



UNIVERSITÀ
DEGLI STUDI
DI PADOVA

Topological conditions drive stability in meta-ecosystems

Network Days: bridging micro with macro

Johannes Nauta
October 25, 2024



Quick disclaimer

Open Access

Topological conditions drive stability in meta-ecosystems

Johannes Nauta and Manlio De Domenico

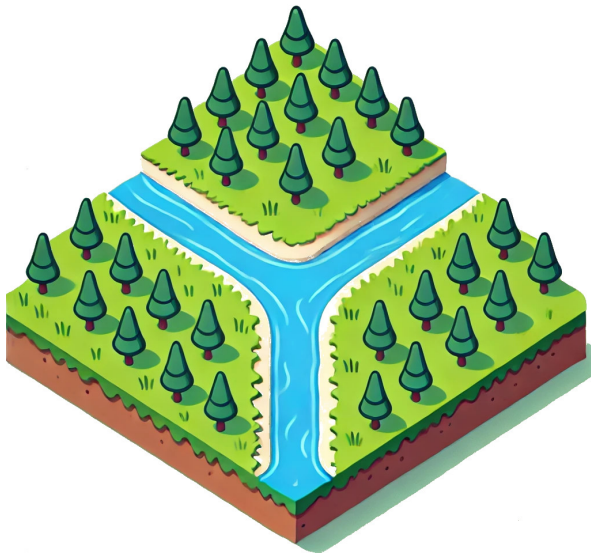
Phys. Rev. Research **6**, 043055 – Published 23 October 2024

<https://doi.org/10.1103/PhysRevResearch.6.043055>



Meta-ecosystems

What are they?



Meta-ecosystems

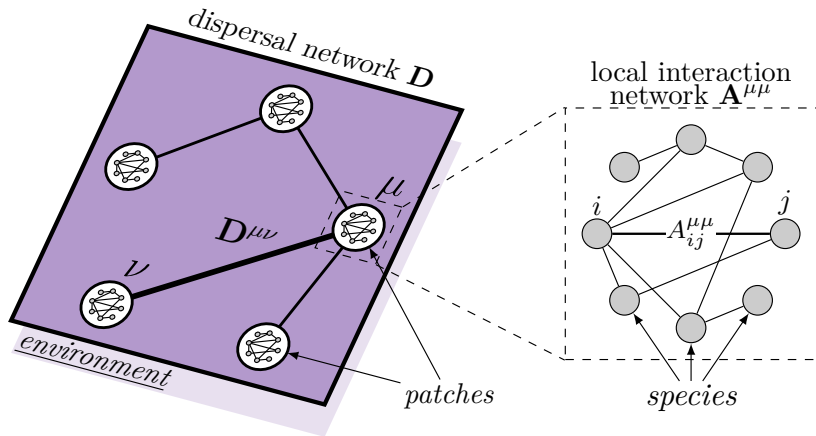
More formally...



CoMuNe lab
COMPLEX MULTILAYER NETWORKS



UNIVERSITÀ
DEGLI STUDI
DI PADOVA



Meta-ecosystems

Even more formally...

S species, M patches

community matrix of the form

$$\mathbf{J} = \mathbf{R} + \mathbf{A} + \mathbf{D}$$

The diagram illustrates the components of the community matrix \mathbf{J} . It shows the equation $\mathbf{J} = \mathbf{R} + \mathbf{A} + \mathbf{D}$. Below the terms, arrows indicate their contributions: 'growth' points to \mathbf{R} , 'interaction' points to \mathbf{A} , and 'dispersal' points to \mathbf{D} . The 'interaction' label is positioned below a horizontal line that spans from the start of the \mathbf{R} term to the start of the \mathbf{D} term.

