Post-doc project: A complex food-web theory of stability against perturbation

Alain Danet

December 16, 2022

Contents

1 Rationale

1.1 Perturbation ecology

- Multiple perturbation affect simultaneously mortality rates of species
- We can assume that those multiple stressors can be summed into environmental stochasticity

1.2 Correlation among pertubations

- Depending on the nature of the stressors and niche of species, we can expect different scenarios
- Perturbations such as fishing will affect primarily some species (e.g. top-trophic level)
- Perturbations in habitat quality will affect species more globally (however some might benefit).
- Perturbation in temperature will affect differently species according to their thermal niche

All the above scenarios can result in quite complex combinations of situation that can be tricky to generalize. Another way to tackle this situation is to test more general theories of ecological communities.

I see four different scenarios of perturbation correlations among species that I name as the following homogeneous, null, guilds, hidden niches. The homogeneous scenario considers that all species are affected in the same way, which would correspond to a general perturbation such as a general improvement/depletion of habitat quality. The null scenario considers that all species respond randomly to stress, i.e. they do not share perturbation, i.e. their perturbations are uncorrelated. The guilds scenario assumes that intra-guild perturbations are positively correlated and that interguild perturbations are not correlated, it is a scenario that assumes that species sharing the same trophic level share the same niche, i.e. there is no intraguild response diversity. The hidden niche scenario comes the theory of the same name(Scheffer and Nes 2006; Barabás et al. 2013; Martínez-Blancas, Belaustegui, and Martorell n.d.). It assumes that cluster of species having similar traits (here food-web trophic position) would have hidden niche dimensions that stabilize their coexistence, such as species in the same guild will have response diversity (portfolio effect), anti-correlated perturbations.

While all the above scenario can seem abstract at a first glance, it is possible to draw realistic situations where they can apply.

The homogeneous scenario can apply in situations where stressors select for homogeneous response to stressors as for example, as it might be the case in altered environments where we can end up with the same functions (i.e. the same food-web) but where the diversity of other niche dimensions have been shrunken (lost of diversity hypothesis). The guild scenario supposes a full niche conservatism where species on the same feeding guild are likely to share the same evolutionary history and such their respond in the same way to environmental perturbation. The hidden niche is the reverse of the former, intraguild species are anti-correlated, such as there is maximal response diversity (insurance hypothesis), which is the mechanism by which biodiversity is thought to maintain long-term stability of ecosystem functions.

While response diversity has been well studied in small food-web modules and competitive communities, it has been overlooked in more complex food-webs. The complex relationships among species across food-web might dampens (compensate), propagate or just scale with food-chain and small food-web modules.

1.3 Stability in food-webs

The question at 1bn pounds is "what is driving stability?", i.e. the propagation of perturbations across food-webs. Early studies focused on the effect of removing one species either by looking at the topology (e.g., Dunne, Williams, and Martinez 2002) or dynamic (Stouffer and Bascompte 2011). In that sense, it would be interesting to see if environmental stochasticity predicts the same pattern that species extinction (i.e. pertubation for one species only).

The big other ingredient of food-web stability is the strength of species interactions, as demonstrated by previous studies (McCann, Hastings, and Huxel 1998; Brose, Williams, and Martinez 2006). McCann, Hastings, and Huxel (1998) showed that food-web having strong interactions can persist if the strong interactions are coupled with weak ones. Interestingly, a strong interaction needs to be coupled in two ways, by a feeding and a competitive interactions. Brose, Williams, and Martinez (2006) showed the strength of interactions are driven by body size, such larger body sized animals produce lower interaction strengths (because of their lower metabolic rates).

Interestingly, I see two schools on the definition of interaction strengths in the Bioenergetic model. McCann defines it by modulating consumer preference (ω) such as $I_{ki} = \omega_{ik} x_i y_i / B_{0i}$ while Brose, Williams, and Martinez (2006) modules interaction strength by modulating predator/prey mass ratios (Z) such as Z decrease the metabolism of predators relative to prey (i.e. x_i and y_i). Thus increasing Z decreases I_{ki}. A common feature of both approaches is that they both consider that the strength of interactions decrease as the trophic level increases.

A main difference between Brose and McCann approaches is that the Brose approach of modulating interactions also modulates metabolic losses ($x_i y_i B_i$). Then the approach of McCann has the advantage to only change feeding rates but it is rather phenomenological modelling while Brose approach is more mechanistic (fully metabolic) but it changes two things at the same time.

