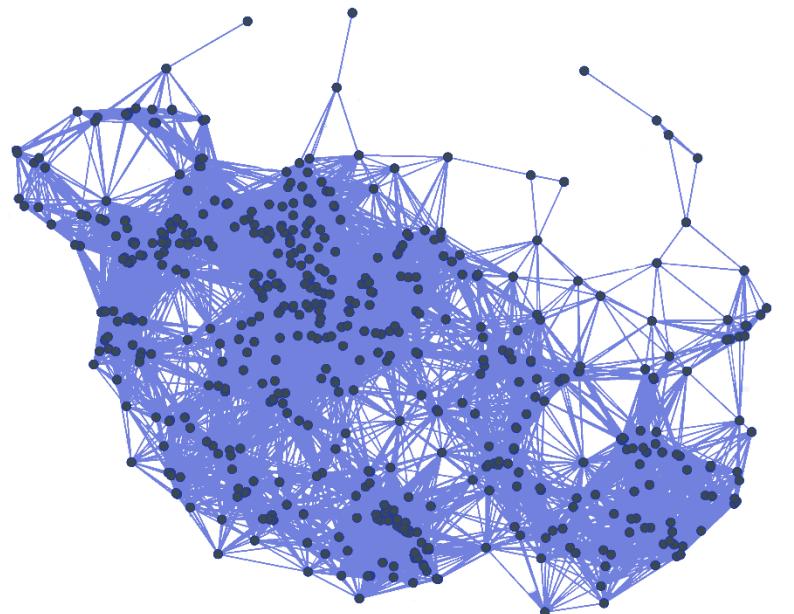
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Introduction to networks

The most important point to built any network is to **define what their main elements (links & nodes) mean ecologically**

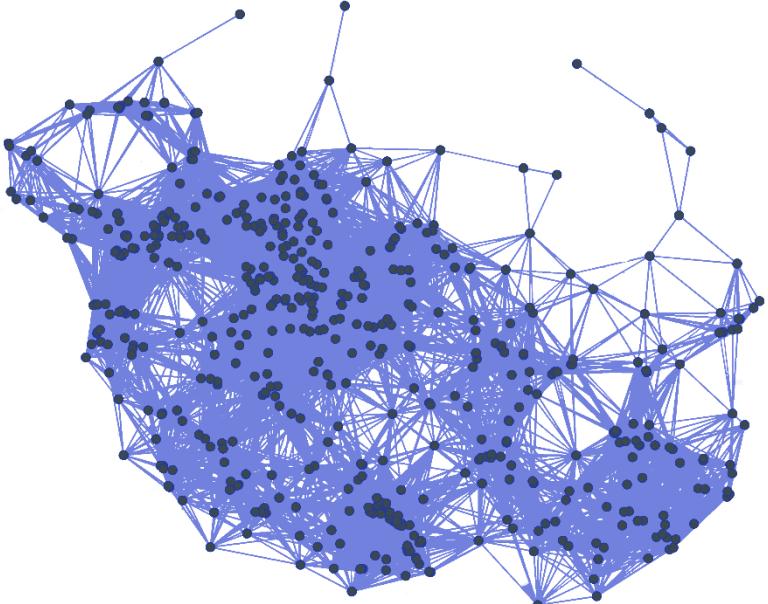
Points in a landscape (xy coordinates) are used to built spatial networks.

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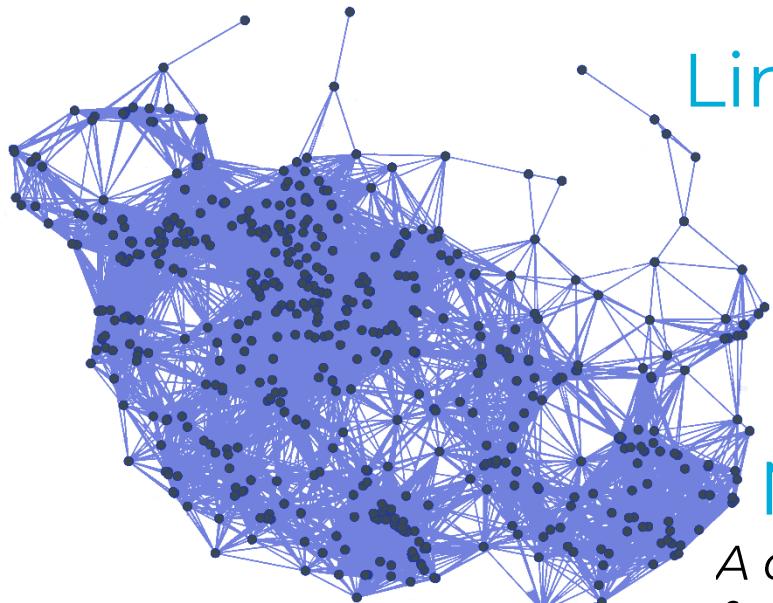
Spatial networks and where to find them

Points in a landscape (xy coordinates) are used to built spatial networks.



Spatial networks and where to find them

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Links meaning

An effective path between two communities throughout individuals can be exchanged.

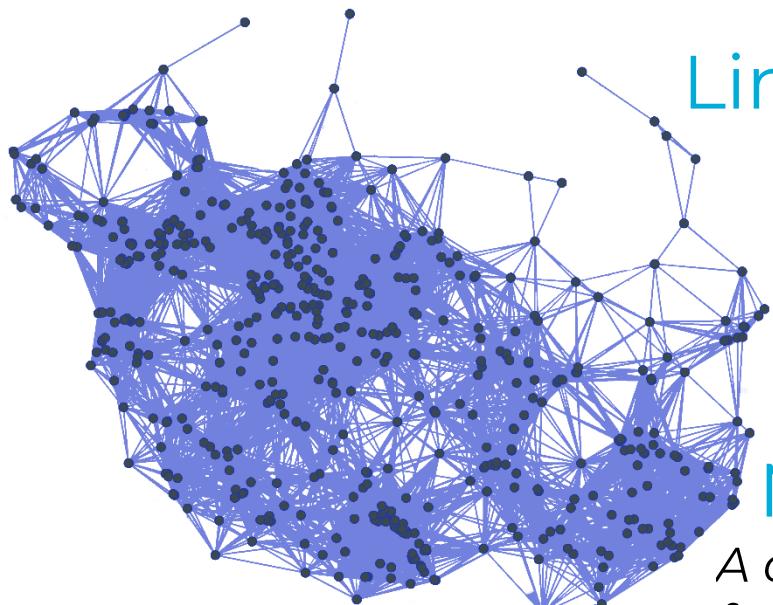
Nodes meaning

A defined community (pond, forest, patch of seagrass)

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Network structure



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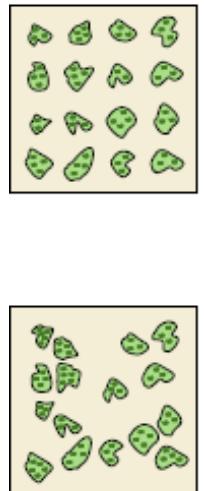
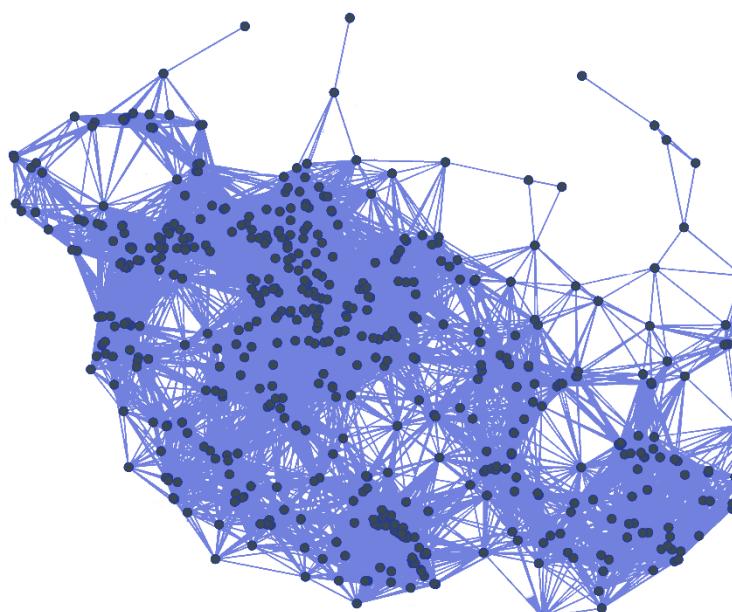
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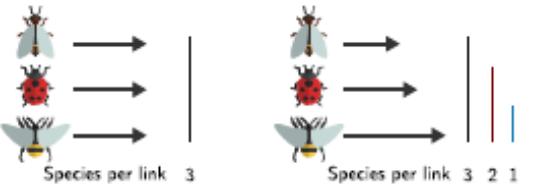
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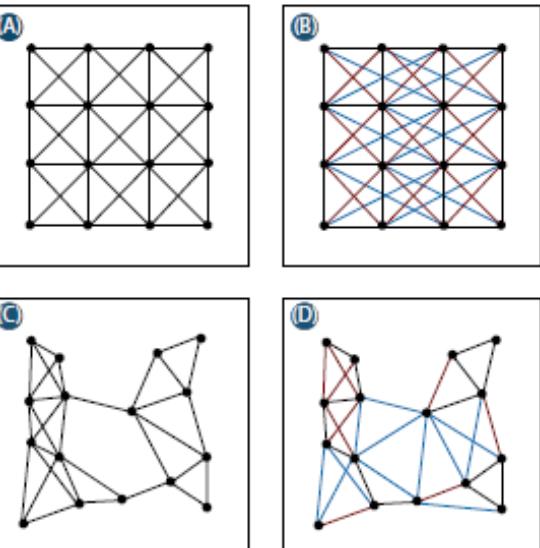
Network structure



Heterogeneity in landscape structure



Heterogeneity in species dispersal capacities



Trends in Ecology & Evolution

Spatial networks and where to find them

Points in a landscape (xy coordinates) are used to built spatial networks.