$$\mathbf{J} = \begin{pmatrix} \begin{matrix} \text{Orange} & \text{Purple} & \text{Purple} & \text{Purple} \\ \text{Purple} & \text{Orange} & \text{Purple} & \text{Purple} \\ \text{Purple} & \text{Purple} & \text{Orange} & \text{Purple} \\ \text{Purple} & \text{Purple} & \text{Purple} & \text{Orange} \end{matrix} & \dots & \begin{matrix} \text{Green} & & & \\ & \text{Green} & & \\ & & \text{Green} & \\ & & & \text{Green} \end{matrix} & \begin{matrix} \text{Green} & & & \\ & \text{Green} & & \\ & & \text{Green} & \\ & & & \text{Green} \end{matrix} \\ \vdots & \begin{matrix} \text{Orange} & \text{Purple} & \text{Purple} & \text{Purple} \\ \text{Purple} & \text{Orange} & \text{Purple} & \text{Purple} \\ \text{Purple} & \text{Purple} & \text{Orange} & \text{Purple} \\ \text{Purple} & \text{Purple} & \text{Purple} & \text{Orange} \end{matrix} & \ddots & \vdots \\ \begin{matrix} \text{Green} & & & \\ & \text{Green} & & \\ & & \text{Green} & \\ & & & \text{Green} \end{matrix} & \dots & \begin{matrix} \text{Orange} & \text{Purple} & \text{Purple} & \text{Purple} \\ \text{Purple} & \text{Orange} & \text{Purple} & \text{Purple} \\ \text{Purple} & \text{Purple} & \text{Orange} & \text{Purple} \\ \text{Purple} & \text{Purple} & \text{Purple} & \text{Orange} \end{matrix} \end{pmatrix}$$

$\rightarrow J_{ii}^{\mu\mu} = R_{ii}^{\mu\mu} + A_{ii}^{\mu\mu} + D_{ii}^{\mu\mu}$
 $\rightarrow J_{ij}^{\mu\mu} = A_{ij}^{\mu\mu}$
 $\rightarrow J_{ii}^{\mu\nu} = D_{ii}^{\mu\nu}$

Stability

Consider **linear stability**

→ **eigenvalues**

$$\lambda_1 = \max_i \operatorname{Re} \lambda_i$$

stability criterion

$$\operatorname{Re} \lambda_1 < 0$$

for $M = 1$, **May** criterion
[May (1972)]

$$\sigma \sqrt{cS} < b - r$$

self-interaction growth

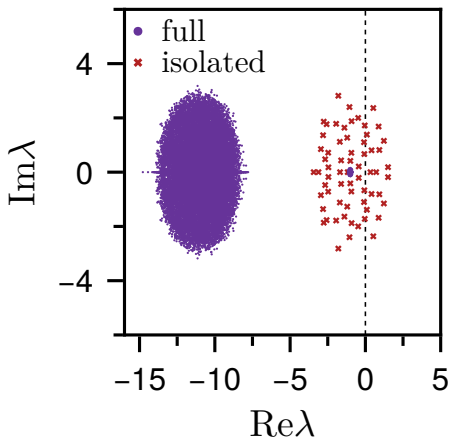
for M , large dispersal rate γ
[Gravel, Massol, and Leibold (2016)].

$$\sigma \sqrt{cS/M} < b - r$$

#patches

Results

Isolated nodes and connected components



assume **connected** networks

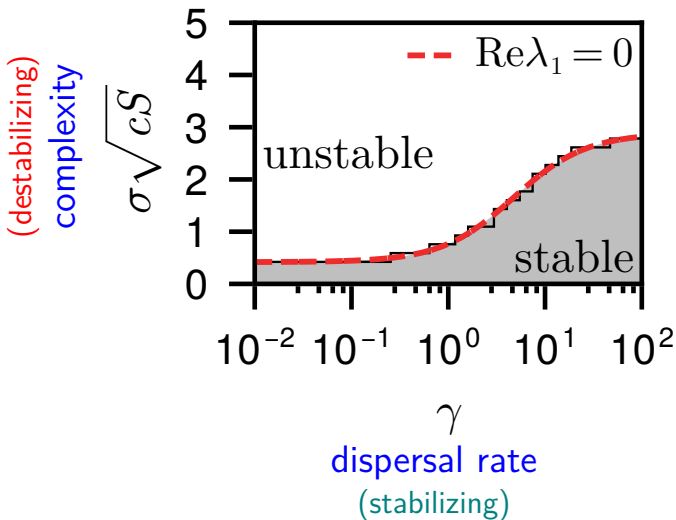
(Tishby et al. 2019)