Although in complex food-webs, Brose method can create strong asymetry in interaction strength by coupling specialists and generalists, as they respectively generate strong and weak interactions. Such mechanism is triggered by the fact that consumer preference is equally shared among preys ($\omega_{ki} = 1 \ \sum_k 1$, such as $\omega_{ki} = 1$ or .1 for a consumer having one prey or 10 preys).

1.3.1 Stability in small modules

- McCann (2000), McCann, Hastings, and Huxel (1998), Vasseur and Fox (2007), Ripa and Ives (2003)

1.3.2 Stability in food-chains

- Barbier and Loreau (2019), Shanafelt and Loreau (2018)

1.3.3 Stability in complex food-web

- Thébault and Fontaine (2010), Brose, Williams, and Martinez (2006)

1.4 Stochasticity in food-webs

Vasseur and Fox (2007) found that Stochasticity and response diversity can stabilize food-web in a McCann model with strong asymetry in species interactions. Is it valid also with a Brose model without this asymetry? Is it also valid with different functional responses?

2 Research questions

2.1 Response diversity

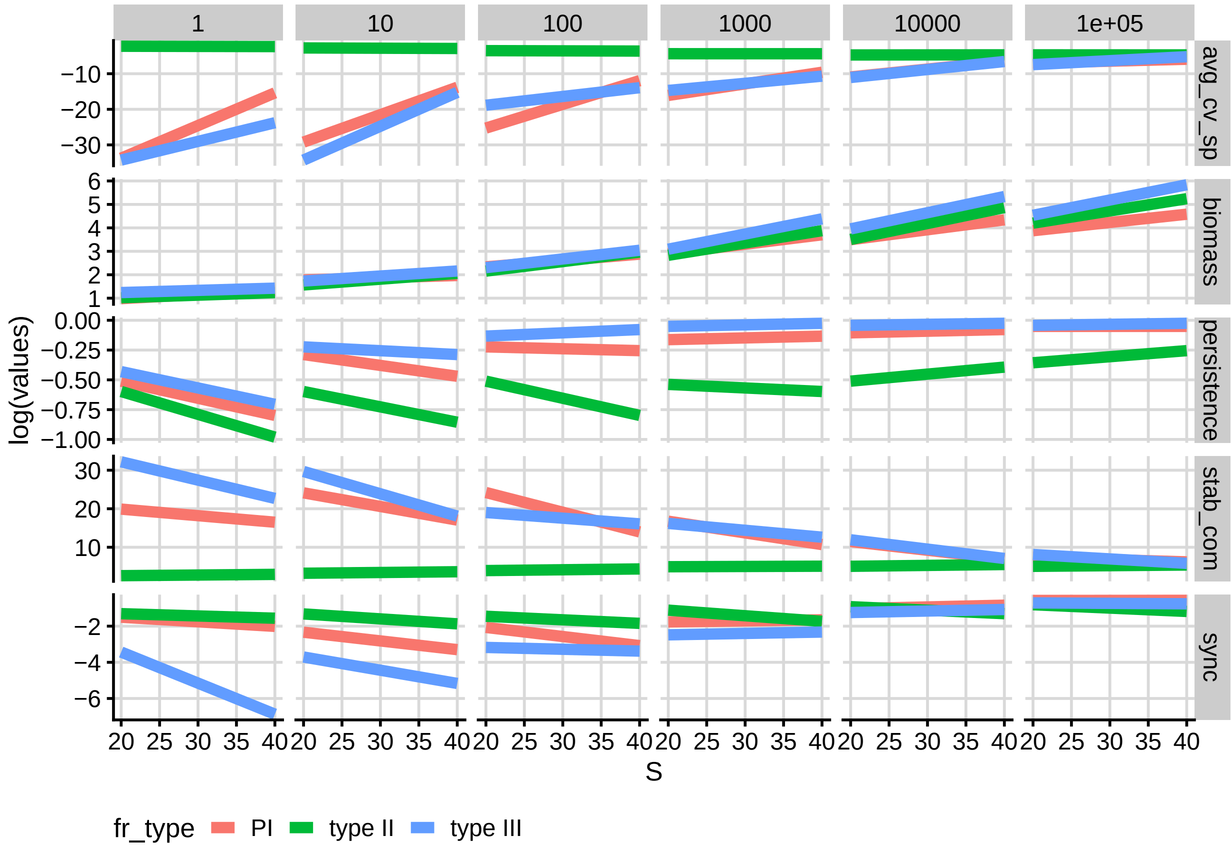
- How does response diversity drive food-web stability?
- How does response diversity affect coupling between predator and preys?
- How does response diversity effect on stability is modulated by interaction strength distribution?