Network structure

Structural elements

Threshold distance

-*Dispersal ability-*

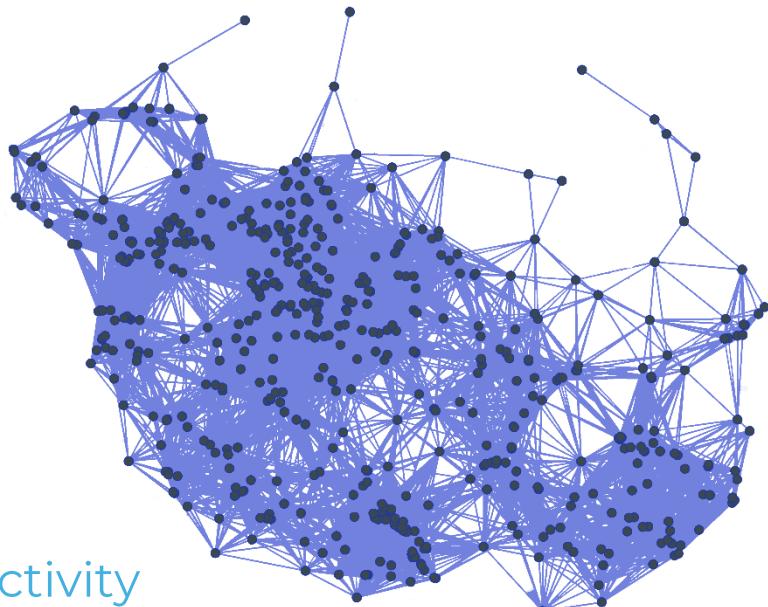
Scale

-*Habitat distribution-*

Quantitative metrics

Spatial connectivity

Spatiotemporal connectivity

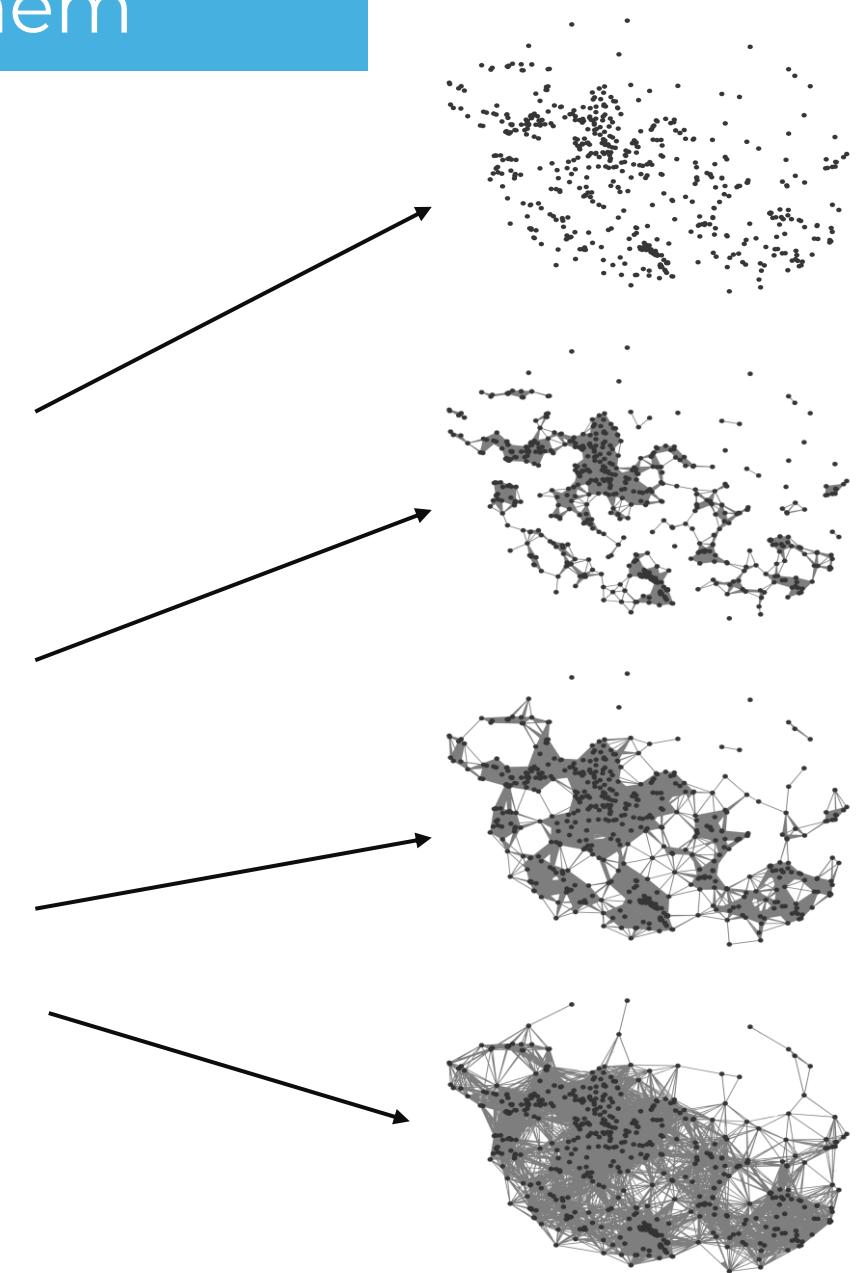


Spatial networks and where to find them

Threshold distance - Dispersal ability

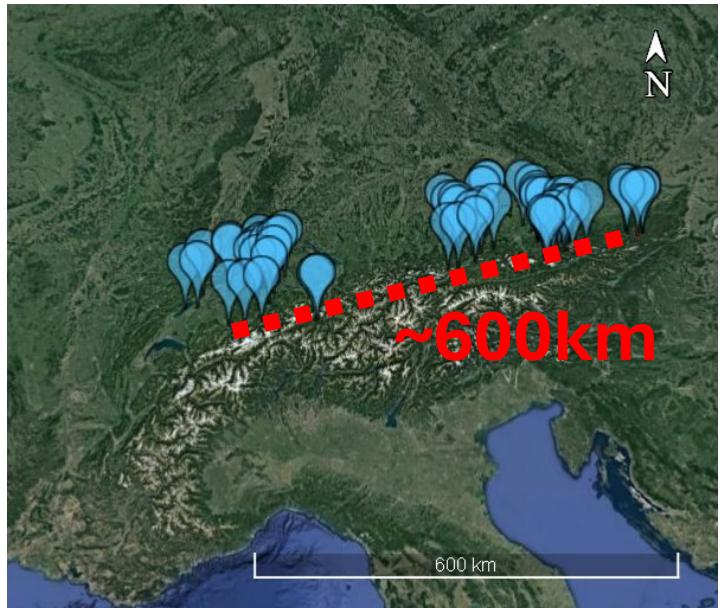


250 m
500 m
1000 m
1500 m
2500 m
2000 m
3000 m
 ≈ 3800 m
5000 m



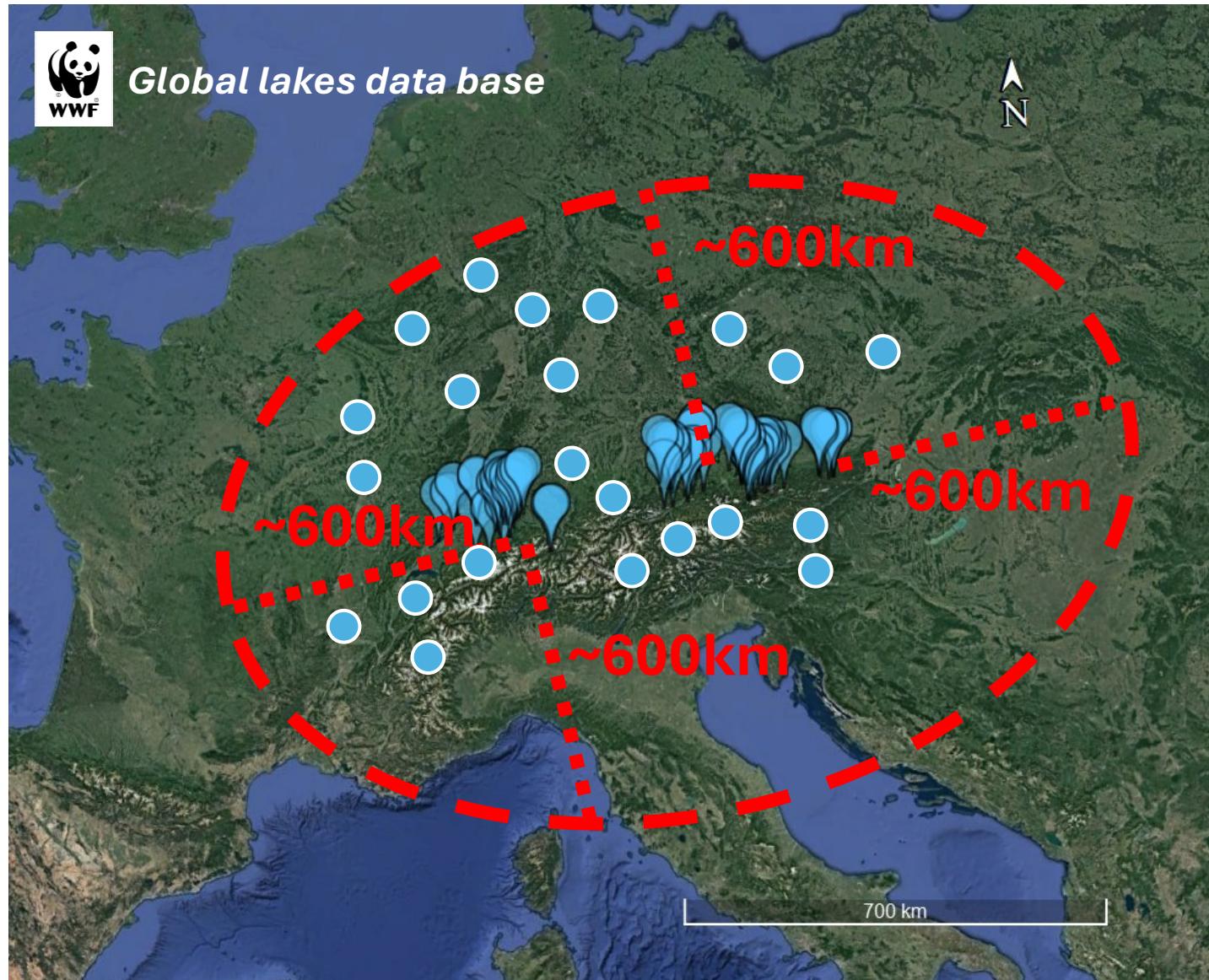
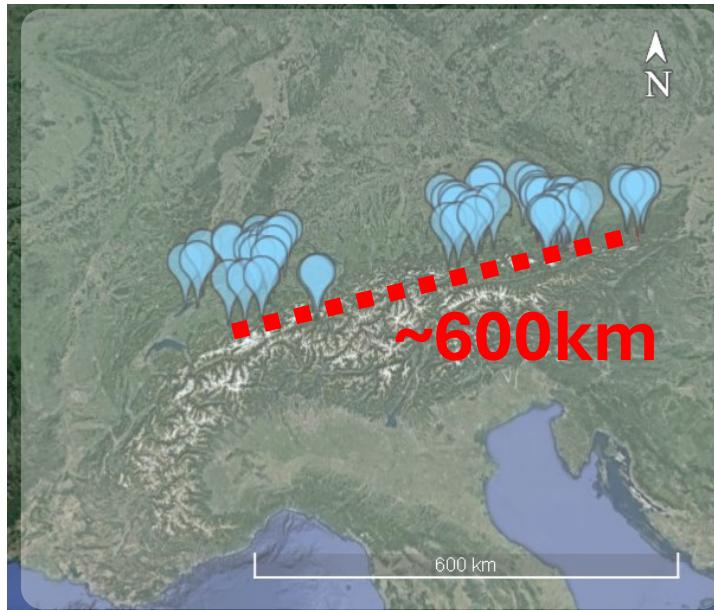
Spatial networks and where to find them

Scale - Habitat distribution



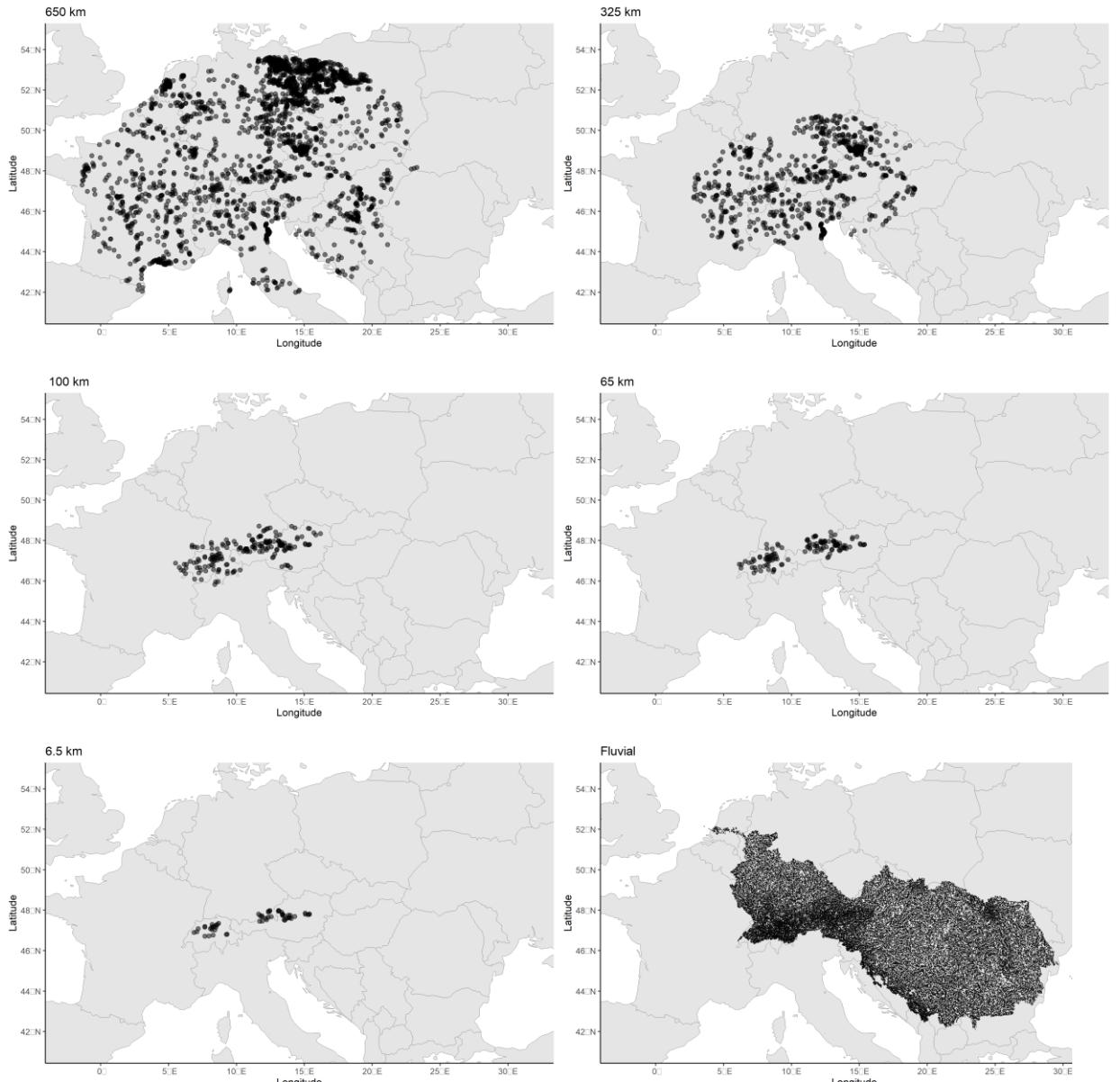
Spatial networks and where to find them

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Spatial networks and where to find them

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Spatial networks and where to find them

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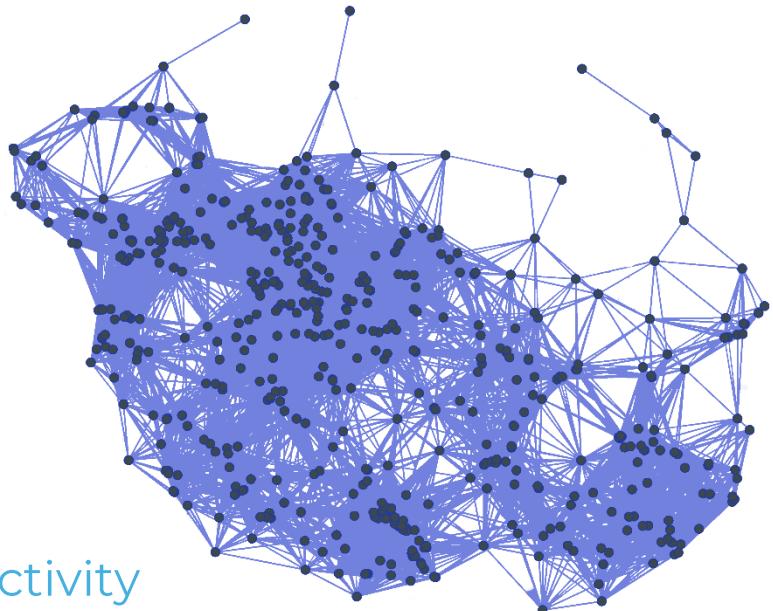
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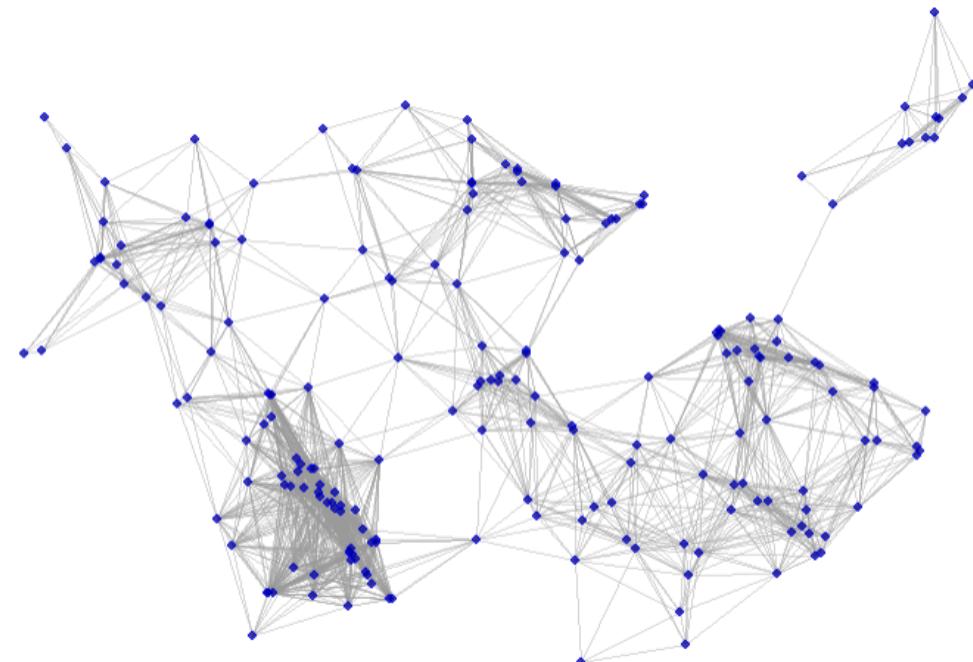
Spatiotemporal connectivity



Network_Part1.R

The percolation network

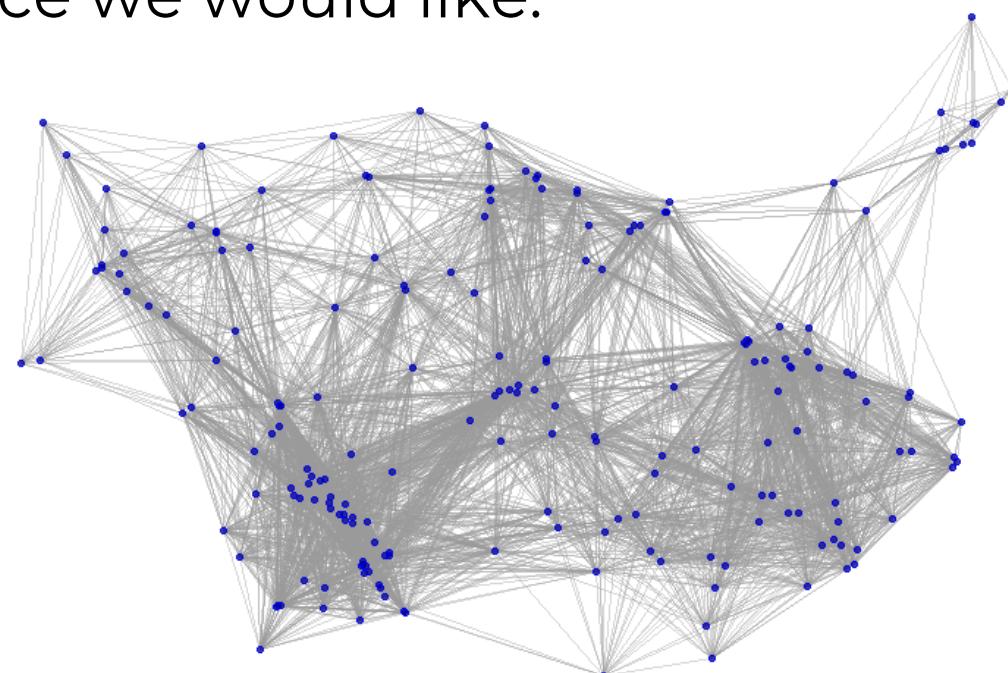
Based on the percolation distance: The minimum distance to ensure that all the nodes of your network are all connected
(they form 1 component)



The percolation network

Based on the percolation distance: The minimum distance to ensure that all the nodes of your network are all connected
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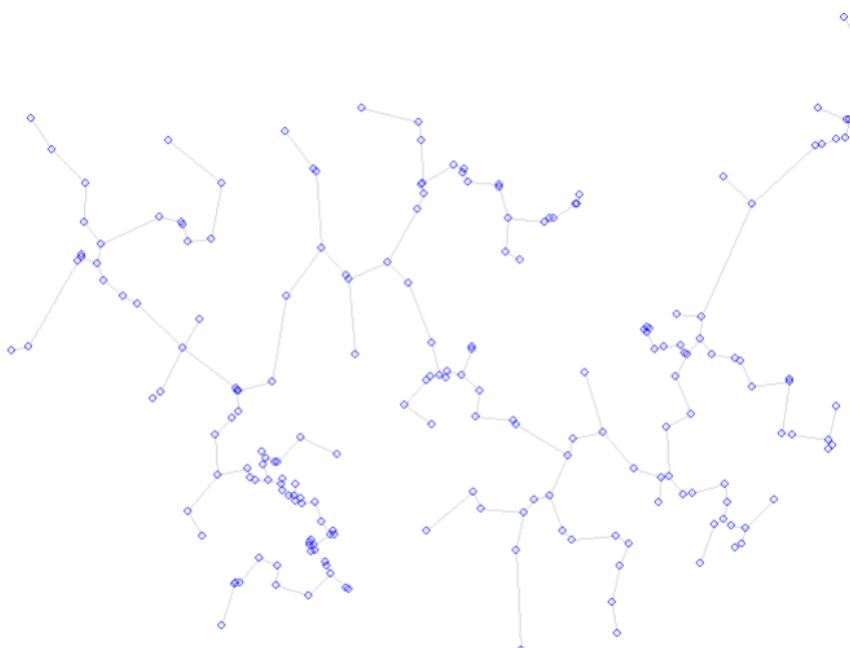
We could use WHATEVER distance we would like.