Results

Dispersal networks and stability: dispersal rate γ

(Poisson deg. distribution)

$$\langle k \rangle = 3$$

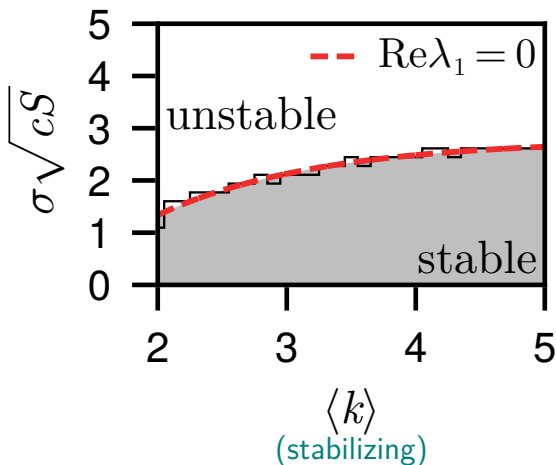


Results

Dispersal networks and stability: edge density $\langle k \rangle$

(Poisson deg. distribution)

$$\gamma = 10$$

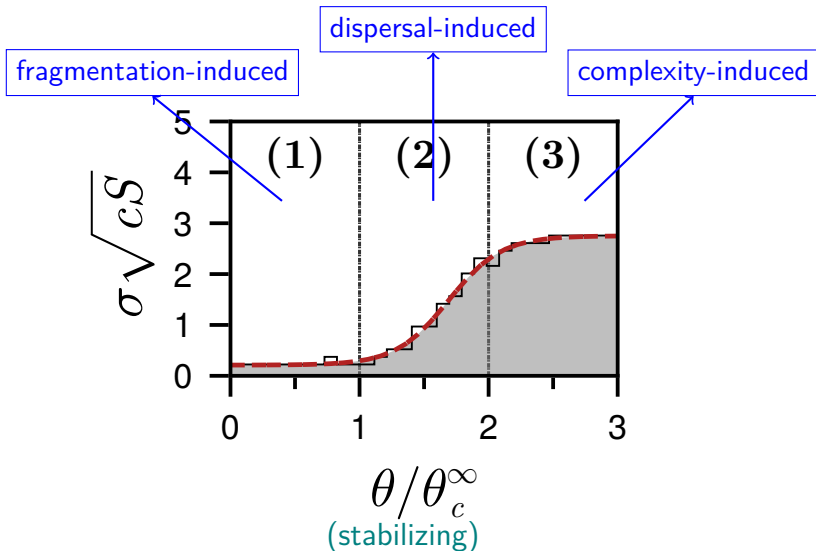


Results

Dispersal networks and stability: fragmentation-induced stability

random geometric graphs

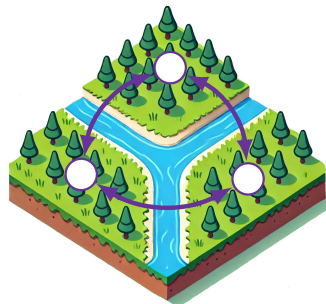
edge if distance $< \theta$





Meta-ecosystems and stability

- 1 species interactions matter!
- 2 network topology matters!
- 3 dispersal matters!
- 4 edge density fosters stability
- 5 fragmentation fosters instability



THANK YOU FOR YOUR ATTENTION

Johannes Nauta



Manlio De Domenico



Nauta, Johannes and Manlio De Domenico, 2024,
“Topological Conditions Drive Stability in Meta-Ecosystems,” *Phys. Rev. Res.*,
DOI: 10.1103/PhysRevResearch.6.043055