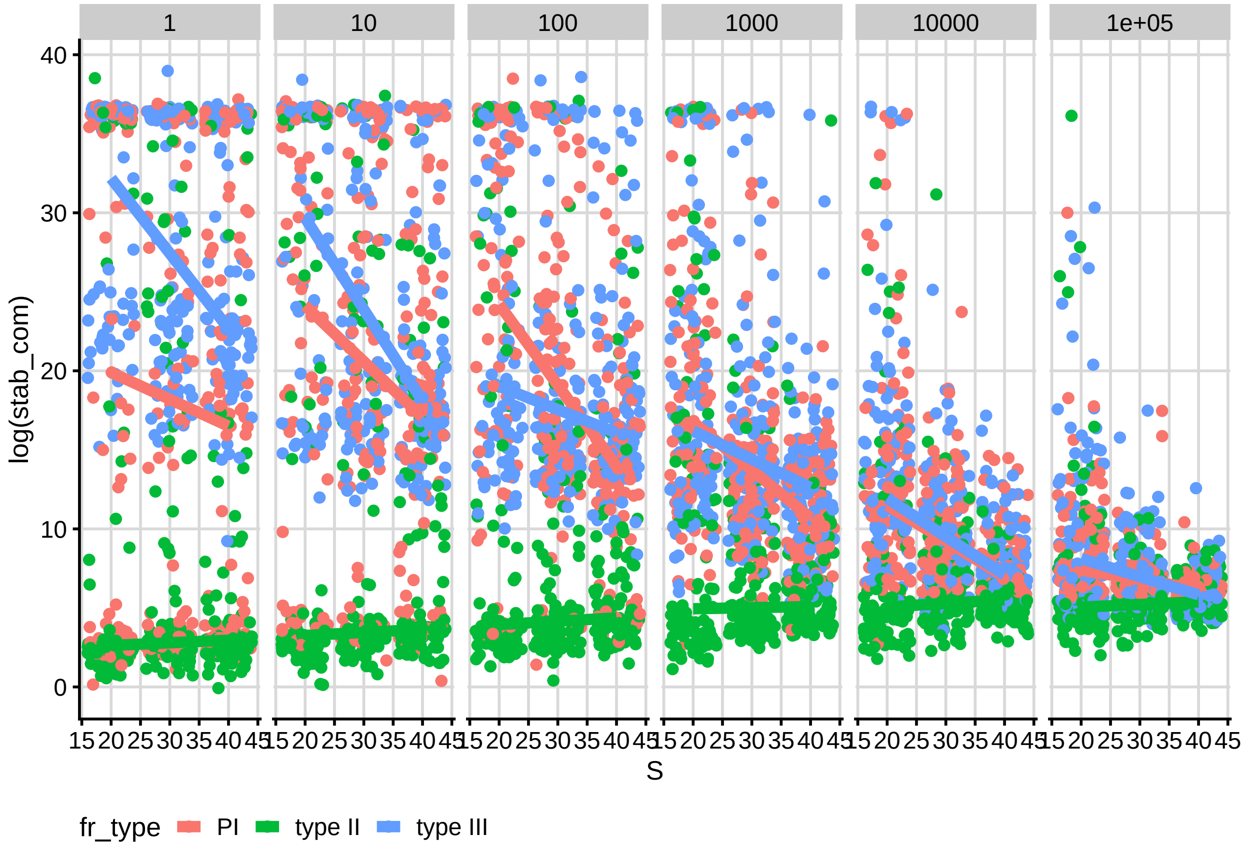
3 Methods

