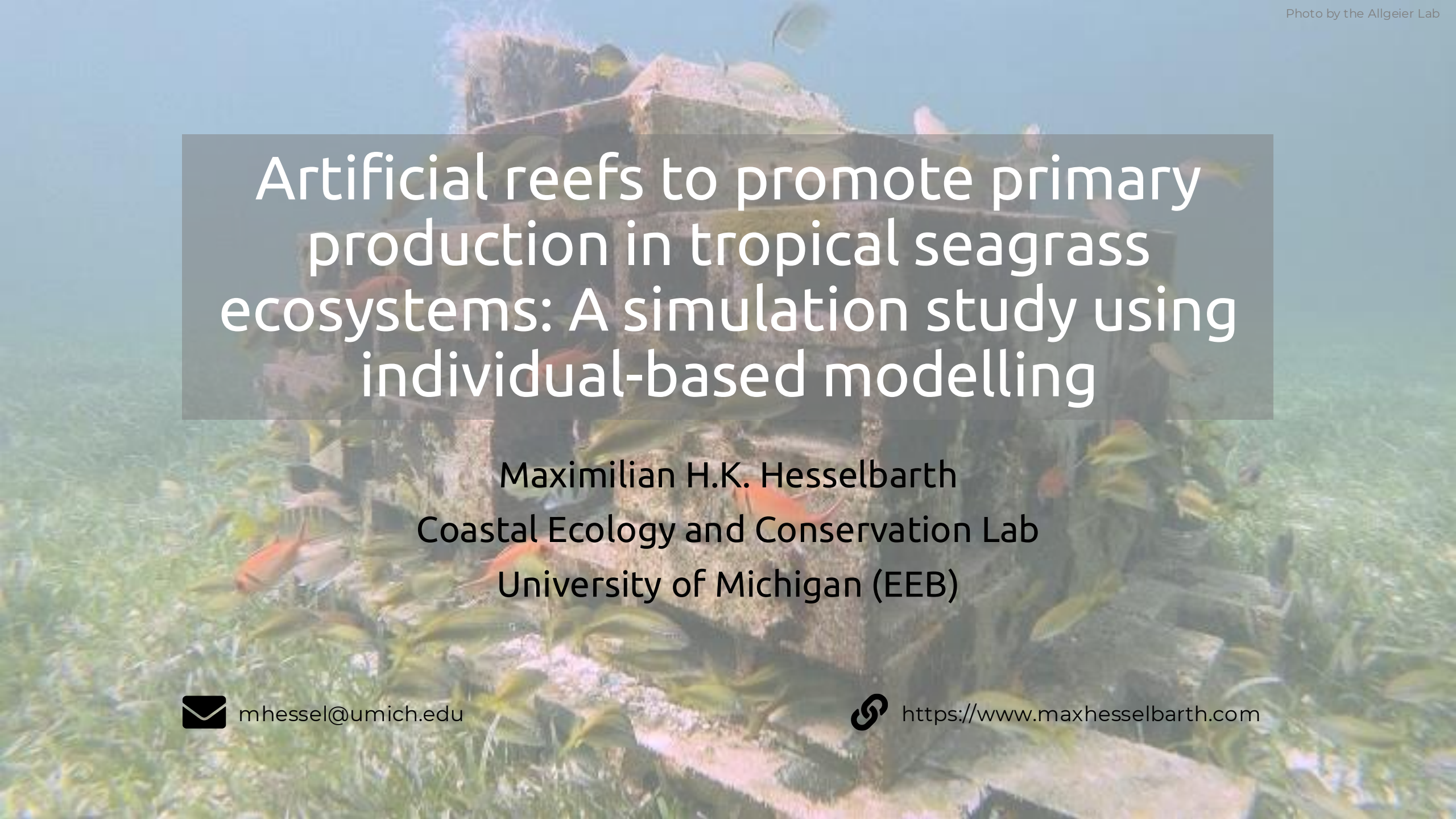

Artificial reefs to promote primary production in tropical seagrass ecosystems: A simulation study using individual-based modelling

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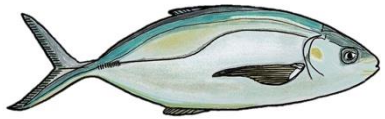
Photo by J. Allgeier
Fish illustrations by K.S. Munsterman
Sea grass illustrations by Vecteezy