Minimum spanning tree

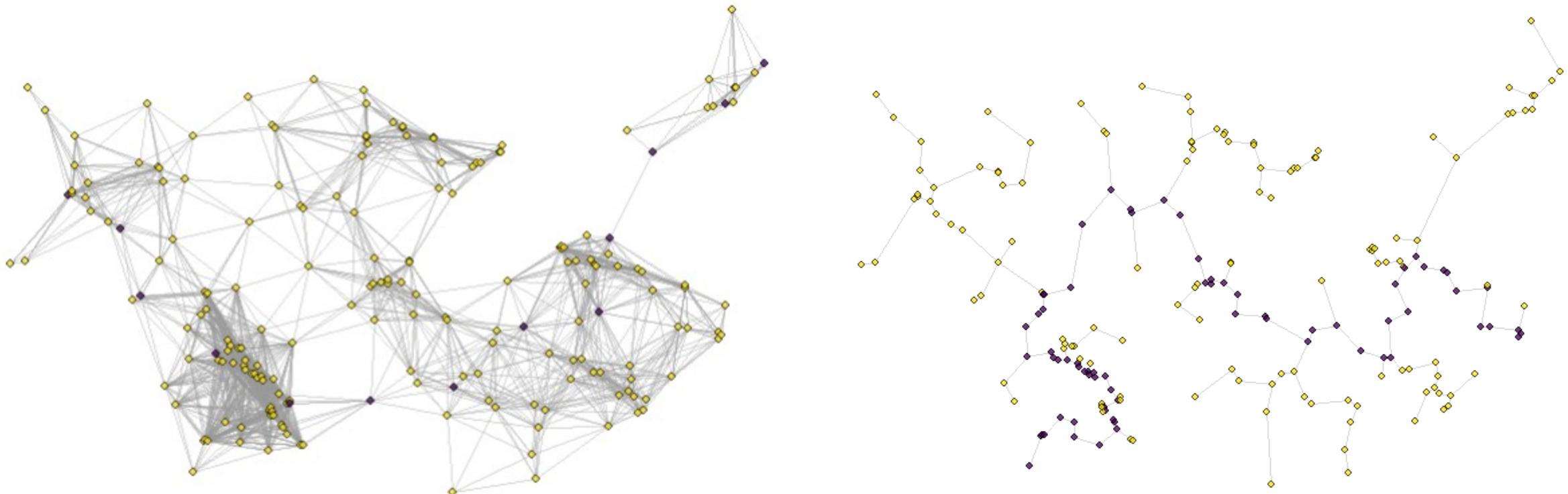
A network where all sites are connected to their “closest” neighbour.
A minimal expression of the landscape structure

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



Centrality metrics

Diameter: The diameter of a graph is the length of the longest geodesic

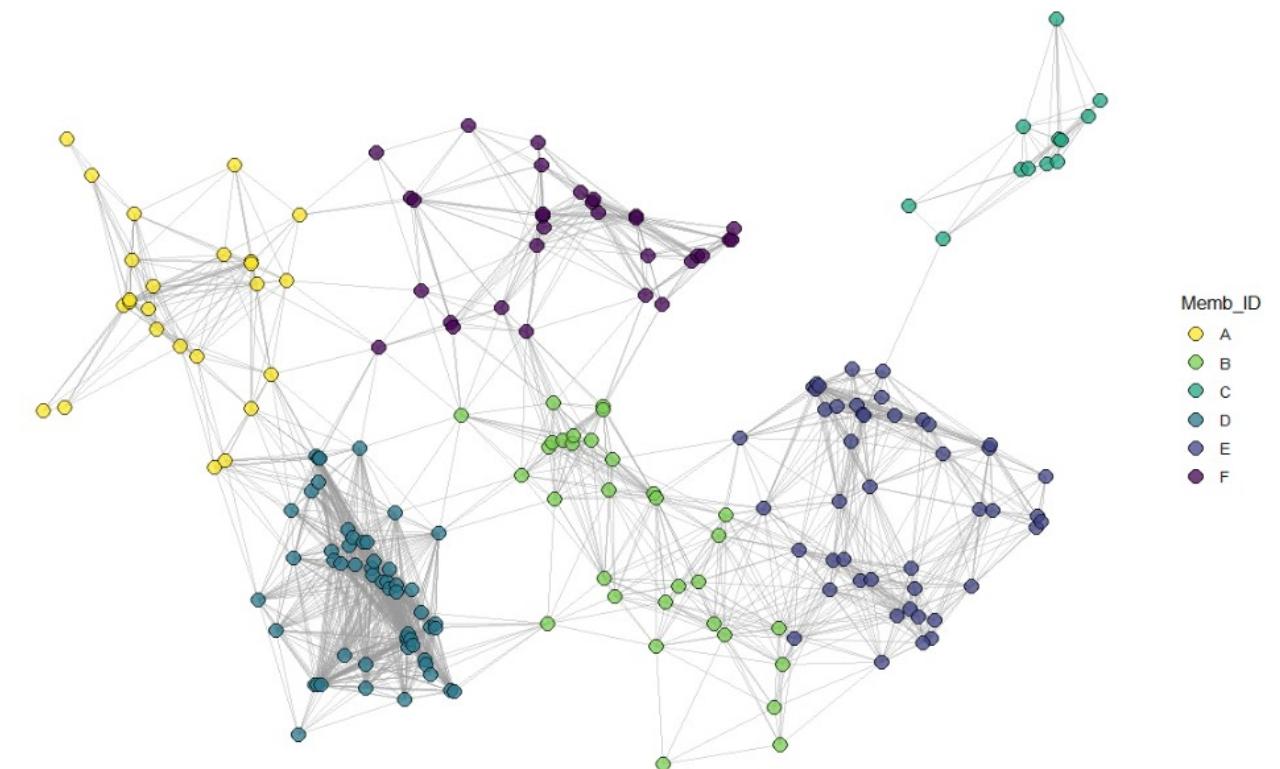


Quantitative metrics - Spatial connectivity

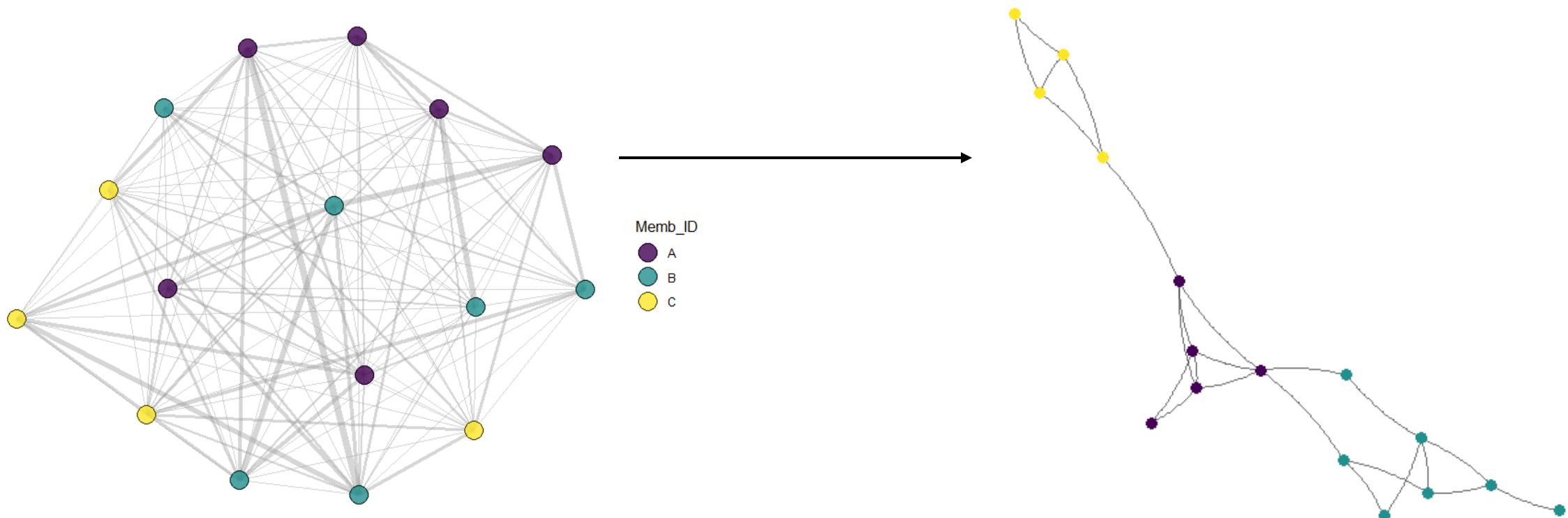
Centrality metrics

Diameter: The diameter of a graph is the length of the longest geodesic

Modularity: A community (AKA: module) is a set of nodes with many edges inside the community and few edges outside it.



Trait co-occurrence network – Network Analysis of Traits (NATs)



Backbone: <https://cran.r-project.org/web/packages/backbone/vignettes/backbone.html>

Gladstone-Gallagher et al 2023. Ecological network analysis of traits reveals variable response capacity to stress. - Proceedings of the Royal Society B: Biological Sciences 290: 20230403.

Siwicka et al 2020. Linking changes in species-trait relationships and ecosystem function using a network analysis of traits. - Ecological Applications 30: e02010.

Quantitative metrics - Spatial connectivity

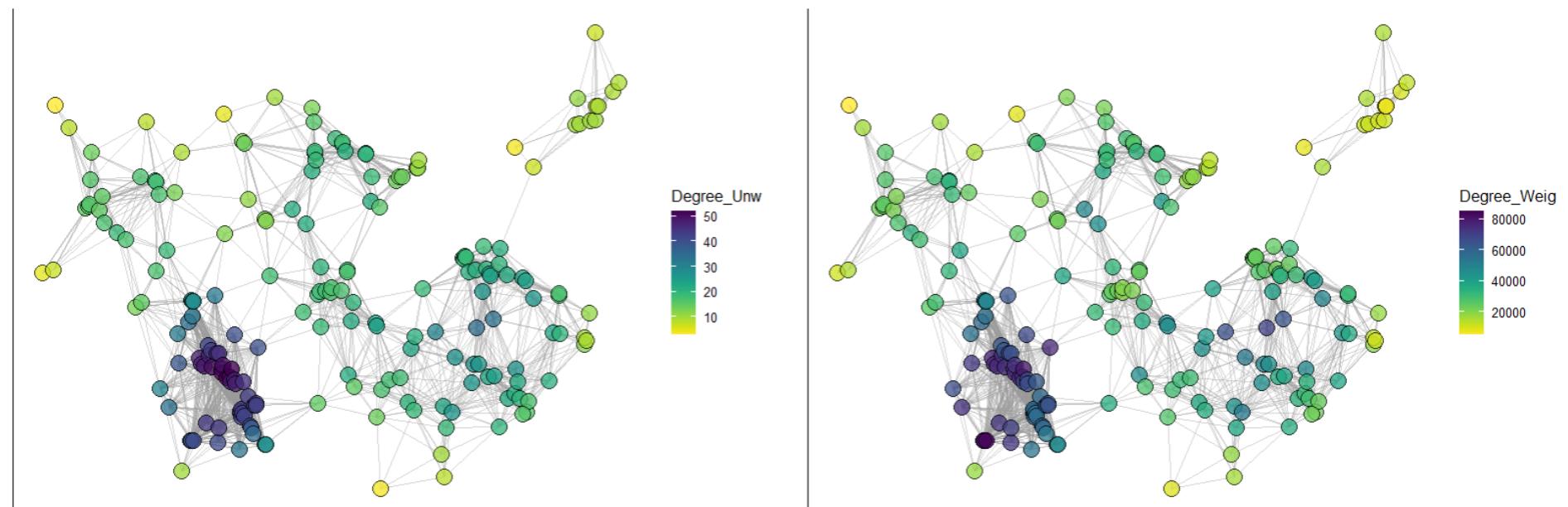
R

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Degree: is a vertex (AKA: node) most basic structural property, the number of its adjacent edges.



Quantitative metrics - Spatial connectivity



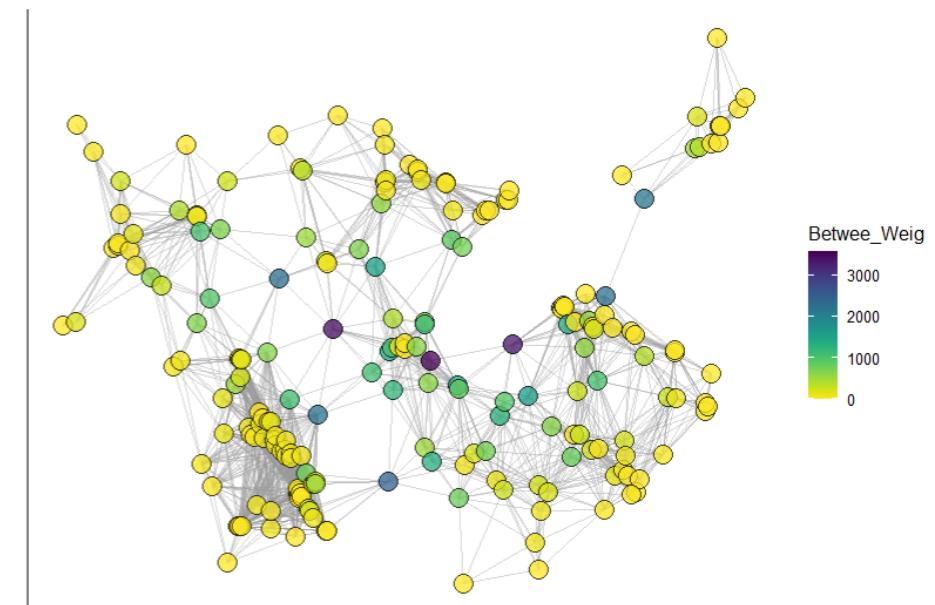
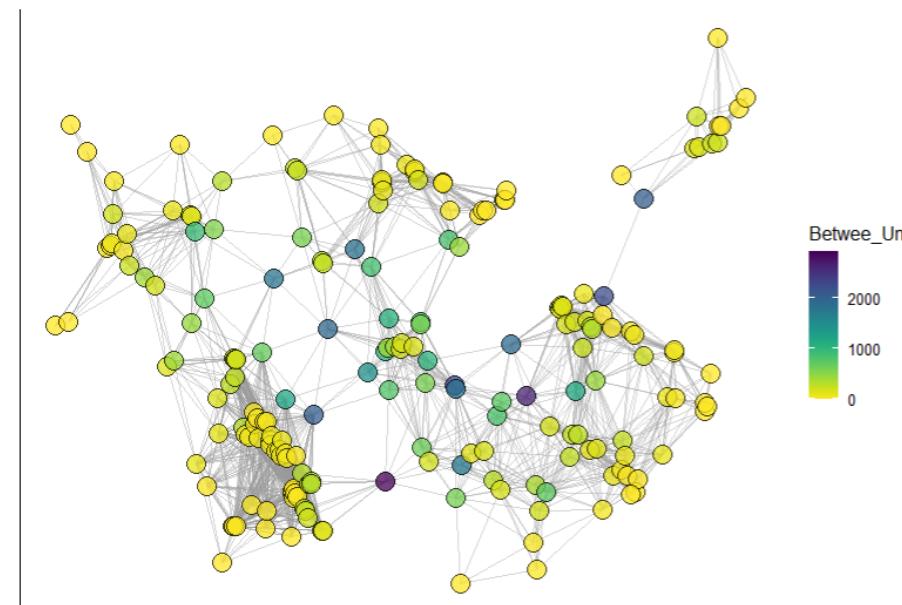
Centrality metrics

Diameter: The diameter of a graph is the length of the longest geodesic

Modularity: A community (AKA: module) is a set of nodes with many edges inside the community and few edges outside it.

Degree: is a vertex (AKA: node) most basic structural property, the number of its adjacent edges.

Betweenness: It is roughly defined by the number of geodesics (shortest paths) going through a vertex or an edge.



Quantitative metrics - Spatial connectivity

R

Centrality metrics

Diameter: The diameter of a graph is the length of the longest geodesic

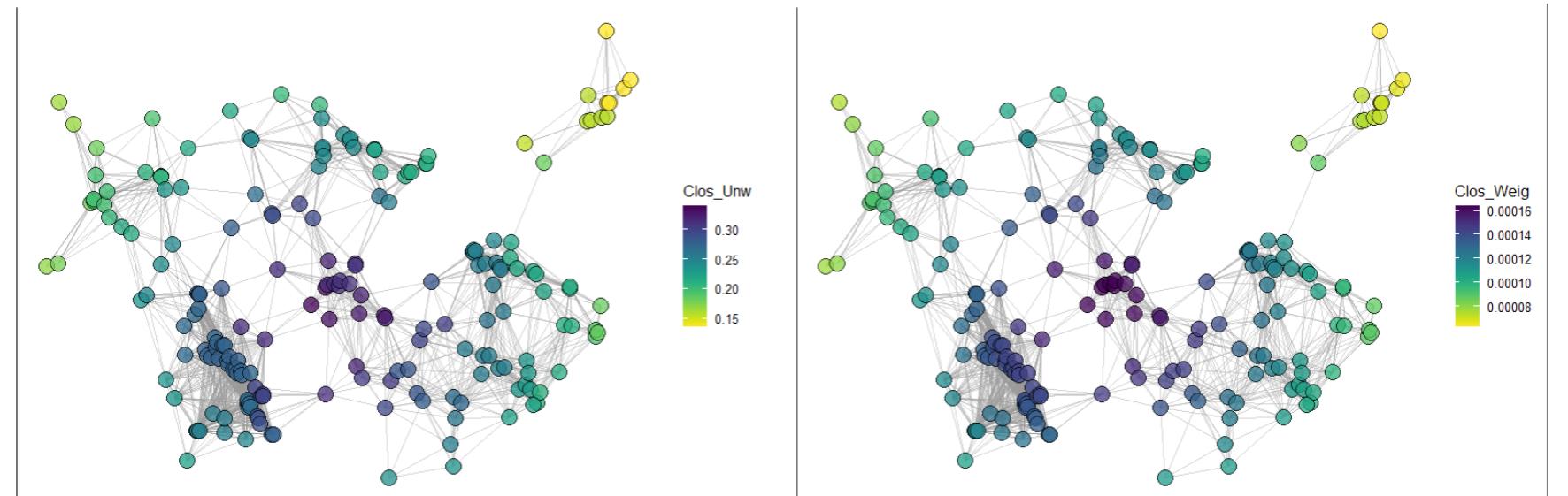
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Degree: is a vertex (AKA: node) most basic structural property, the number of its adjacent edges.