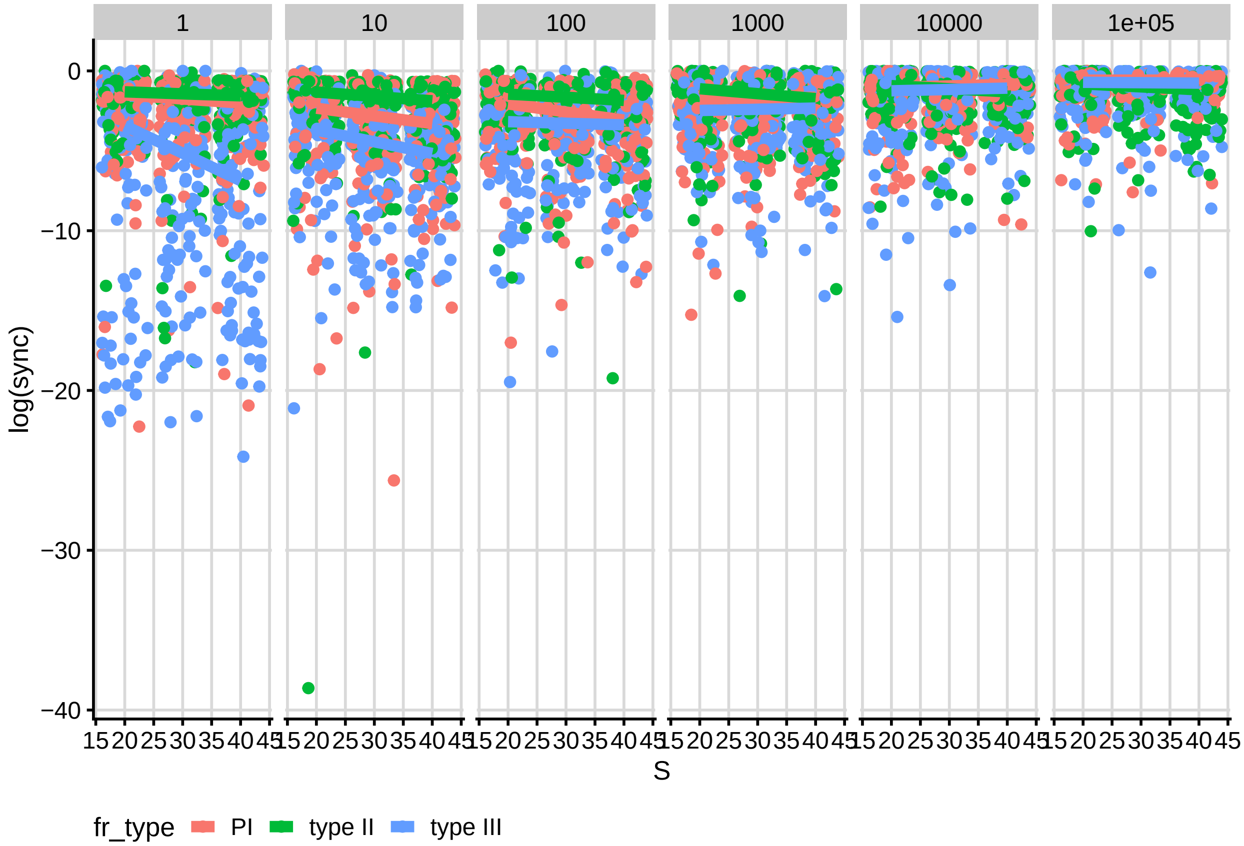
3.1 Simulation framework:

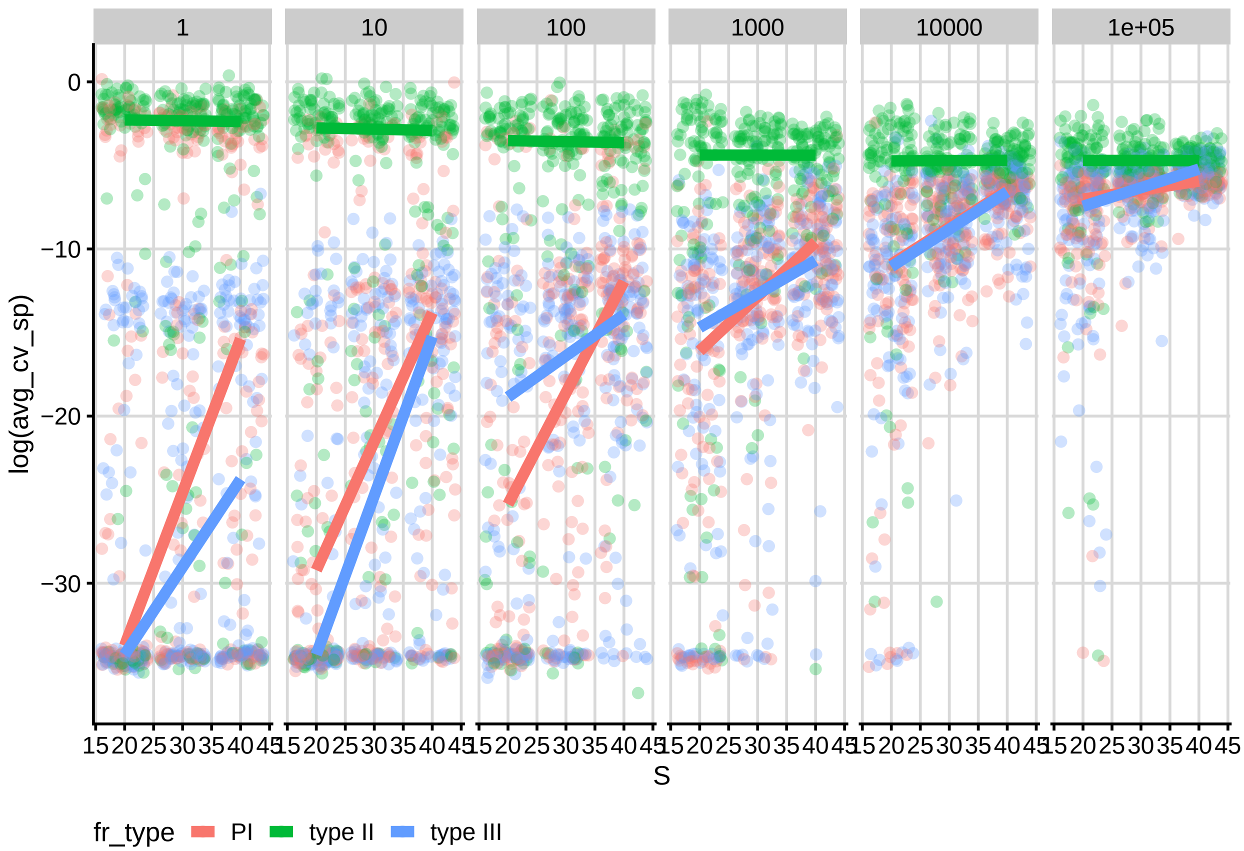
- Start analysis with really robust food-webs (high Z and type III functional response) to avoid species extinction
- Really general propagation: one species pertubated at the time (are there differences with extinction pattern ?)
- Modulating interaction strength distribution: generate random asymetric consumer preference ($\omega_i j$) but with constraints on predator ($\sum \omega_i = 1$) and preys (prey should be involved in one strong interaction at the time may be).