Primary production in marine ecosystems

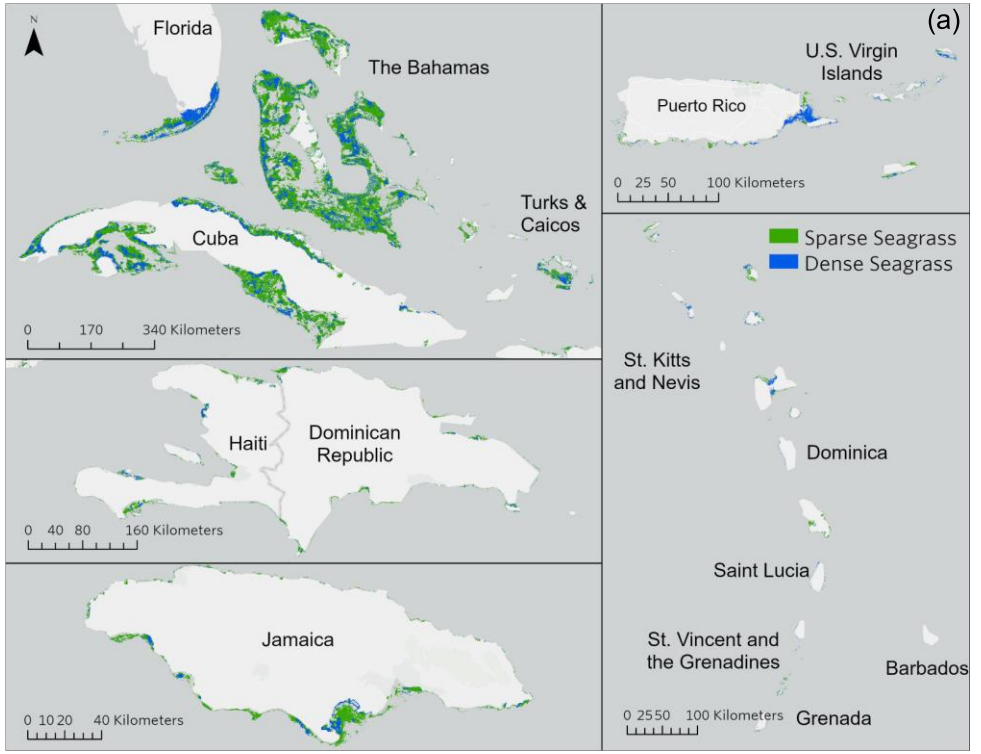
Fisheries

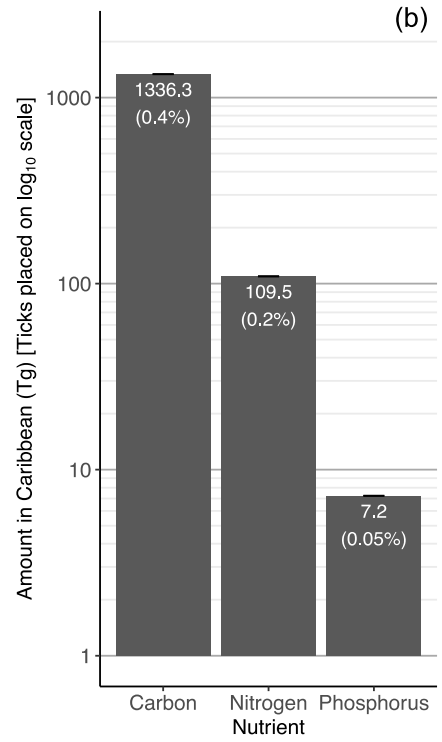
Predators



Herbivores

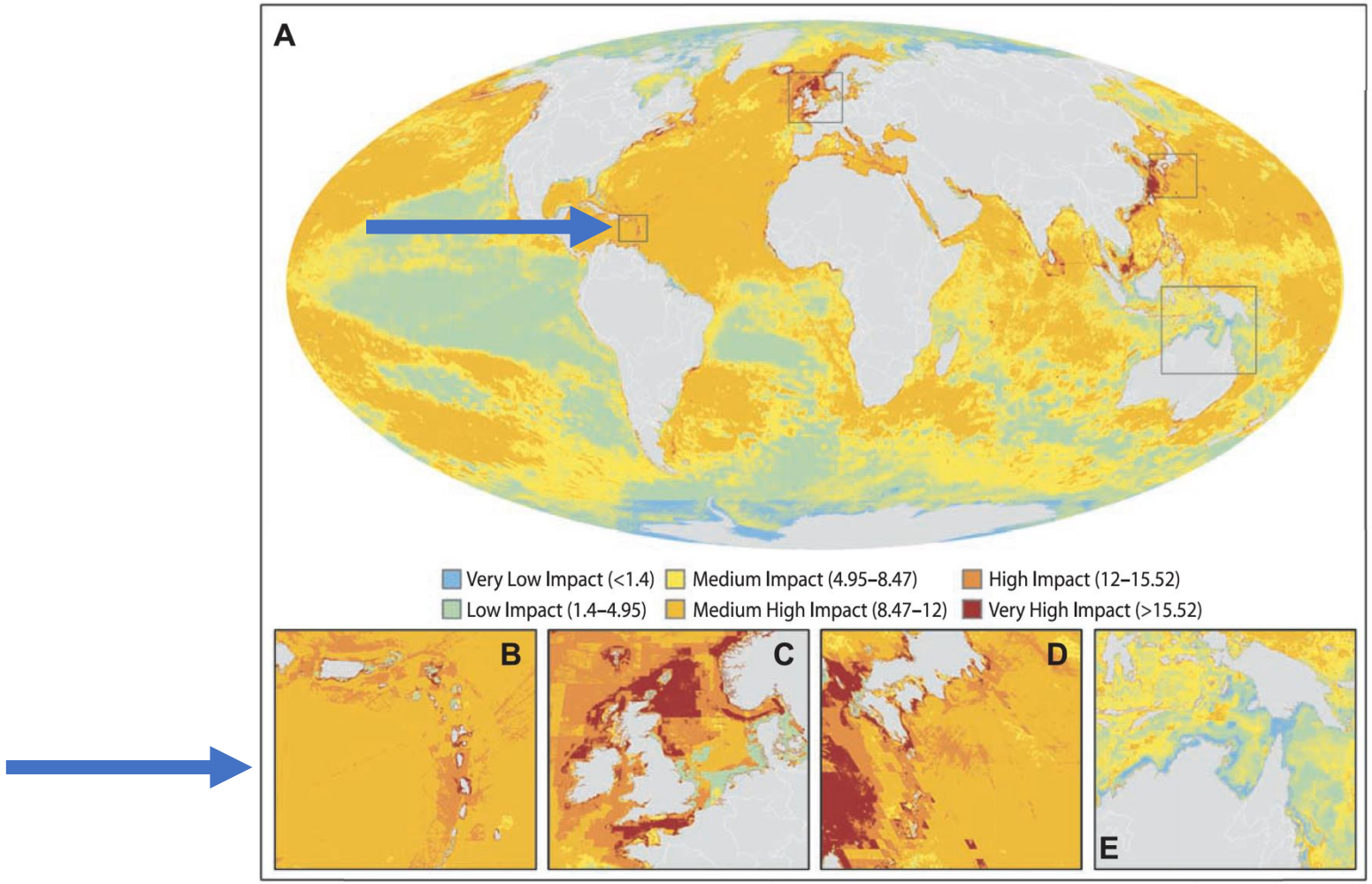
Primary production





Shayka, B.F., Hesselbarth, M.H.K., Schill, S.R., Currie, W.S., Allgeier, J.E., under review. The natural capital of seagrass beds in the Caribbean: evaluating their blue carbon trade and ecosystem service potential. Biological Letters.