Betweenness: It is roughly defined by the number of geodesics (shortest paths) going through a vertex or an edge.

Closeness centrality: It measures how many steps is required to access every other vertex from a given vertex.

-- **Harmonic centrality** for fragmented graphs.



Quantitative metrics - Spatial connectivity

R

Centrality metrics

Diameter: The diameter of a graph is the length of the longest geodesic

Modularity: A community (AKA: module) is a set of nodes with many edges inside the community and few edges outside it.

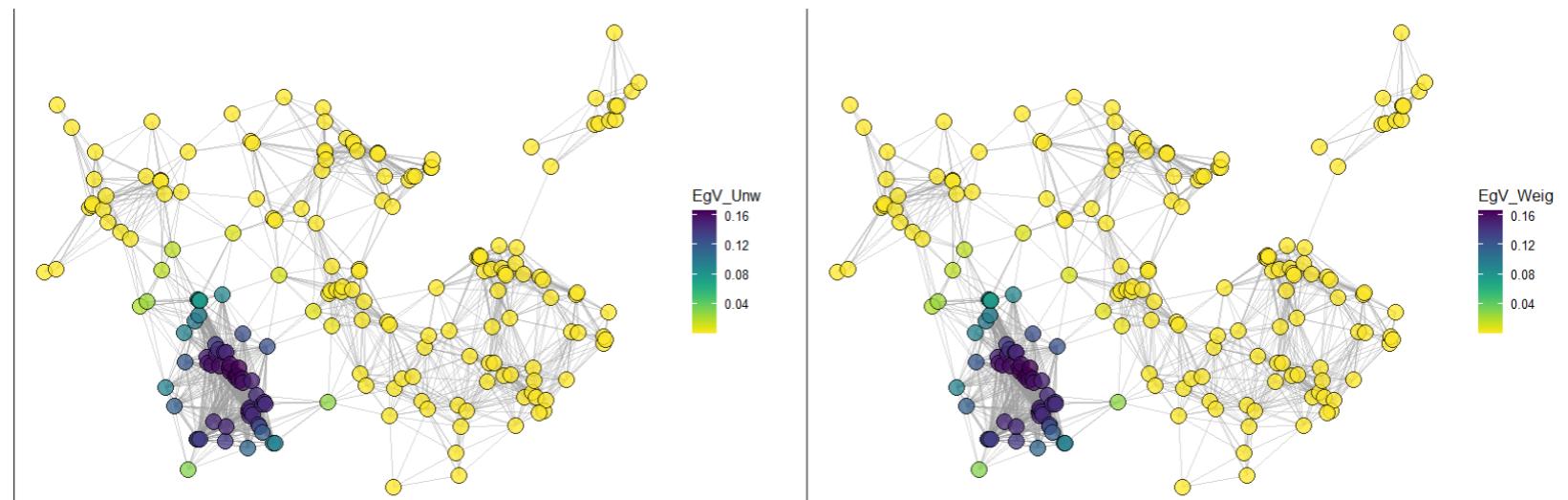
Degree: is a vertex (AKA: node) most basic structural property, the number of its adjacent edges.

Betweenness: It is roughly defined by the number of geodesics (shortest paths) going through a vertex or an edge.

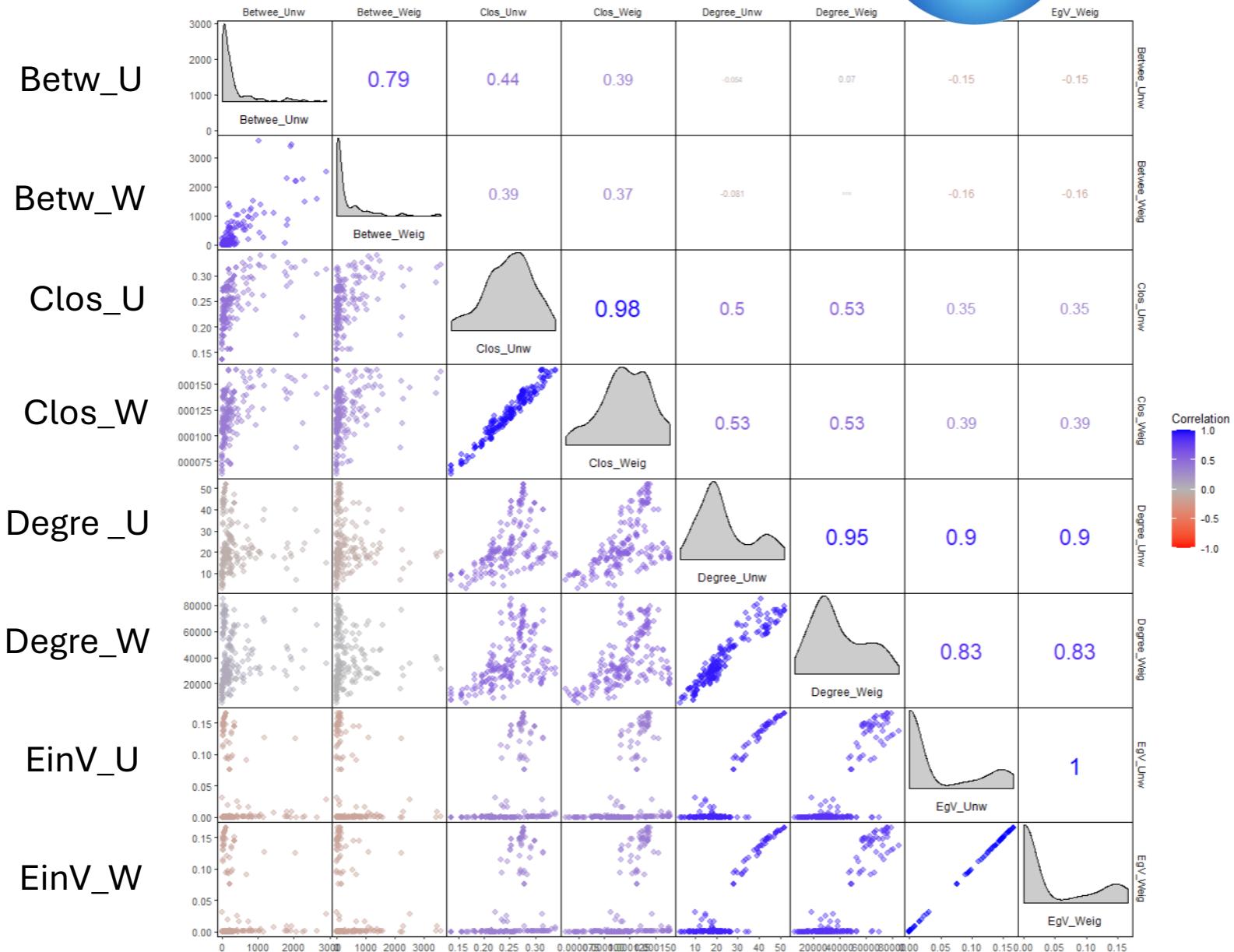
Closeness centrality: It measures how many steps is required to access every other vertex from a given vertex.

-- **Harmonic centrality** for fragmented graphs

Eigenvector centrality scores may be interpreted as the centrality of each node as a proportion to the sum of the centralities of those actors to whom he or she is connected.

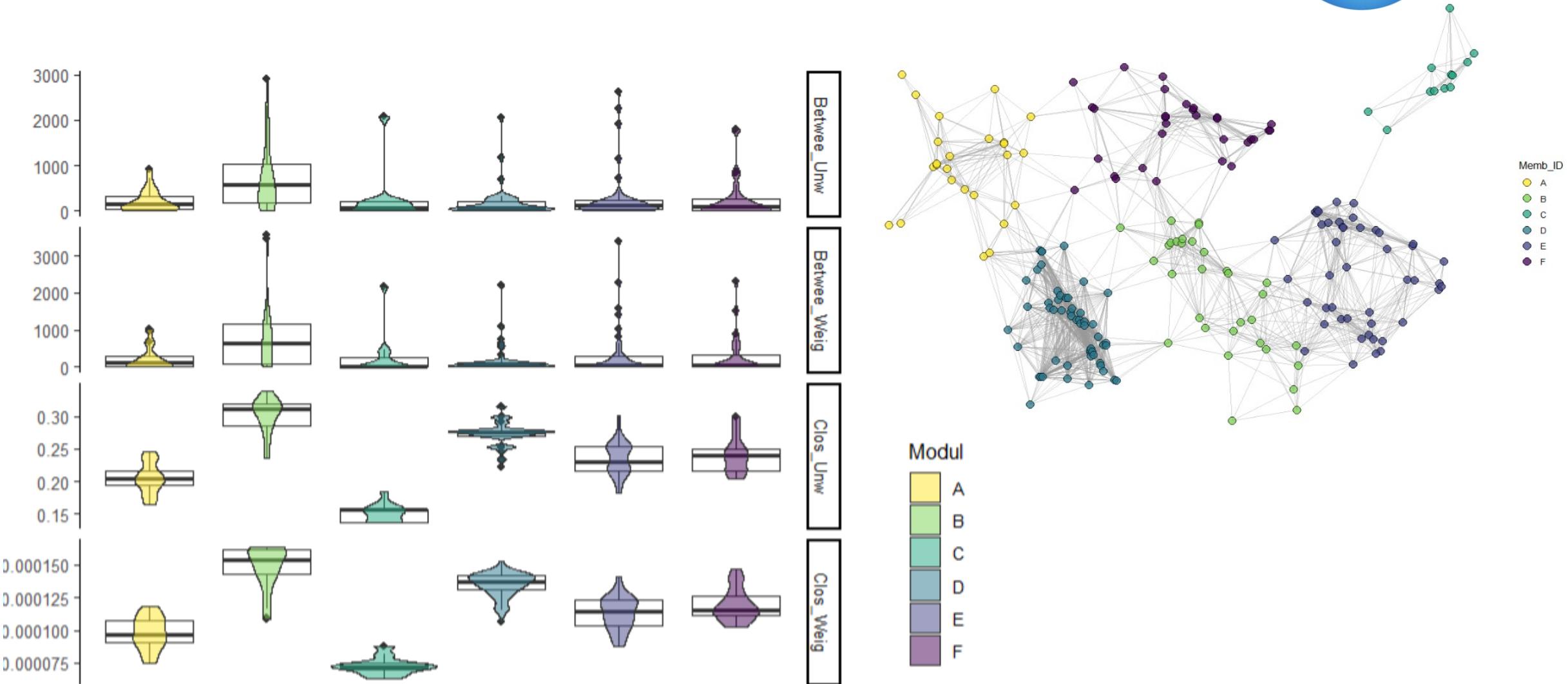


Quantitative metrics - Spatial connectivity

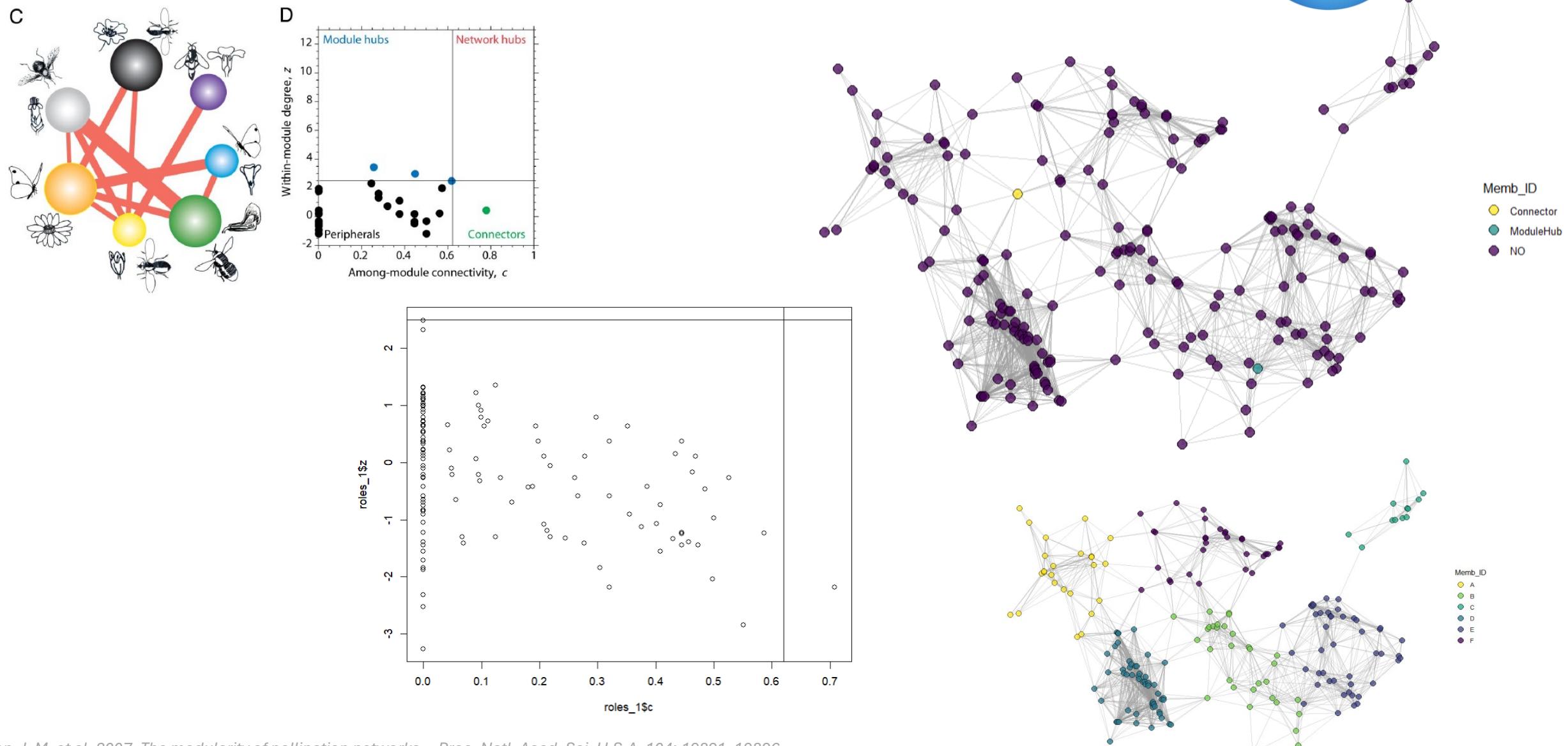


Quantitative metrics - Spatial connectivity

R



Quantitative metrics - Spatial connectivity



Spatial networks and where to find them

Points in a landscape (xy coordinates) are used to built spatial networks.