4 Early results



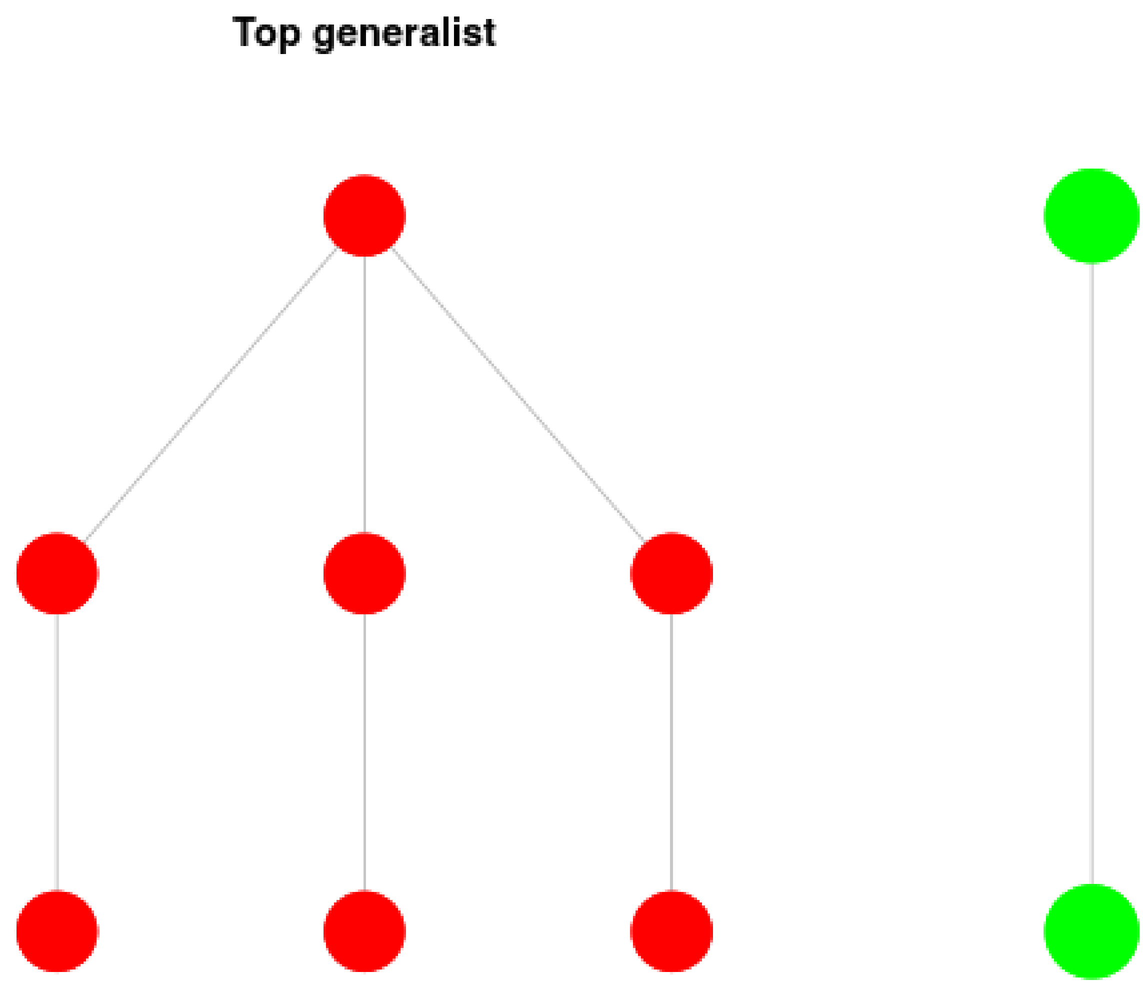

1
10
100
1000
10000
1e+05
log(stab_com)
S
fr_type
PI
type II
type III

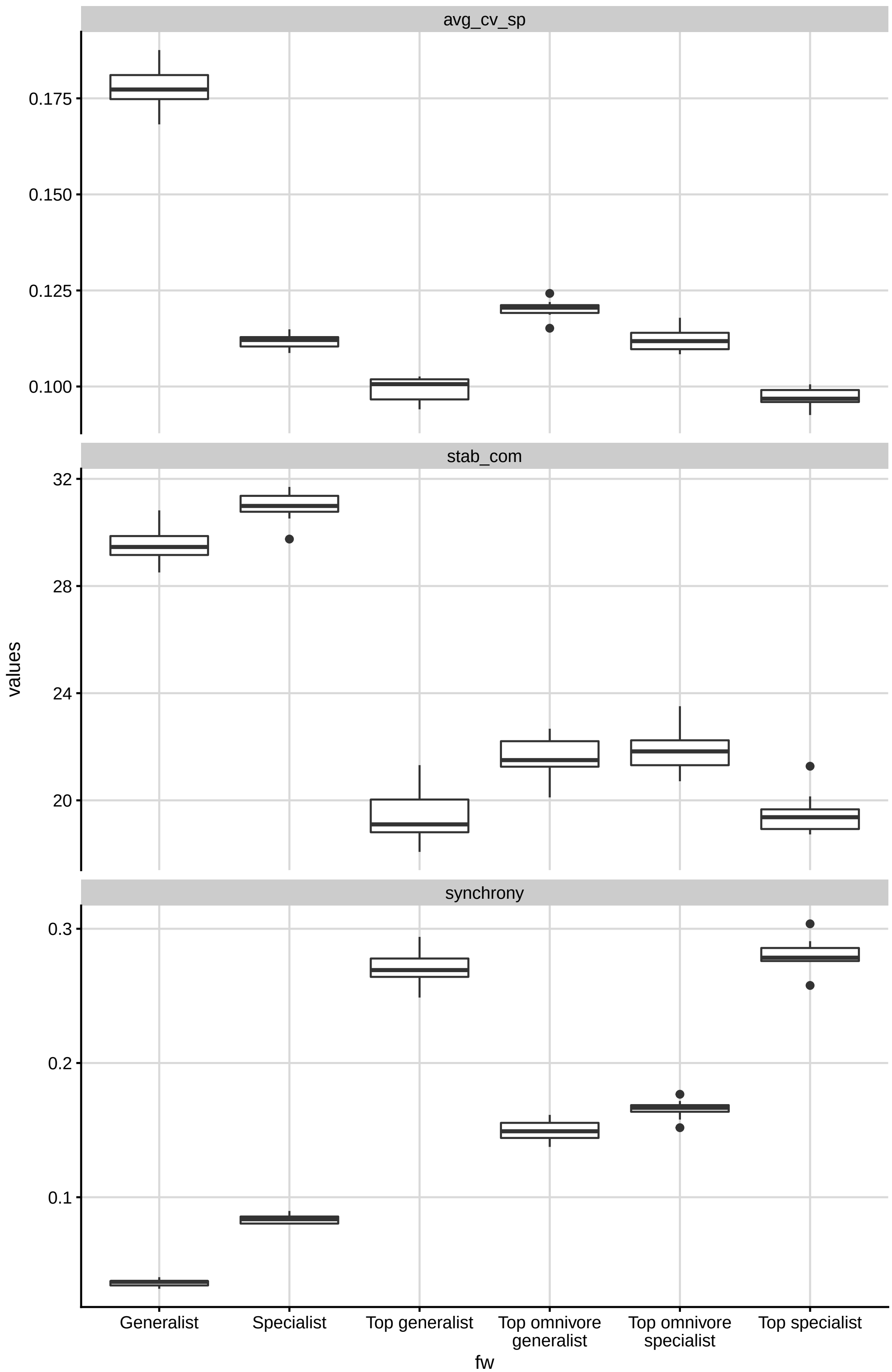

1
10
100
1000