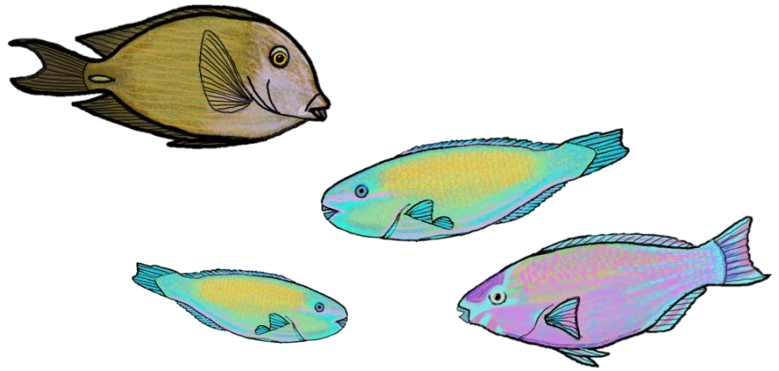
Human impact on marine ecosystems



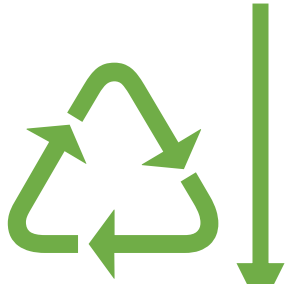
Adapted from: Halpern, B.S., Walbridge, S., Selkoe, K.A., Kappel, C.V., Micheli, F., D'Agrosa, C., Bruno, J.F., Casey, K.S., Ebert, C., Fox, H.E., Fujita, R., Heinemann, D., Lenihan, H.S., Madin, E.M.P., Perry, M.T., Selig, E.R., Spalding, M., Steneck, R., Watson, R., 2008. A global map of human impact on marine ecosystems. Science 319, 948–952. https://doi.org/10.1126/science.1149345

Sources of nutrients promoting primary production

Nutrients supply by fish



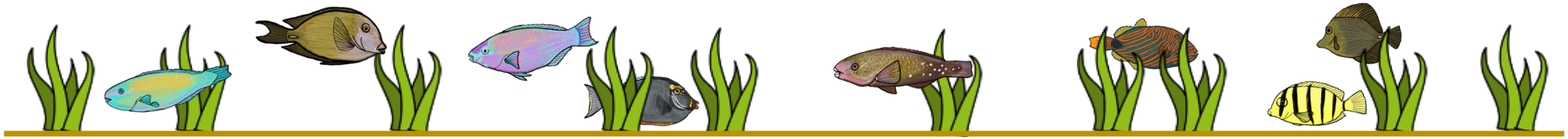
Recycling of nutrients by fish

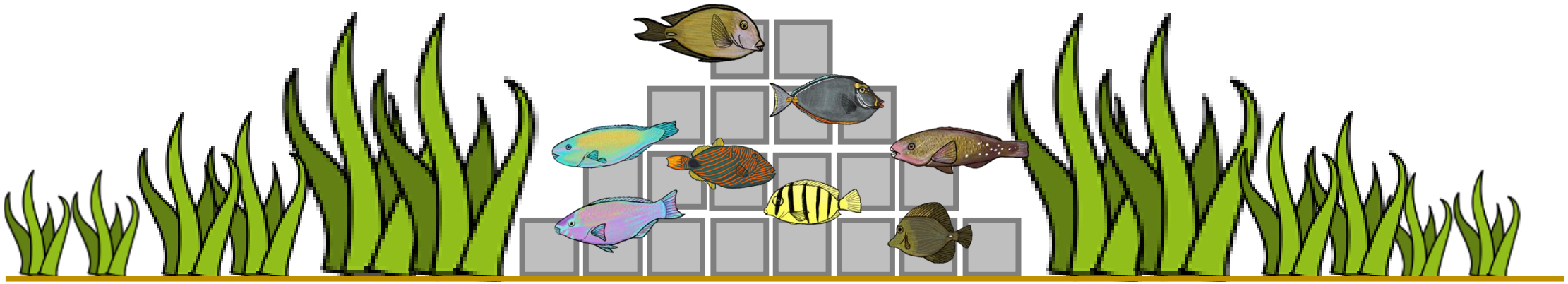


Abiotic nutrients supply

Fish illustrations by K.S. Munsterman
Sea grass illustrations by Vecteezy

Artificial reefs (ARs)





Adapted from: Layman, C.A., Allgeier, J.E., Montaña, C.G., 2016. Mechanistic evidence of enhanced production on artificial reefs: A case study in a Bahamian seagrass ecosystem. Ecological Engineering 95, 574–579. https://doi.org/10.1016/j.ecoleng.2016.06.109