Network structure

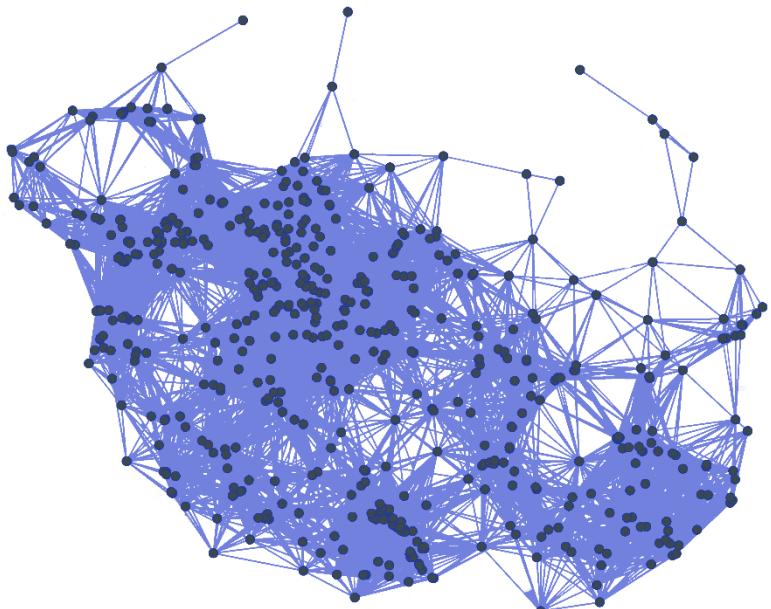
Structural elements

Threshold distance

-*Dispersal ability-*

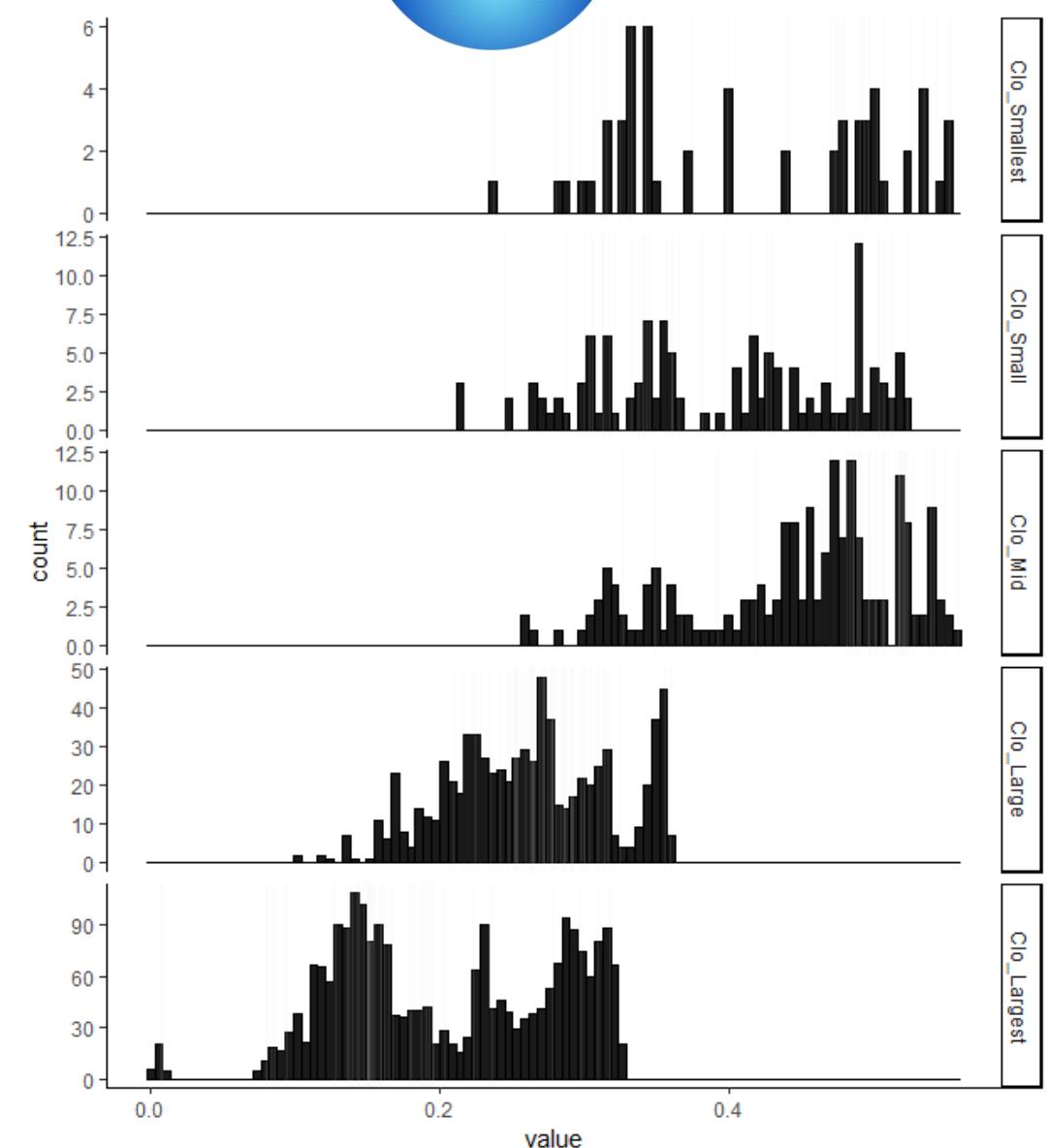
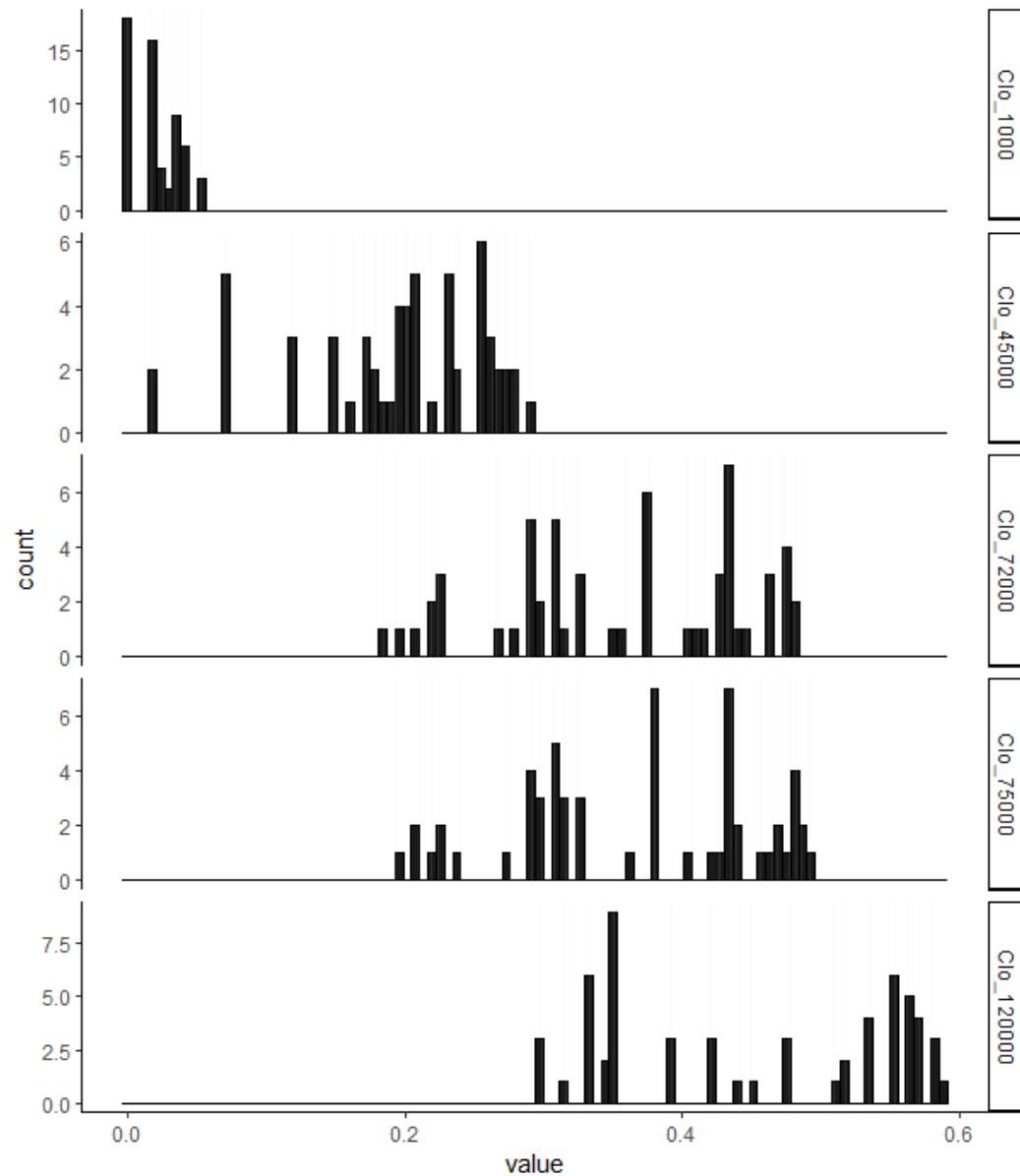
Scale

-*Habitat distribution-*



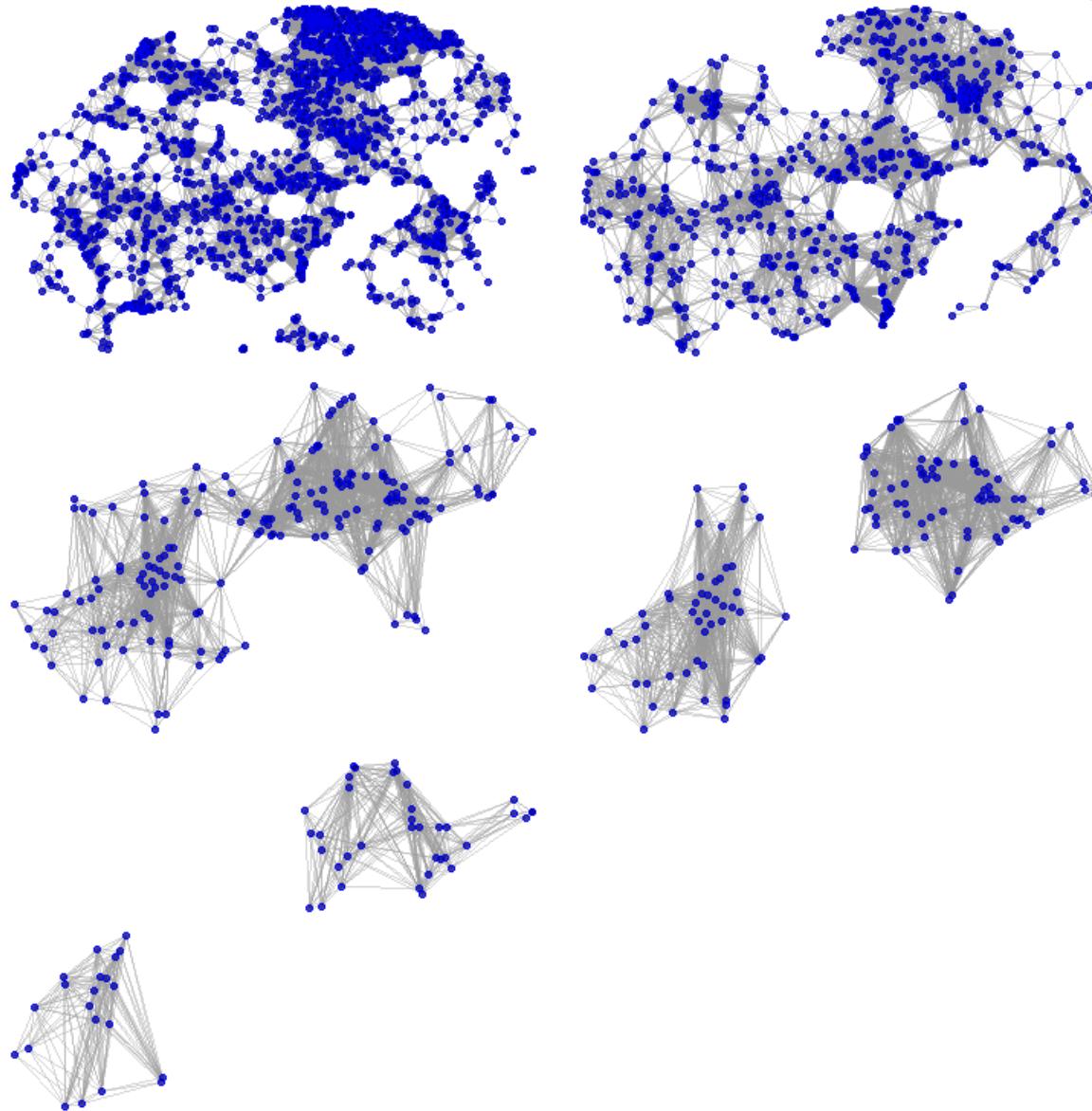
Network_Part2.R

Spatial networks and where to find them



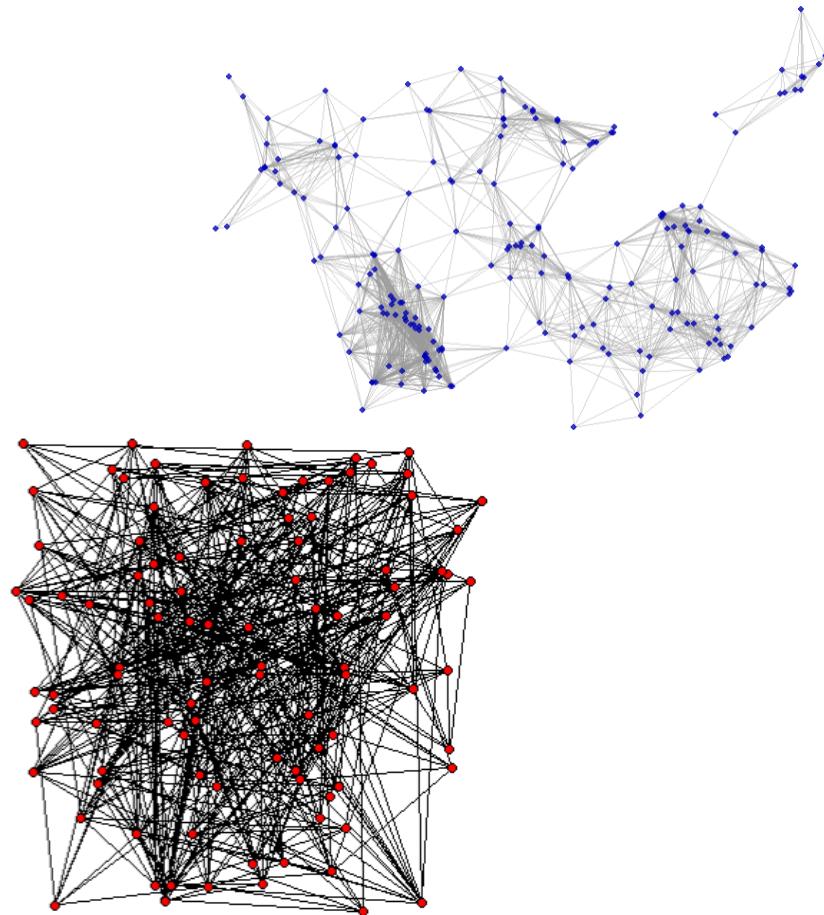
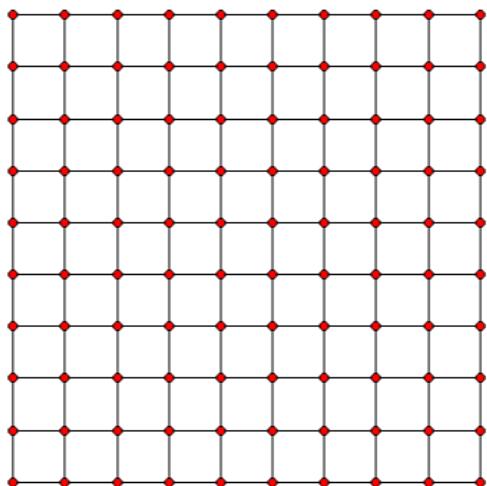
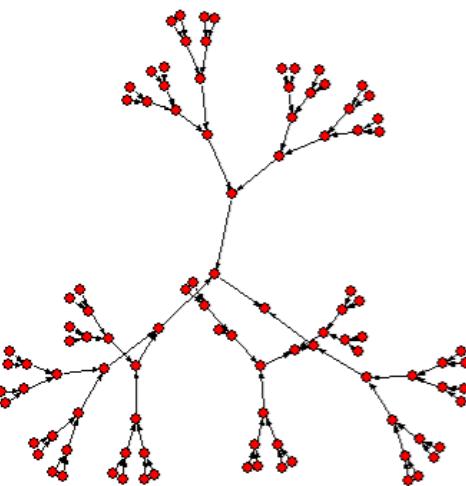
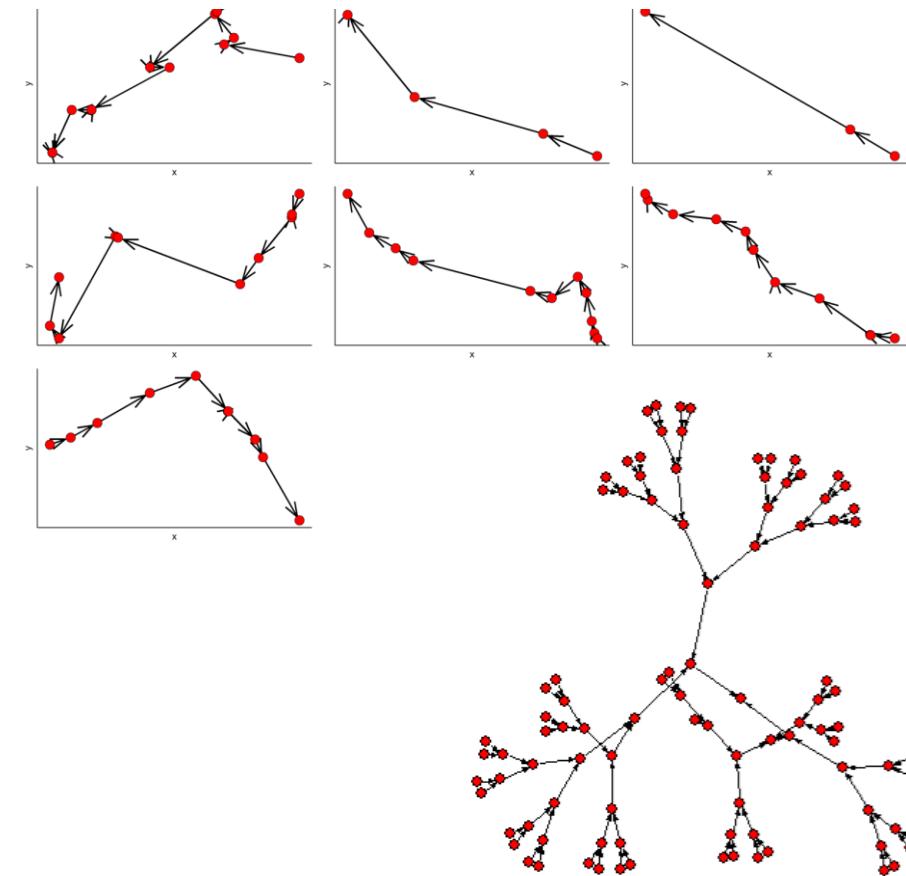
Spatial networks and where to find them

