Network stability in co-evolved spatially-explicit model ecological communities

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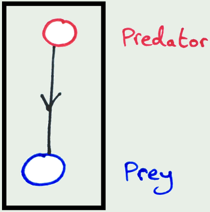
Population models: introduction

We may be familiar with two-species models in population dynamics:

Predator-prey model

Predator: $$\frac{\mathrm{d}y}{\mathrm{d}t} = \lambda g(x,y)y - dy$$

Prey: $$\frac{\mathrm{d}x}{\mathrm{d}t} = f(x)x - g(x,y)y$$



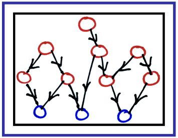
e.g. with logistic prey growth and Lotka-Volterra predation. . .

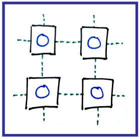
Predator: $$\frac{\mathrm{d}y}{\mathrm{d}t} = \lambda cxy - dy$$

Prey: $$\frac{\mathrm{d}x}{\mathrm{d}t} = rx(1-x) - cxy$$

Extending population dynamics models

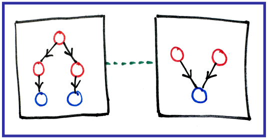
Community models



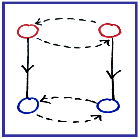


Meta-population models

Eco-evolutionary models



Meta-community models



Eco-Evolutionary Meta-Community Models

Eco-evolutionary meta-community models

Combine all three features:

- Mutation and evolution
- Multiple species
- Spatial structure

Conceptual challenges:

- How to define species (one vs. multiple traits)?
- Dynamically determine feeding relationships (based on traits)?
- Population dynamics (reproduction, functional response)?
- Network structure of the spatial landscape?
- Dispersal mechanism (diffusion, probabilistic, adaptive)?

One example of eco-evolutionary meta-community model

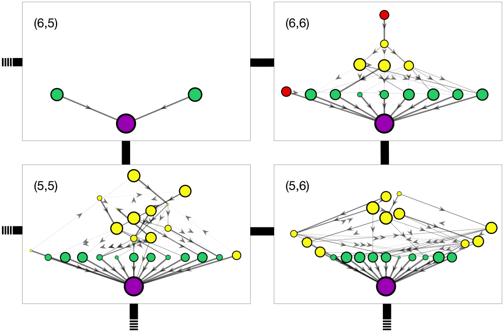
Species are defined by a bodysize and discrete set of traits that score against other traits. Begin with one species, and resources in each patch on a square spatial lattice. Simulation occurs in nested loops:

- **Evolutionary loop:** choose a parent species and introduce mutant (with 9/10 of parent's traits and similar bodysize).
    - **Ecological loop:** feeding, reproduction, death, dispersal.
        - **Foraging loop:** local populations adaptively decide feeding strategies (avoid competition, prefer populous prey).

Developed from the Webworld foodweb model (*Drossel et al.*, 2001).

Assembled meta-communities

Simulating evolutionary assembly of an ecological meta-community in space from first species.



For each local population N:

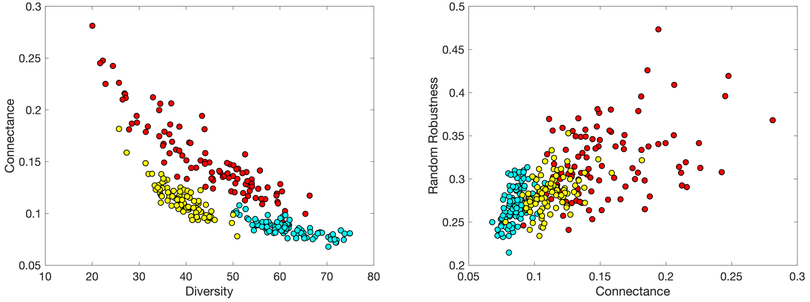
$$\frac{\mathrm{d}N}{\mathrm{d}t} = F - M - P + \mu_i - \mu_e$$

where:

F = gains due to feeding;
M = natural mortality;
P = loss due to predation;
μ_e, μ_i = em/immigration.

Four local communities of a 6×6 meta-communities.

Foodweb structure and stability



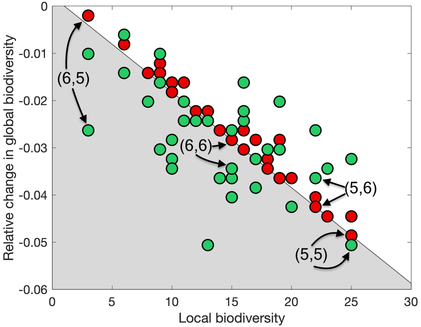
(a) Structure

(b) Robustness

(a) **Structure:** How do realised feeding links L scale with species S? Connectance $(L/(S(S-1))$ decreases with diversity.

(b) **Stability:** Community robustness increases with connectance.

Applications: resilience to climate change, species extinctions and invasions:



Effect of displacement vs. elimination in a 6×6 meta-community of 458 species.

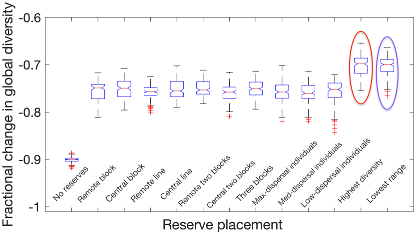
Displacement to neighbouring patches *can be more damaging* than their extinction.
(For example: patch $(6, 5)$)

In a similar experiment (7000 species in 15 M-C's):

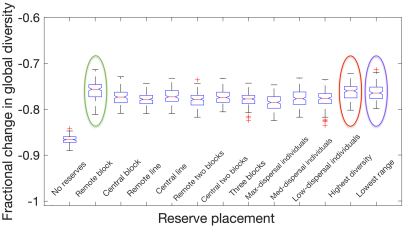
- Each species is deleted, (max loss 2.1%).
- Then re-introduced to *all* patches (max loss 12%).

Habitat loss and nature reserves - effect on biodiversity

Patches subjected to repeated random disturbances, except for 6 (of 36) designated as nature reserves. What is the best choice?



(c) Elimination

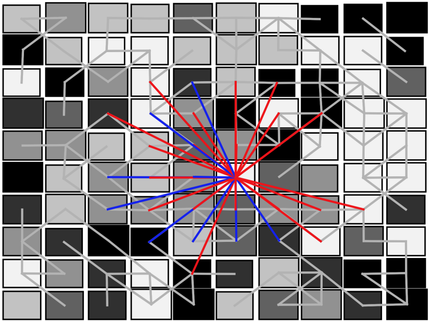


(d) Displacement

- Reliable to select patches with the greatest biodiversity or to protect the rarest species.
- If disturbed populations are displaced (rather than eliminated), isolating large, remote areas *from invasion* also effective.

New EEMCM development

New design emphasises spatial structure and habitat distribution.



- Simplified trait-space with specialist-generalist trade-off;
- Variable species perceptions of habitat (currently feeding; would feed on live prey);
- Complex spatial mosaic of discrete habitat types.

Future research focus on impact of spatiotemporal variation and perturbations in environment.

References

- **Original model:** Drossel, B., Higgs, P. G., & McKane, A. J. (2001). The influence of predator–prey population dynamics on the long-term evolution of food web structure. *Journal of Theoretical Biology*, 208(1), 91-107.

- **Recent publication of work presented:** Abernethy, G. M. (2022). Perturbation responses in co-evolved model meta-communities. *Ecology and Evolution*, 12(11), e9534.

- **Review:** Gross et al. (2020). Modern models of trophic meta-communities. *Philosophical transactions of the Royal Society B*, 375: 20190455.