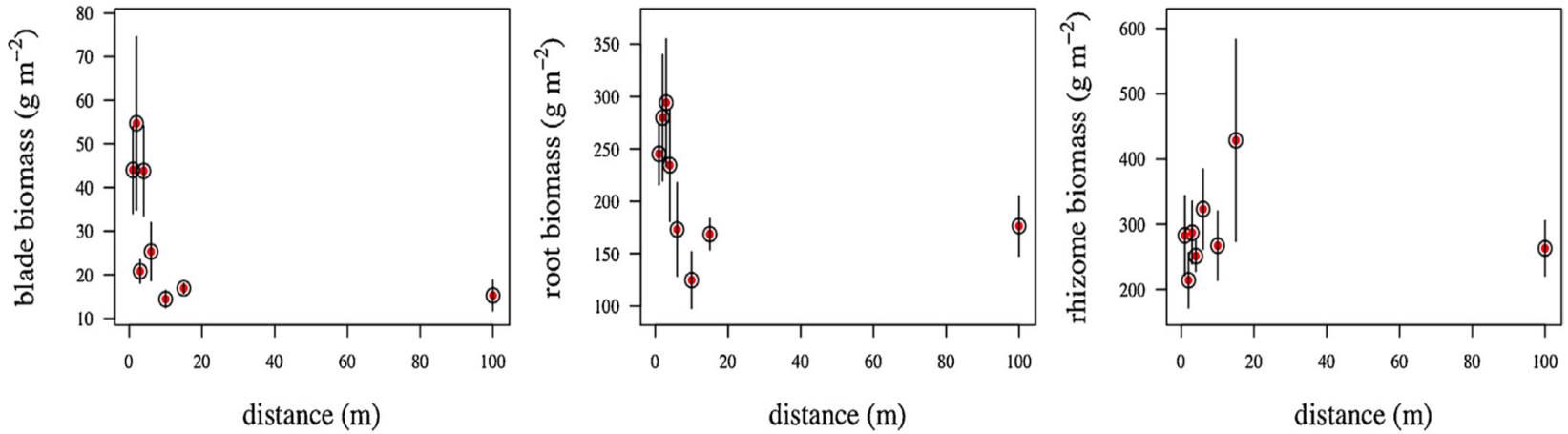
Photos by the Allgeier Lab

Artificial reefs (ARs)

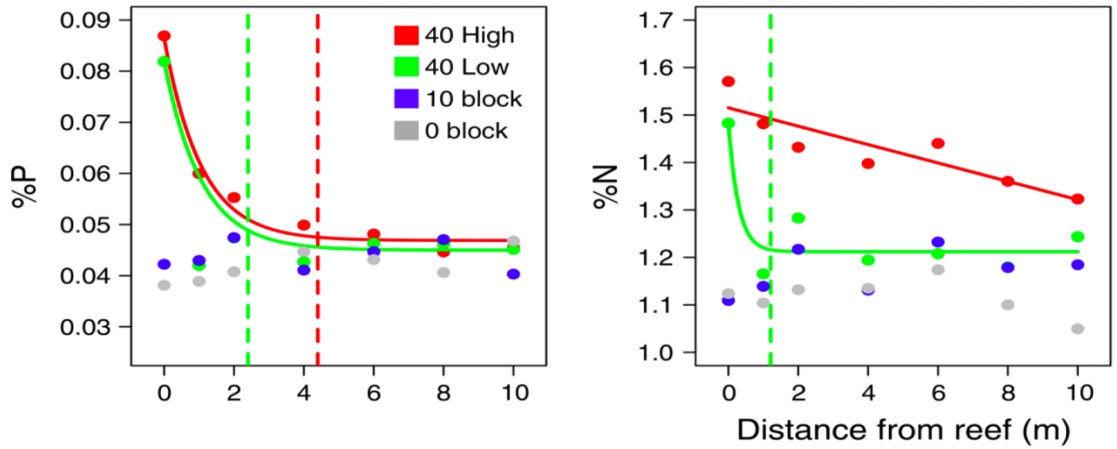





Empirical research artificial reefs



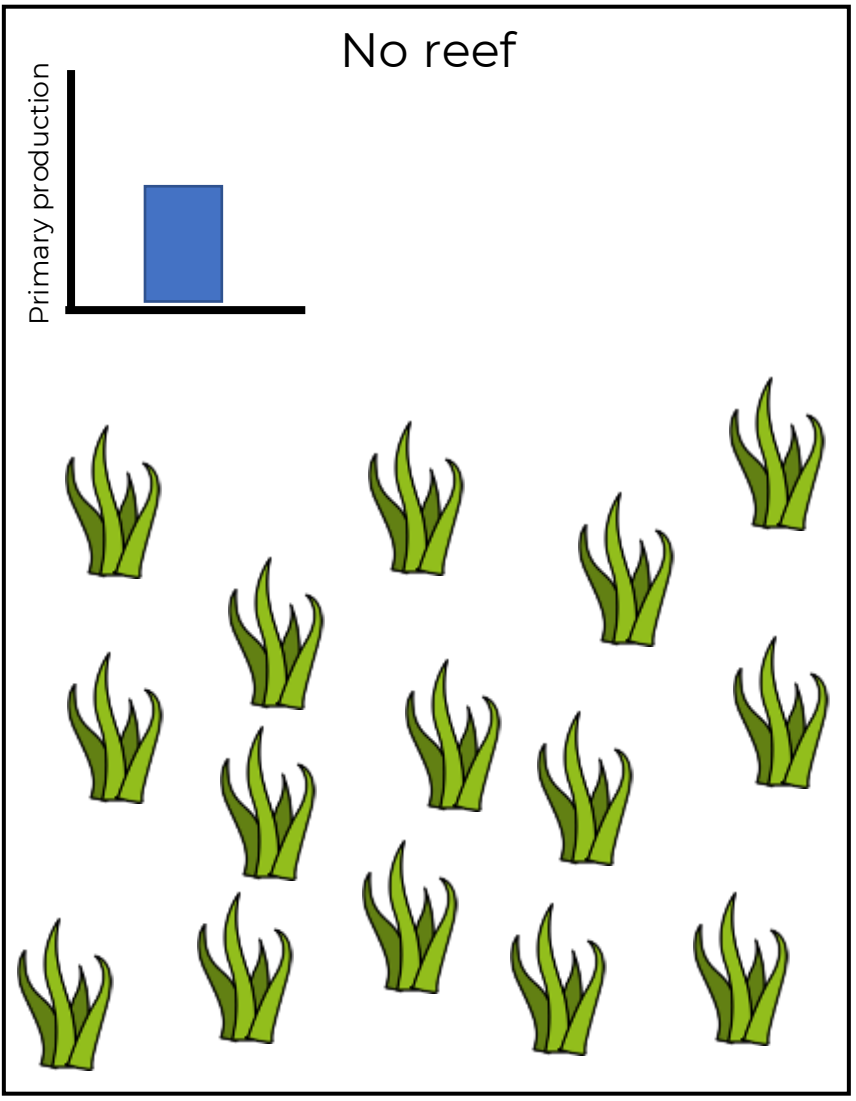
Layman, C.A., Allgeier, J.E., Montaña, C.G., 2016. Mechanistic evidence of enhanced production on artificial reefs: A case study in a Bahamian seagrass ecosystem. Ecological Engineering 95, 574–579. https://doi.org/10.1016/j.ecoleng.2016.06.109