R



Quantitative metrics - Spatial connectivity

R



Quantitative metrics - Spatiotemporal connectivity



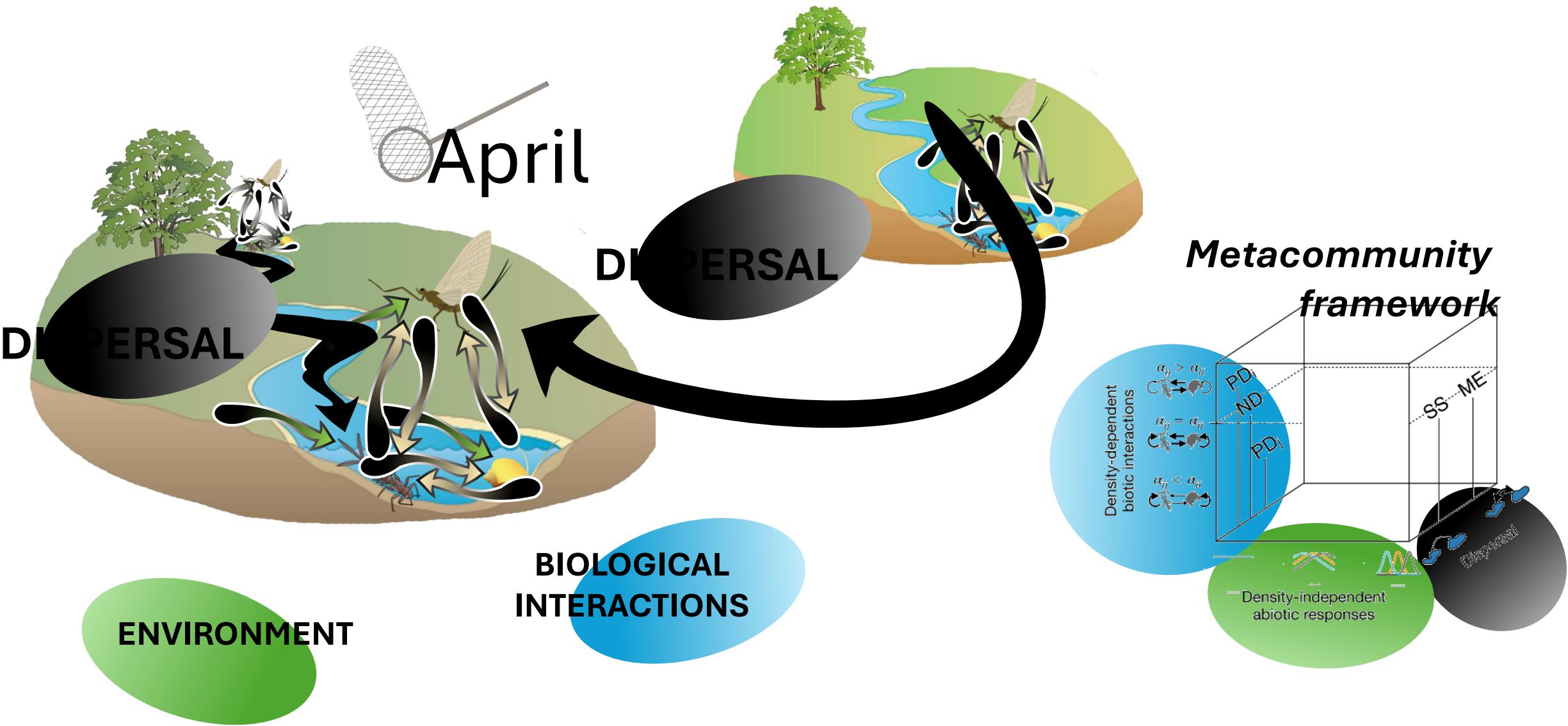
Navigating through space and time: A methodological approach to quantify spatiotemporal connectivity using stream flow data as a case study

Cunillera-Montcusí, D. et al. 2023. Navigating through space and time: A methodological approach to quantify spatiotemporal connectivity using stream flow data as a case study. - Methods in Ecology and Evolution 14: 1780–1795.

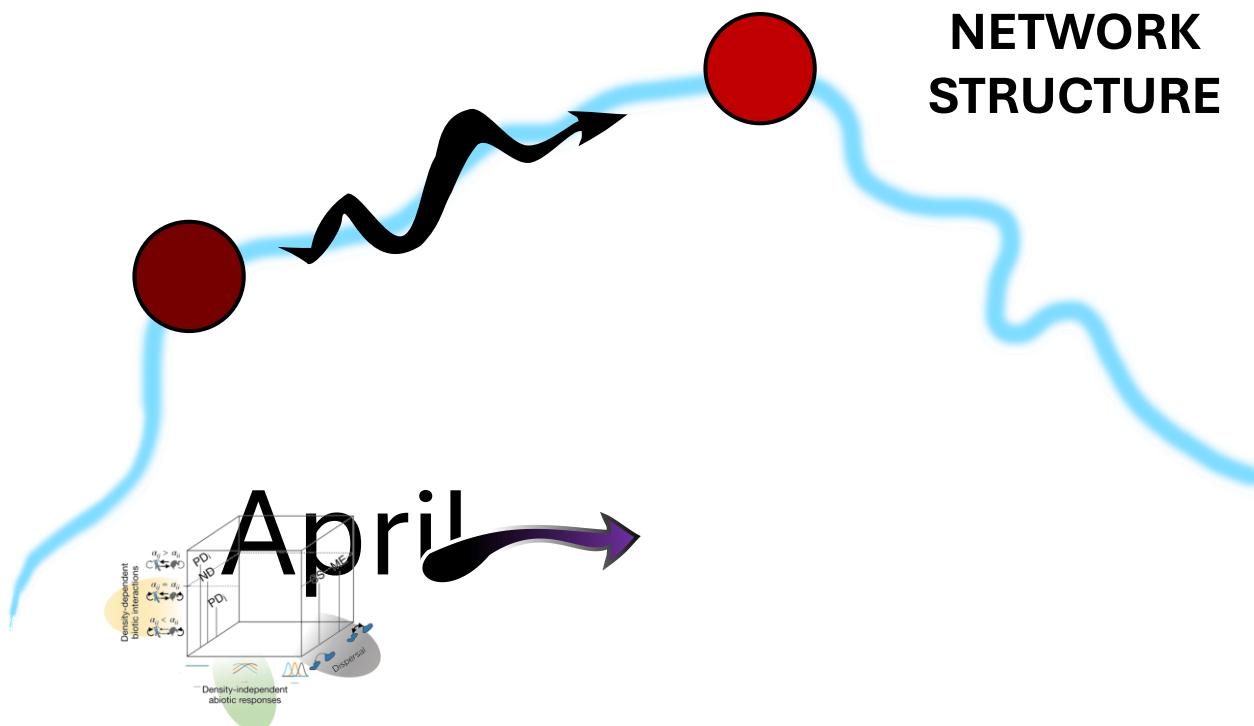


This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 869226

Quantitative metrics - Spatiotemporal connectivity

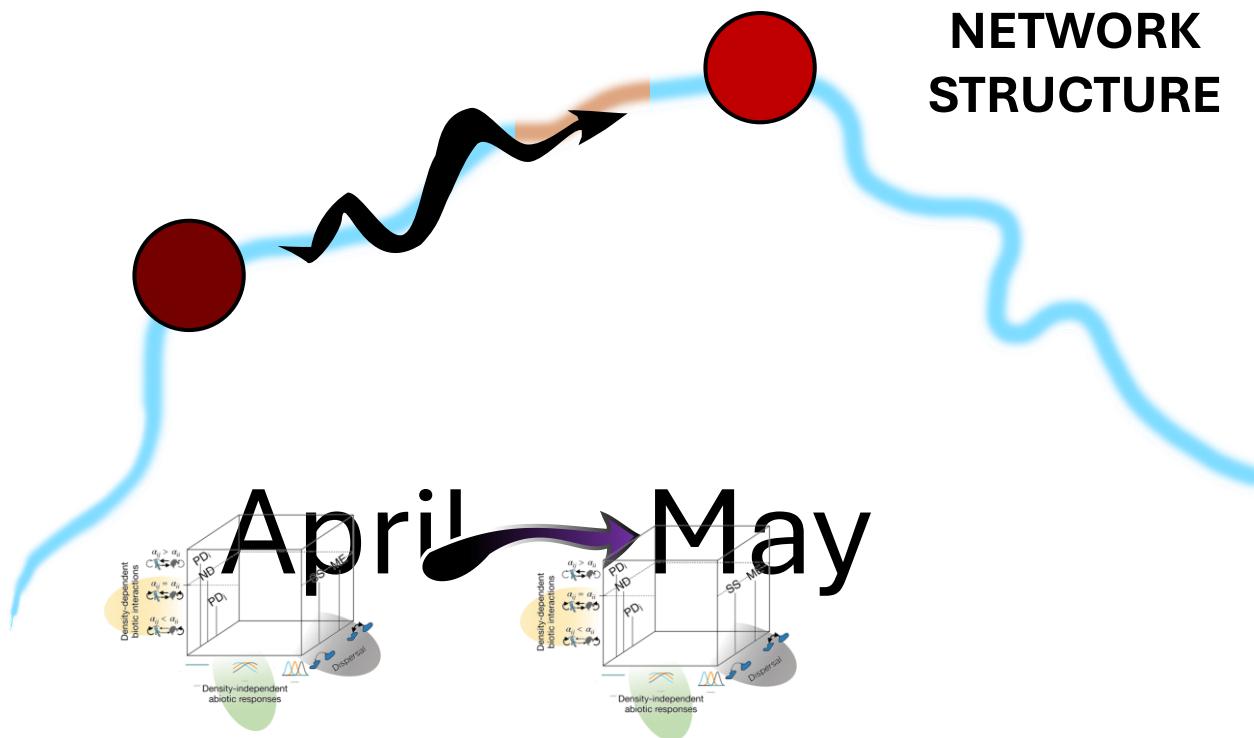


Quantitative metrics - Spatiotemporal connectivity

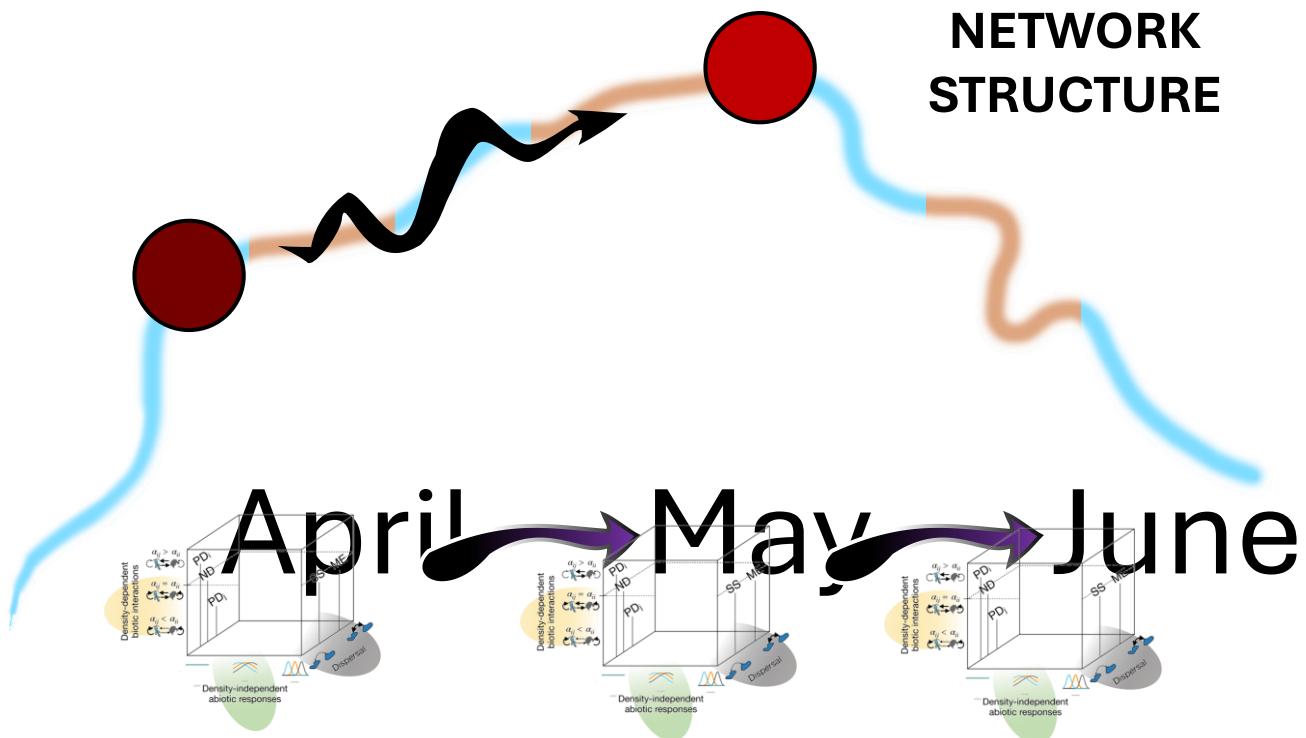
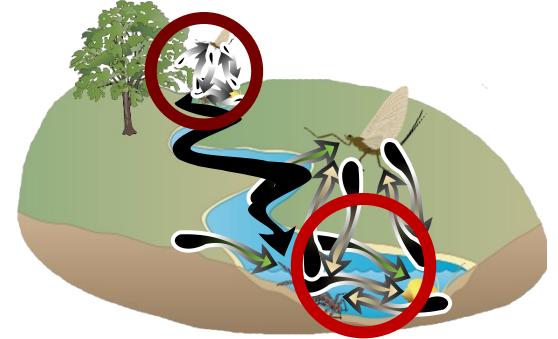


**NETWORK
STRUCTURE**

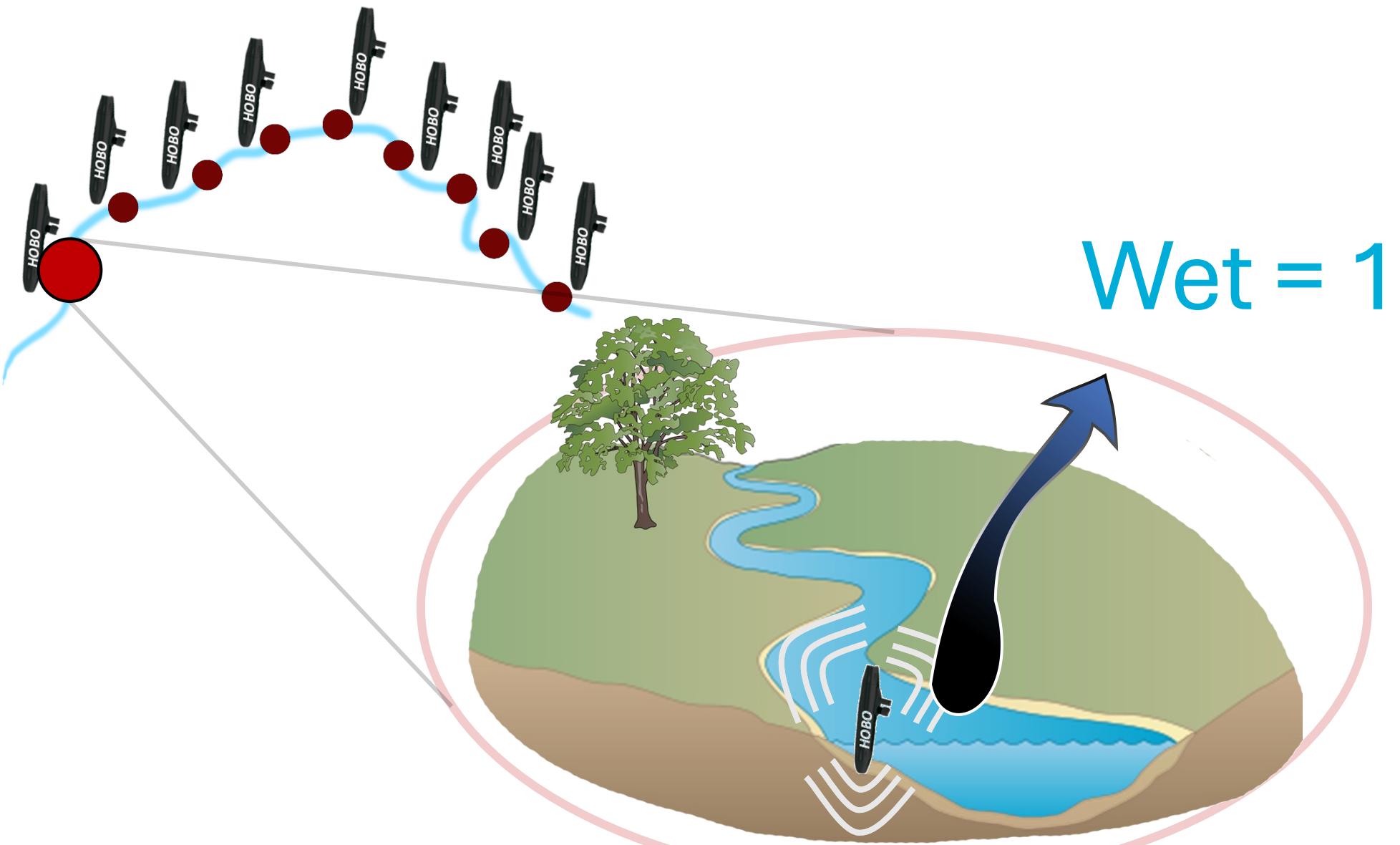
Quantitative metrics - Spatiotemporal connectivity