10000
1e+05
log(sync)
0
−10
−20
−30
−40
15 20 25 30 35 40 45
S
fr_type
PI
type II
type III



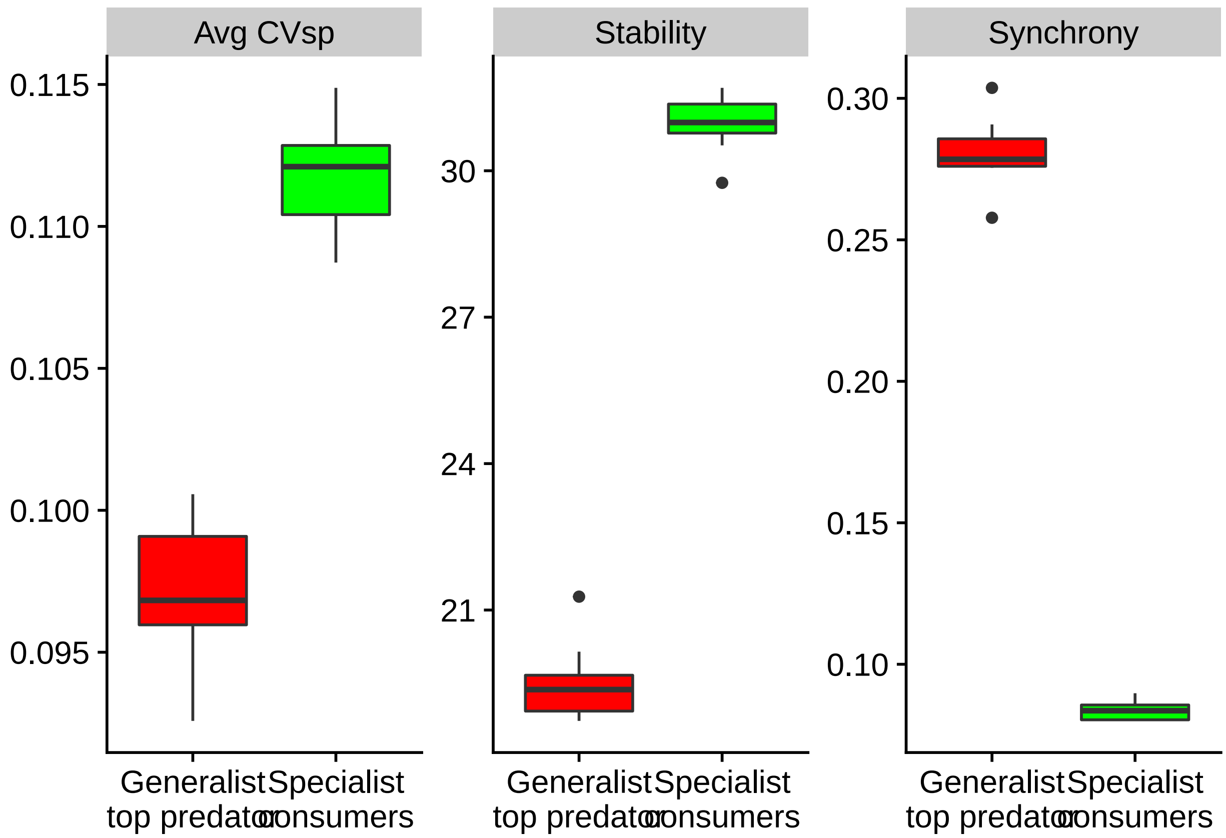
4.1 Module and stability

```
#> pdf
#>   2
```