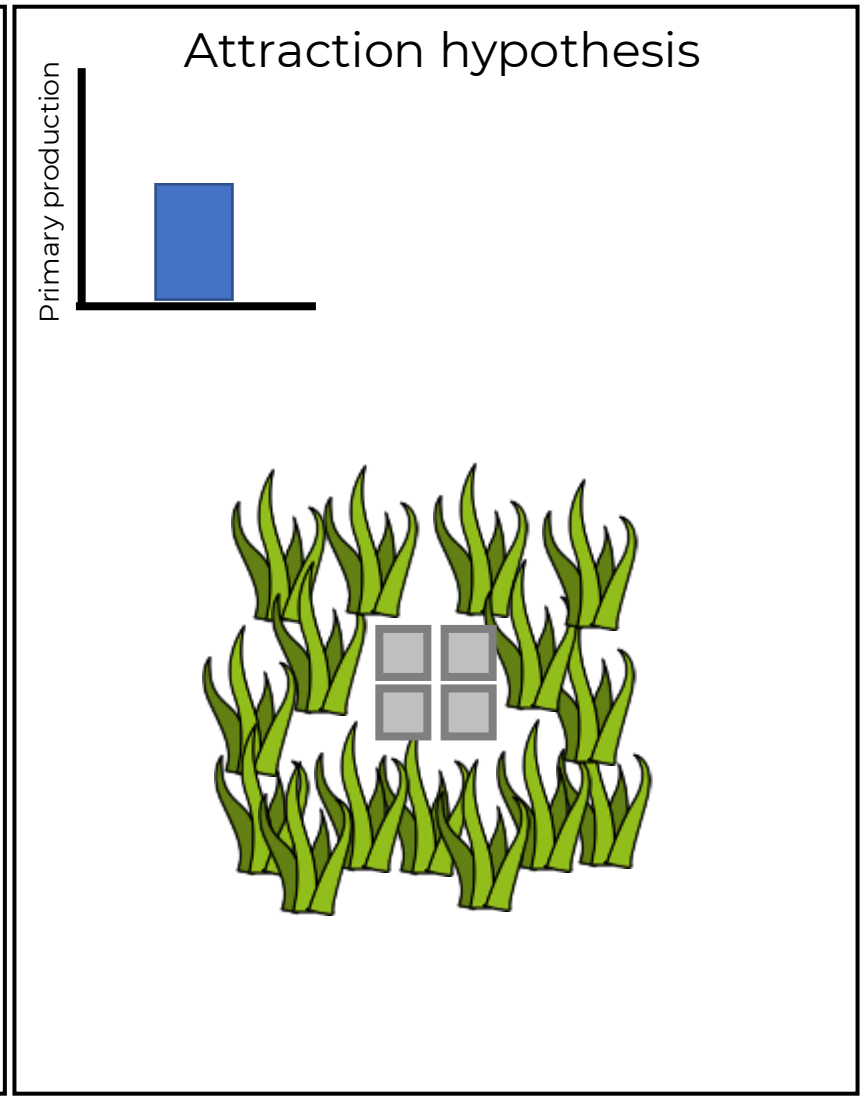


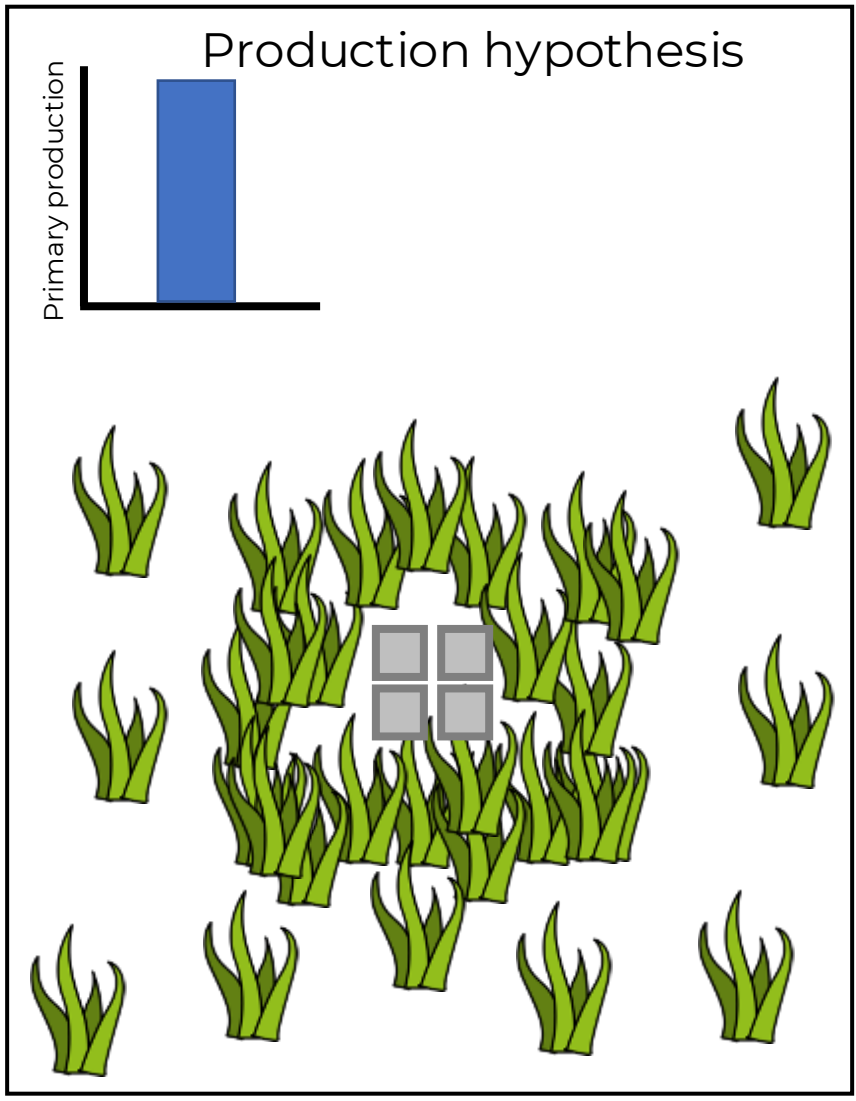
Adapted from: Layman, C.A., Allgeier, J.E., Yeager, L.A., Stoner, E.W., 2013. Thresholds of ecosystem response to nutrient enrichment from fish aggregations. Ecology 94, 530–536. https://doi.org/10.1890/12-0705.1