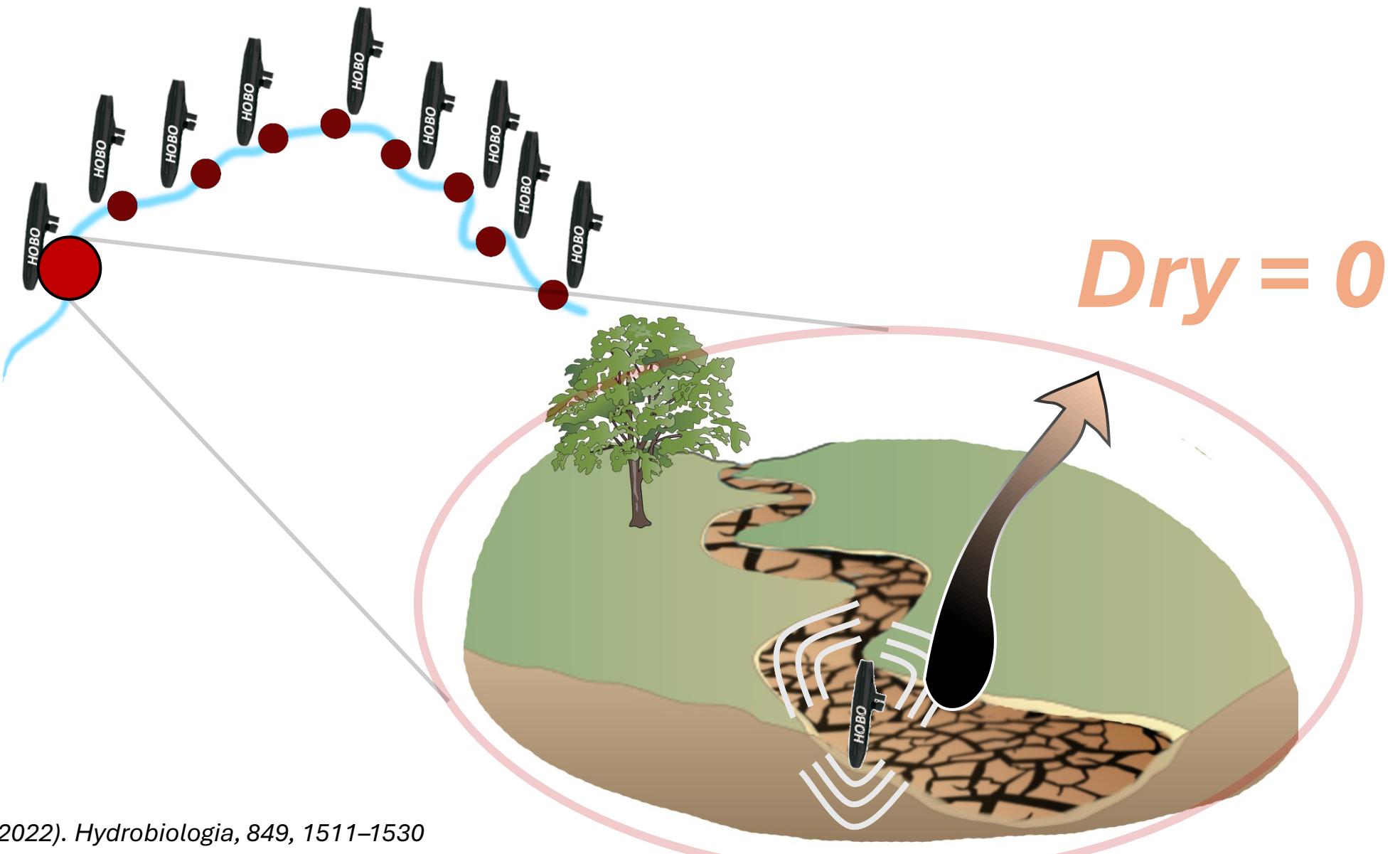
Quantitative metrics - Spatiotemporal connectivity



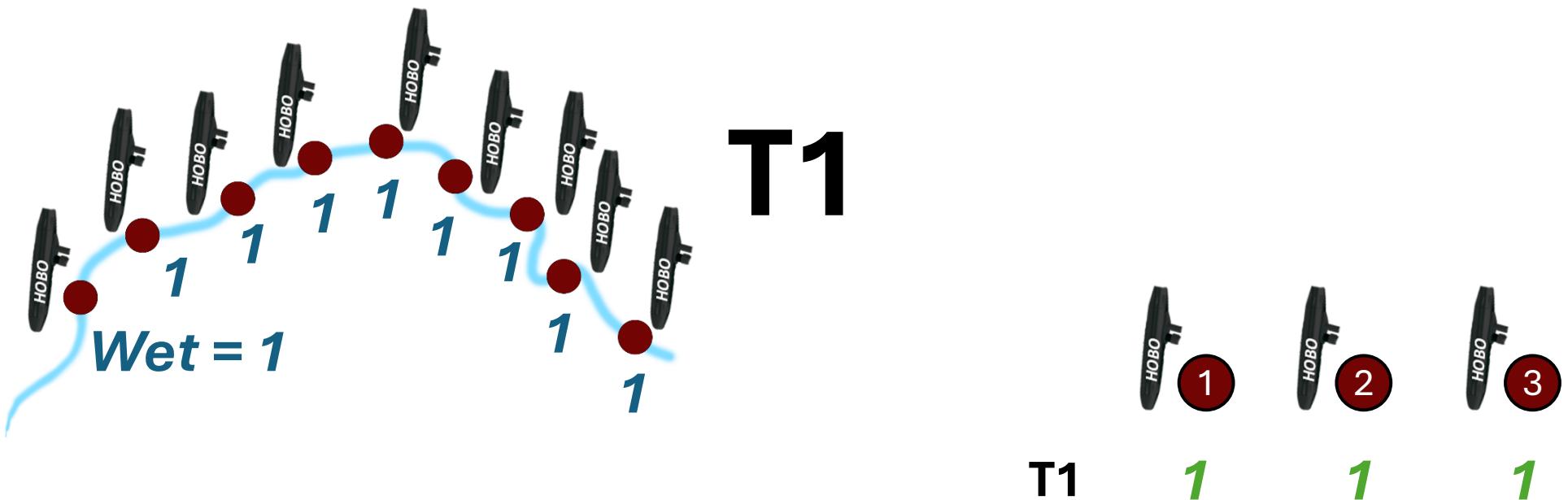
Quantitative metrics - Spatiotemporal connectivity



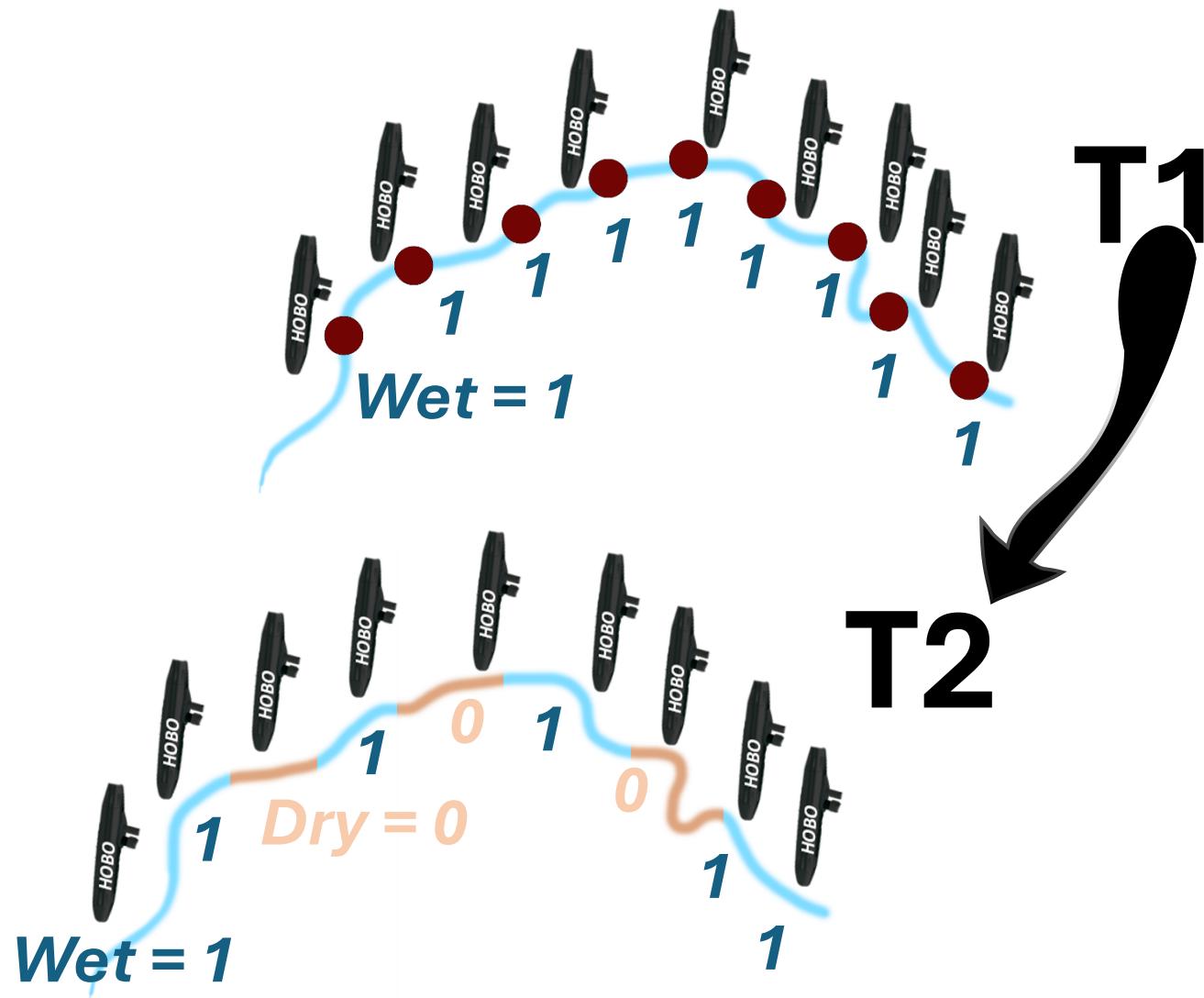
Quantitative metrics - Spatiotemporal connectivity



Quantitative metrics - Spatiotemporal connectivity



Quantitative metrics - Spatiotemporal connectivity



T1	1	1	1
T2	1	1	0
...			

**Permanence
database**

Quantitative metrics - Spatiotemporal connectivity



	1	2	3
T1	1	1	1
T2	1	1	0
T3	0	0	1
T4	1	0	1
...			

FIRST IMPORTANT ELEMENT

FLOW/NO-FLOW
DATABASE

Quantitative metrics - Spatiotemporal connectivity

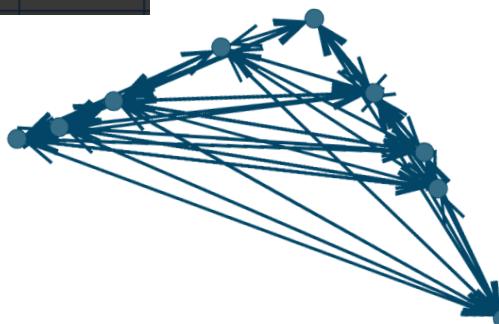
“What is a network? It is just a matrix...”

▲	1	2	3	4	5	6	7
1	0.0000	2673.3805	171.1212	478.8186	495.7922	733.7658	687.7677
2	2673.3805	0.0000	2825.2894	2938.2897	2592.0787	2177.5616	2453.6054
3	171.1212	2825.2894	0.0000	346.5546	485.2156	809.3923	701.5861
4	478.8186	2938.2897	346.5546	0.0000	366.5456	788.6309	571.3328
5	495.7922	2592.0787	485.2156	366.5456	0.0000	424.5368	222.5385
6	733.7658	2177.5616	809.3923	788.6309	424.5368	0.0000	284.9015
7	687.7677	2453.6054	701.5861	571.3328	222.5385	284.9015	0.0000



SECOND IMPORTANT ELEMENT

NETWORK STRUCTURE

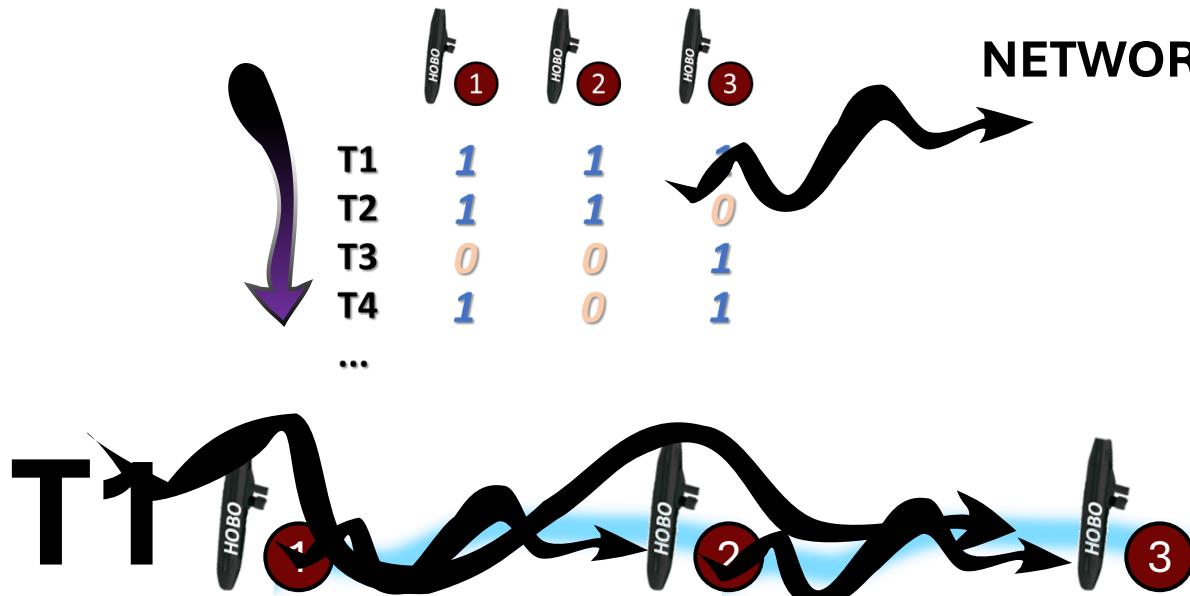


THIRD IMPORTANT ELEMENT

XY
COORDINATES

Quantitative metrics - Spatiotemporal connectivity

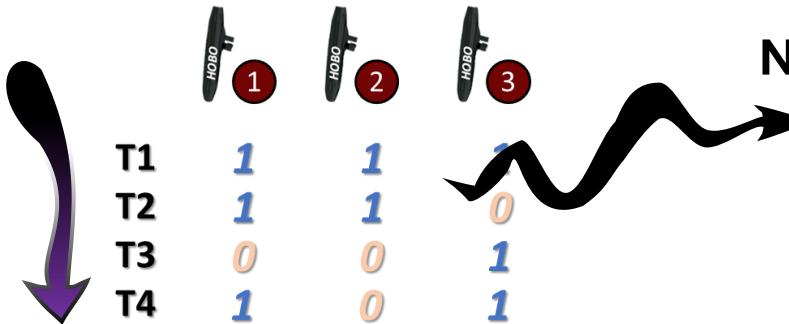
Water permanence database



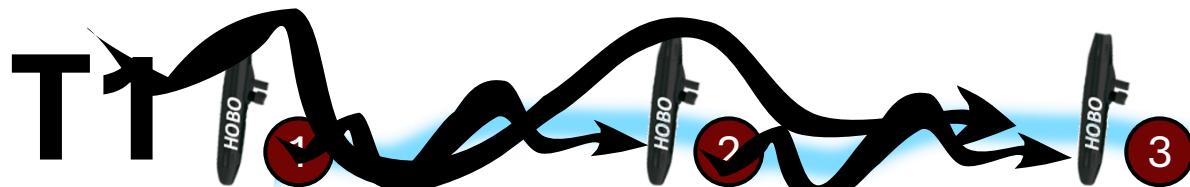
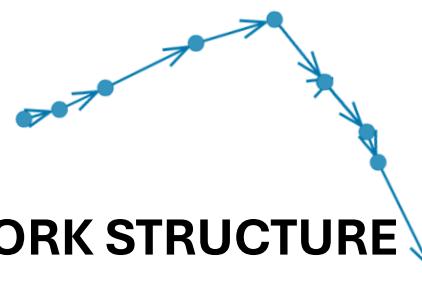
	T1	T1	T1	T2	T2	T2
T1	1	-	1	1		
T1	2	-	-	1		
T1	3			-		
T2	1			-		
T2	2				-	
T2	3					-