Top generalist



avg_cv_sp
0.175
0.150
0.125
0.100
stab_com
32
28
24
20
synchrony
0.3
0.2
0.1
values
Generalist
Specialist
Top generalist
Top omnivore generalist
Top omnivore specialist
Top specialist
fw



References

Barabás, György, Rafael D'Andrea, Rosalyn Rael, Géza Meszéna, and Annette Ostling. 2013. "Emergent Neutrality or Hidden Niches?" *Oikos* 122 (11): 1565–72. https://doi.org/10.1111/j.1600-0706.2013.00298.x.

Barbier, Matthieu, and Michel Loreau. 2019. "Pyramids and Cascades: A Synthesis of Food Chain Functioning and Stability." Edited by Dr. Hillary Young. *Ecology Letters* 22 (2): 405–19. https://doi.org/10.1111/ele.13196.

Brose, Ulrich, Richard J. Williams, and Neo D. Martinez. 2006. "Allometric Scaling Enhances Stability in Complex Food Webs." *Ecology Letters* 9 (11): 1228–36. https://doi.org/10.1111/j.1461-0248.2006.00978.x.

Dunne, Jennifer A., Richard J. Williams, and Neo D. Martinez. 2002. "Network Structure and Biodiversity Loss in Food Webs: Robustness Increases with Connectance." *Ecology Letters* 5 (4): 558–67. https://doi.org/10.1046/j.1461-0248.2002.00354.x.

Martínez-Blancas, Alejandra, Ian Xul Belaustegui, and Carlos Martorell. n.d. "Species Alliances and Hidden Niche Dimensions Drive Species Clustering Along a Hydric Gradient in a Semiarid Grassland." *Ecology Letters* n/a (n/a). Accessed November 1, 2022. https://doi.org/10.1111/ele.14122.

McCann, Kevin, Alan Hastings, and Gary R. Huxel. 1998. "Weak Trophic Interactions and the Balance of Nature." *Nature* 395 (6704): 794–98. https://doi.org/10.1038/27427.

McCann, Kevin Shear. 2000. "The Diversity–Stability Debate." *Nature* 405 (May): 228–33. https://www.nature.com/articles/35012234.

Ripa, Jörgen, and Anthony R. Ives. 2003. "Food Web Dynamics in Correlated and Autocorrelated Environments." *Theoretical Population Biology*, Understanding the role of environmental vatiation in population and community dynamics, 64 (3): 369–84. https://doi.org/10.1016/S0040-5809(03)00089-3.

Scheffer, Marten, and Egbert H. van Nes. 2006. "Self-Organized Similarity, the Evolutionary Emergence of Groups of Similar Species." *Proceedings of the National Academy of Sciences* 103 (16): 6230–5. https://doi.org/10.1073/pnas.0508024103.

Shanafelt, David W., and Michel Loreau. 2018. "Stability Trophic Cascades in Food Chains." *Royal Society Open Science* 5 (11): 180995. https://doi.org/10.1098/rsos.180995.

Stouffer, Daniel B., and Jordi Bascompte. 2011. "Compartmentalization Increases Food-Web Persistence." *Proceedings of the National Academy of Sciences* 108 (9): 3648–52. https://doi.org/10.1073/pnas.1014353108.

Thébault, Elisa, and Colin Fontaine. 2010. "Stability of Ecological Communities and the Architecture of Mutualistic and Trophic Networks." *Science* 329 (5993): 853–56. https://doi.org/10.1126/science.1188321.

Vasseur, David A., and Jeremy W. Fox. 2007. "Environmental Fluctuations Can Stabilize Food Web Dynamics by Increasing Synchrony." *Ecology Letters* 10 (11): 1066–74. https://doi.org/10.1111/j.1461-0248.2007.01099.x.