Sea grass illustrations by Vecteezy

Attraction vs. production debate

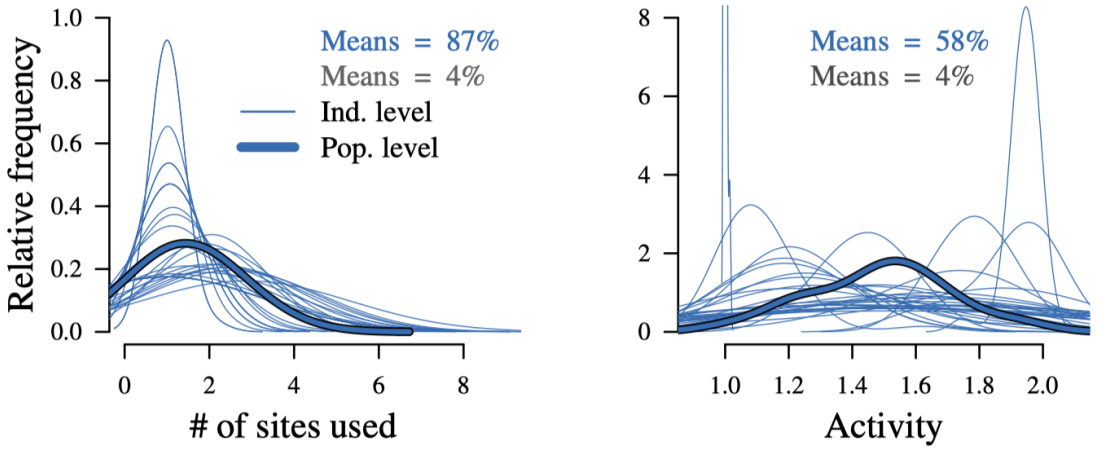






Individual-based simulation models

- Bottom-up approach
- Highly mechanistic
- Spatially explicit & individual variability



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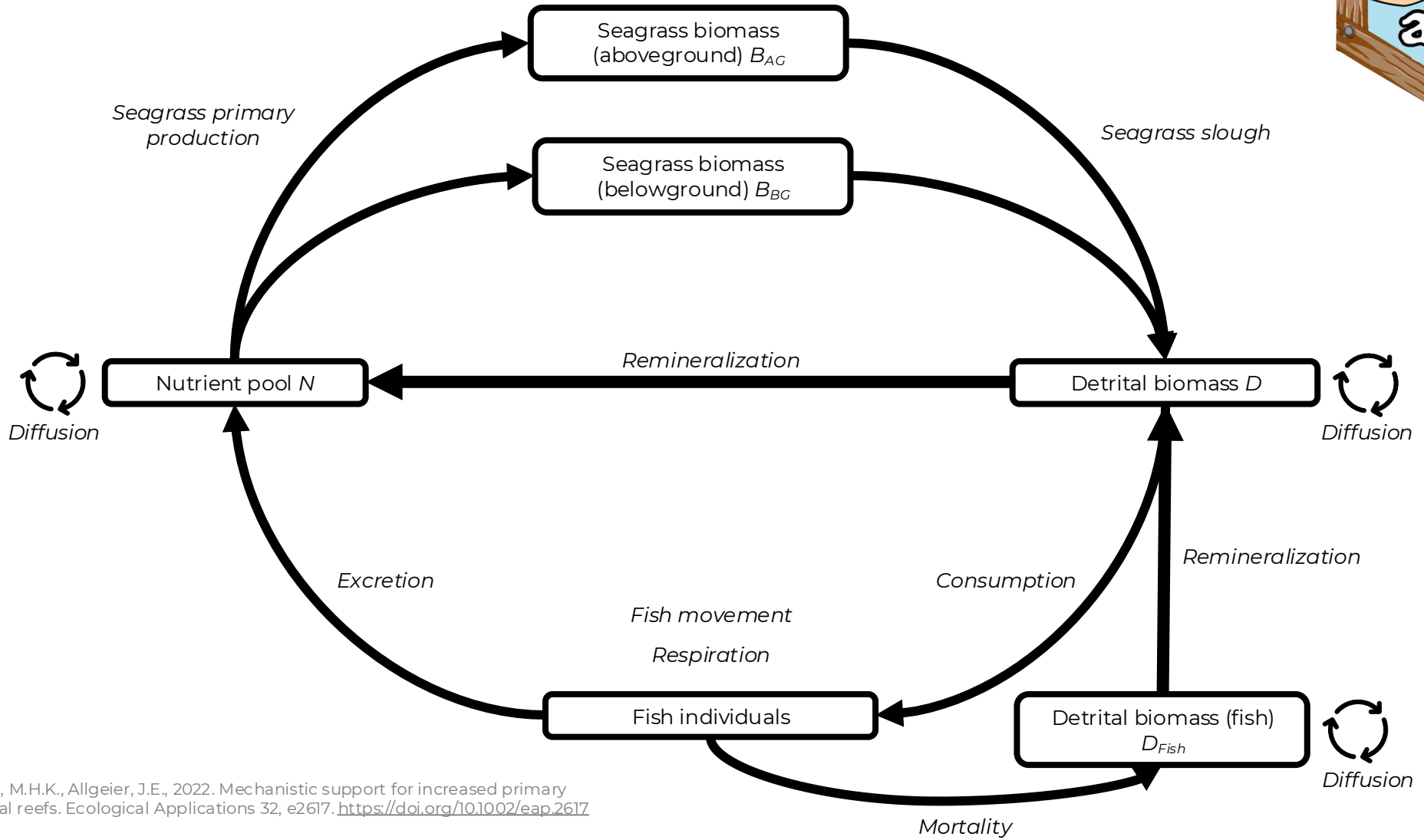
https://brotherbrain.tumblr.com/post/172496198777/pac-attack