Quantitative metrics - Spatiotemporal connectivity

Water permanence database



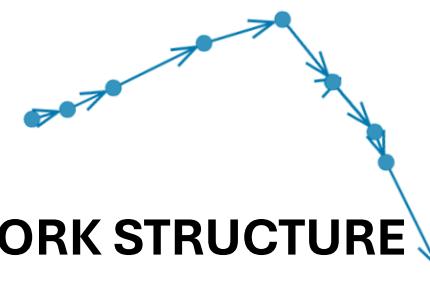
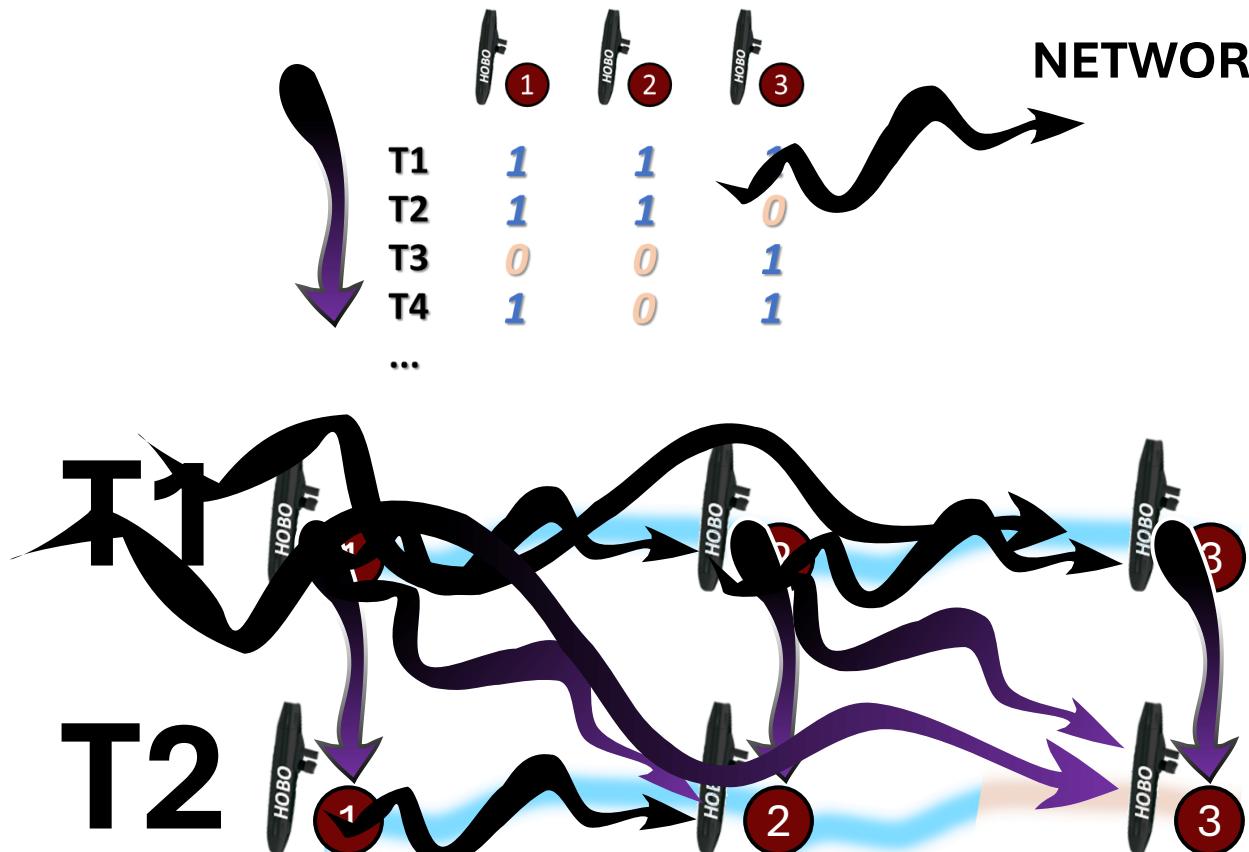
NETWORK STRUCTURE



	T1	T1	T1	T2	T2	T2
T1	1	-	1	1		
T1	2	-	1	1		
T1	3	-	-	-		
T2	1	-	1	0		
T2	2	-	-	-		
T2	3	-	-	0		

Quantitative metrics - Spatiotemporal connectivity

Water permanence database



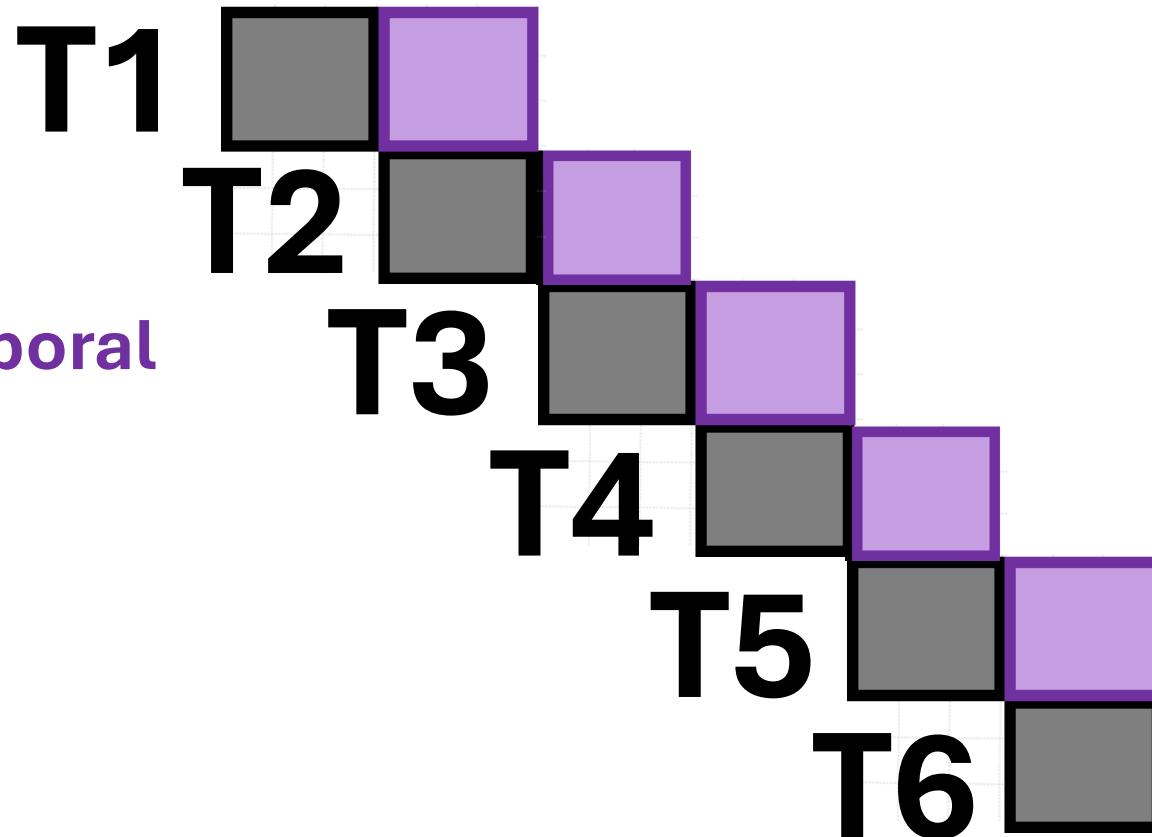
	T1	T1	T1	T2	T2	T2
T1	1	-	1	1	1	1
T1	2	-	-	1	1	1
T1	3	-	-	-	-	0
T2	1	-	-	-	1	0
T2	2	-	-	-	-	0
T2	3	-	-	-	-	-

Quantitative metrics - Spatiotemporal connectivity

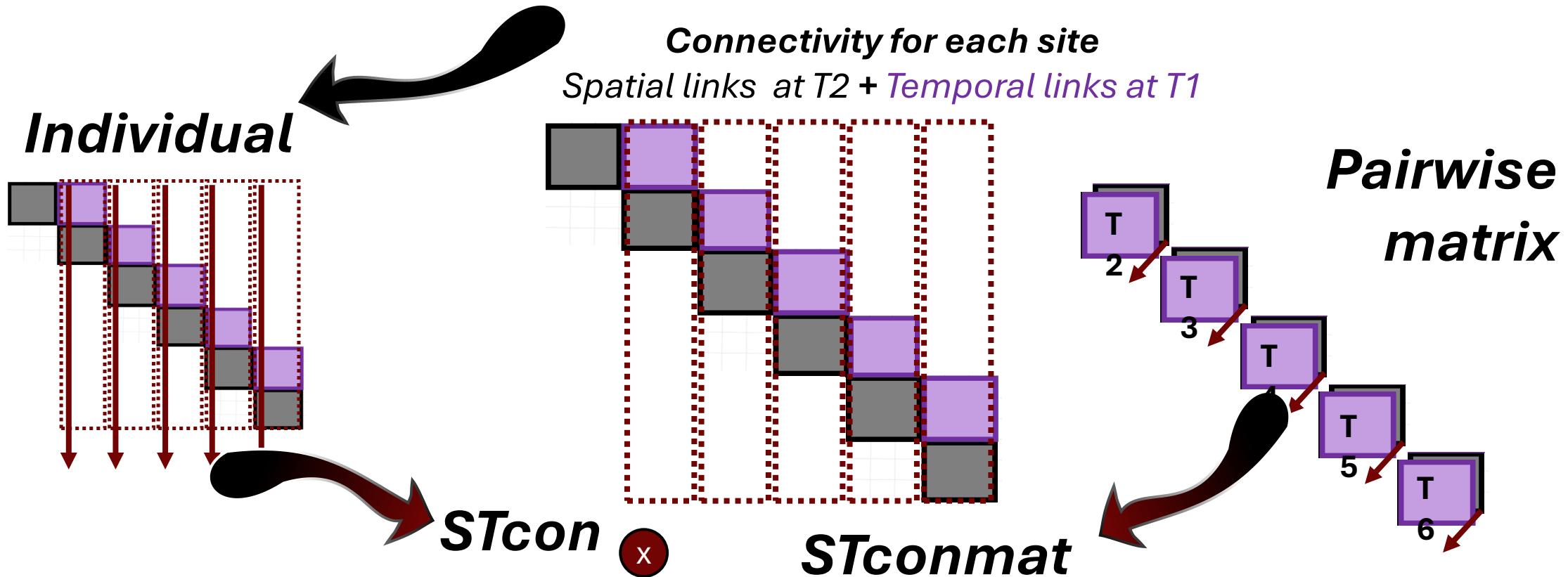
Spatiotemporal matrix

T1	T1	T1	T2	T2	T2	
T1	1	2	3	1	2	3
T1	1	-	1	1	1	1
T1	2	-	1	1	1	1
T1	3	-	-	0	0	0
T2	1	Spatial	-	1	0	0
T2	2	-	-	0	0	0
T2	3	-	-	-	-	-

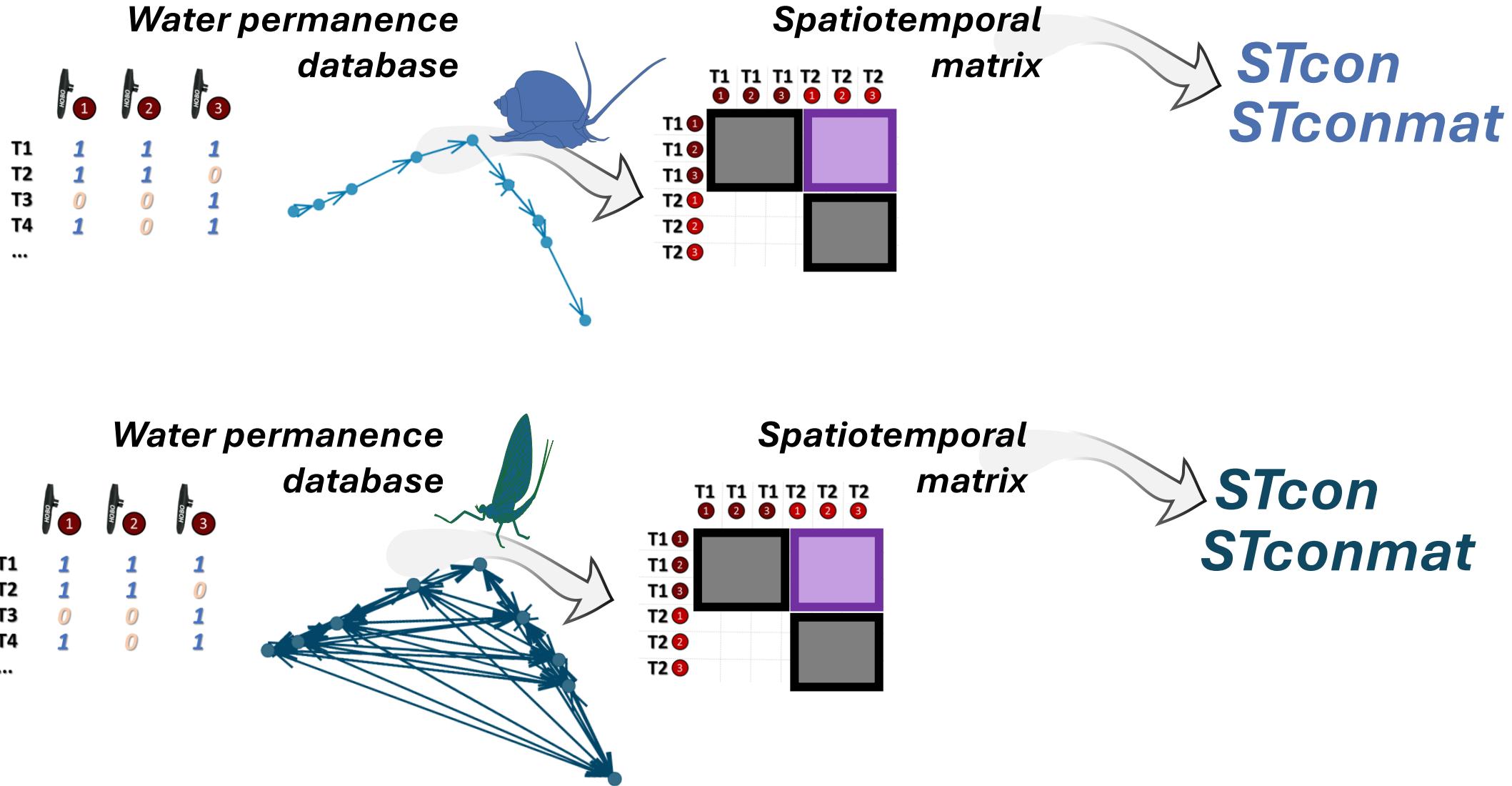
Temporal



Quantitative metrics - Spatiotemporal connectivity



Quantitative metrics - Spatiotemporal connectivity



Quantitative metrics - Spatiotemporal connectivity

Received: 2 August 2022 | Accepted: 15 March 2023

DOI: 10.1111/2041-210X.14105

RESEARCH ARTICLE

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Navigating through space and time: A methodological approach to quantify spatiotemporal connectivity using stream flow data as a case study

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FIRST IMPORTANT ELEMENT

FLOW/NO-FLOW
DATABASE

SECOND IMPORTANT ELEMENT

NETWORK
STRUCTURE

THIRD IMPORTANT ELEMENT

XY
COORDINATES

FOURTH IMPORTANT ELEMENT

DISTANCE
MATRIX

Link weights + Legacy effects + Temporal windows