Artificial reefs in R https://allgeier-lab.github.io/arrR/

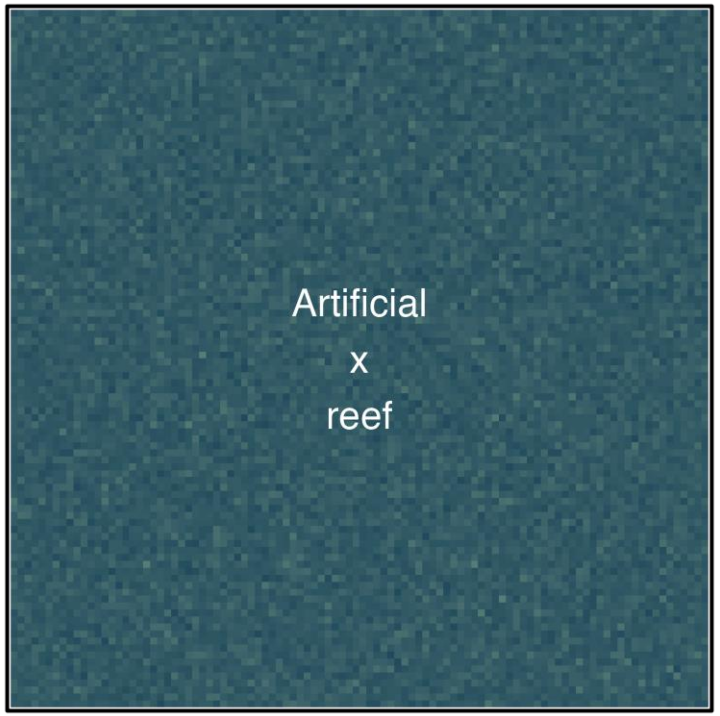
Logo by S. Iliff



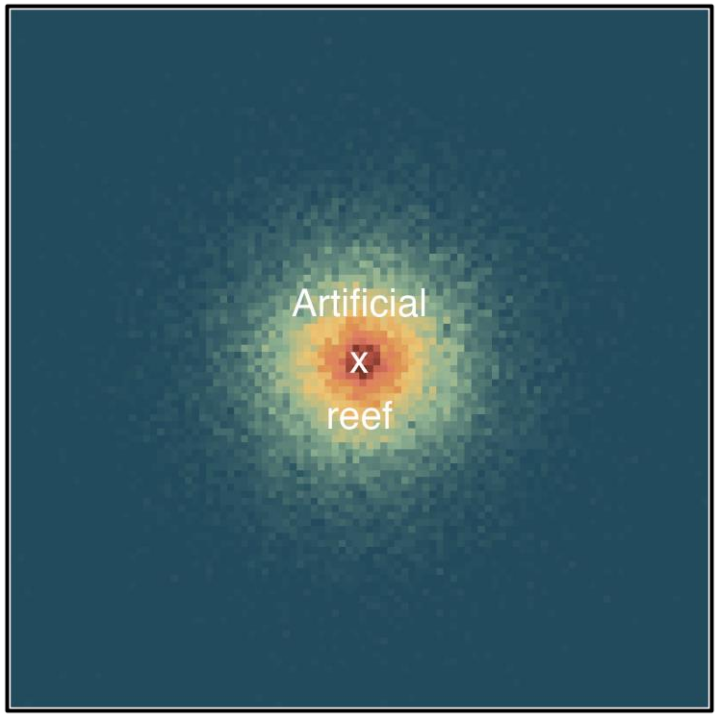
Esquivel, K.E., Hesselbarth, M.H.K., Allgeier, J.E., 2022. Mechanistic support for increased primary production around artificial reefs. Ecological Applications 32, e2617. https://doi.org/10.1002/eap.2617

Experiment: Movement behavior

Random movement

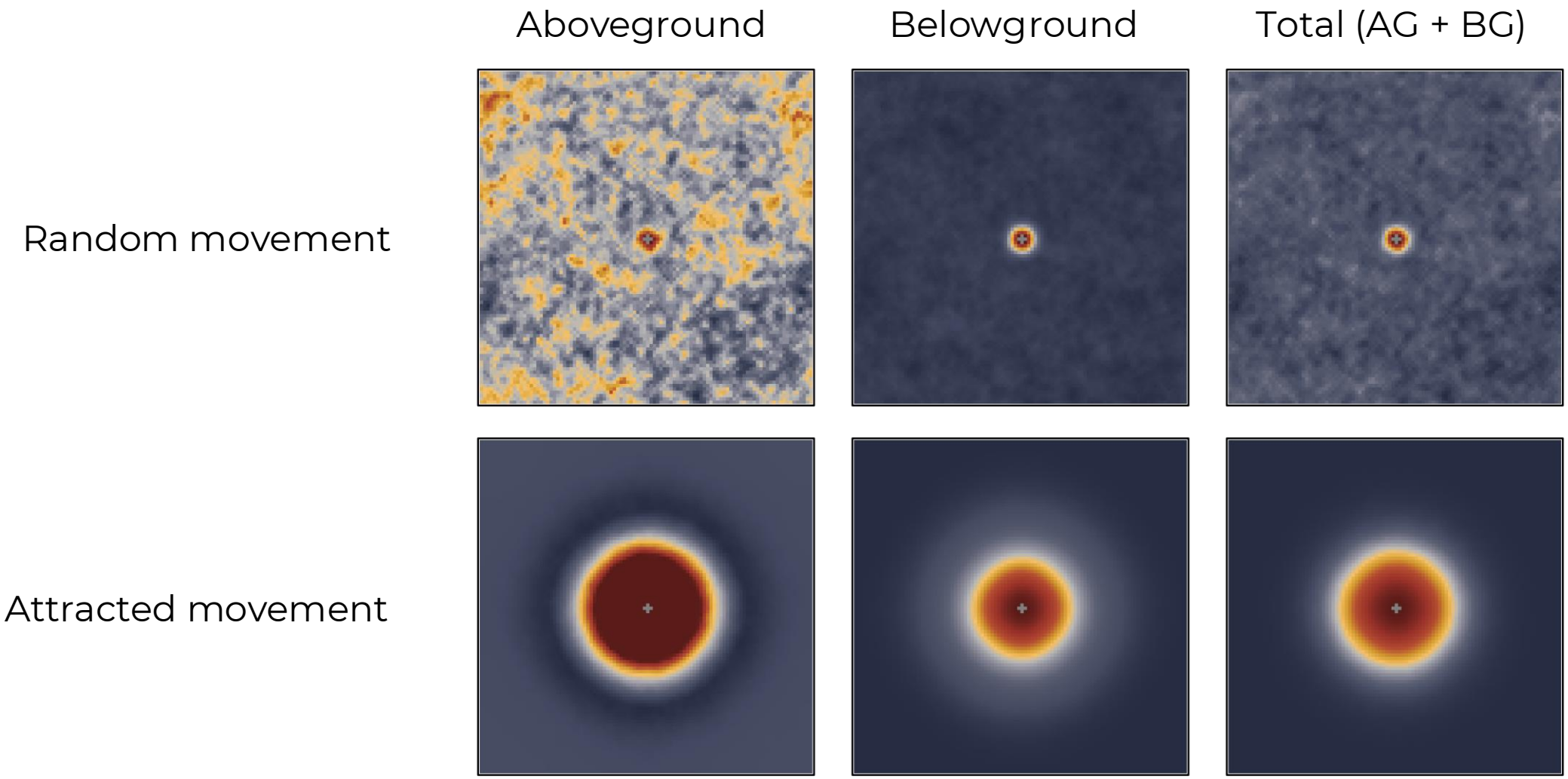


Attracted movement

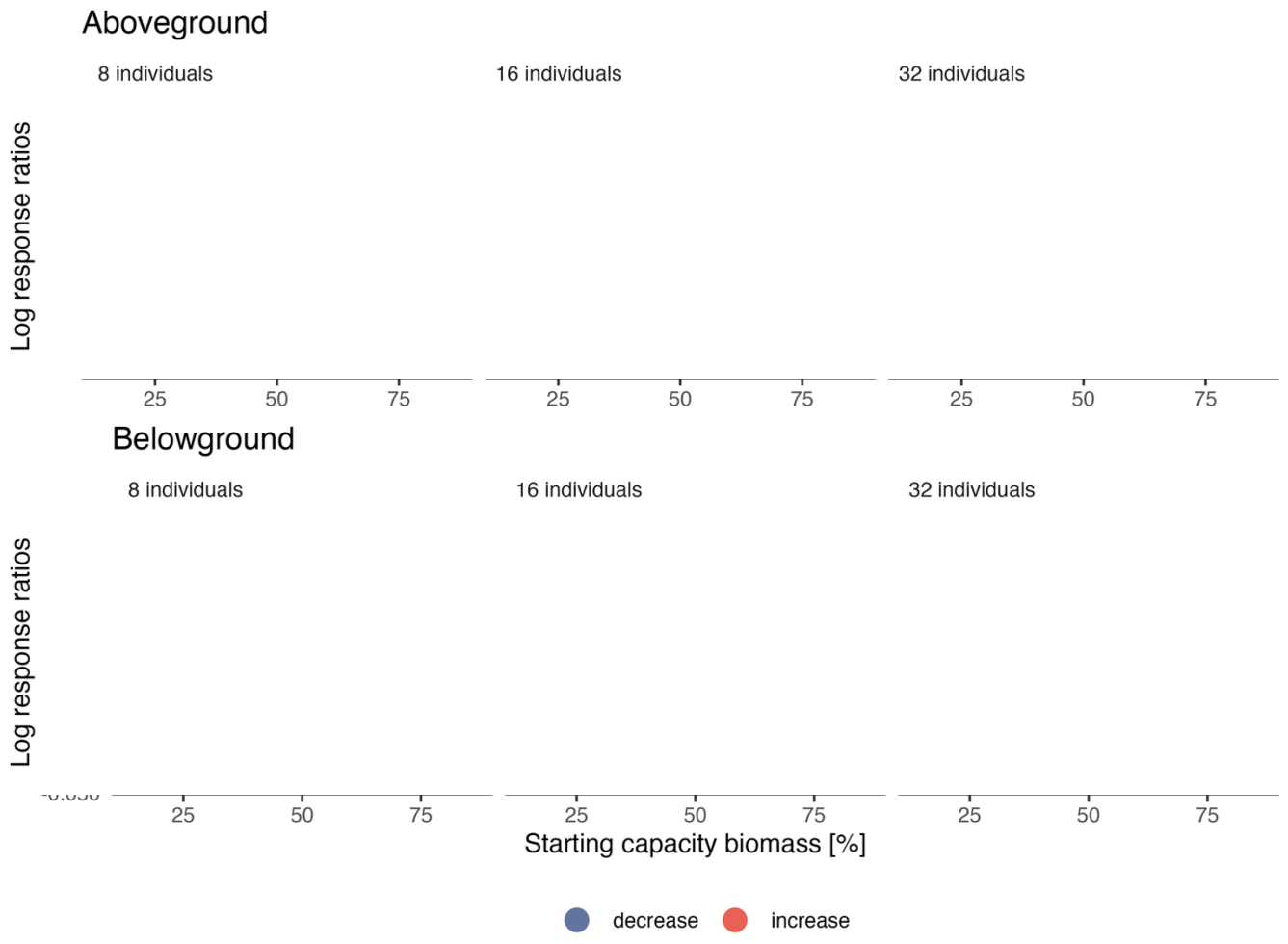


Density of fish individuals

Spatial explicit biomass



Ecosystem primary production



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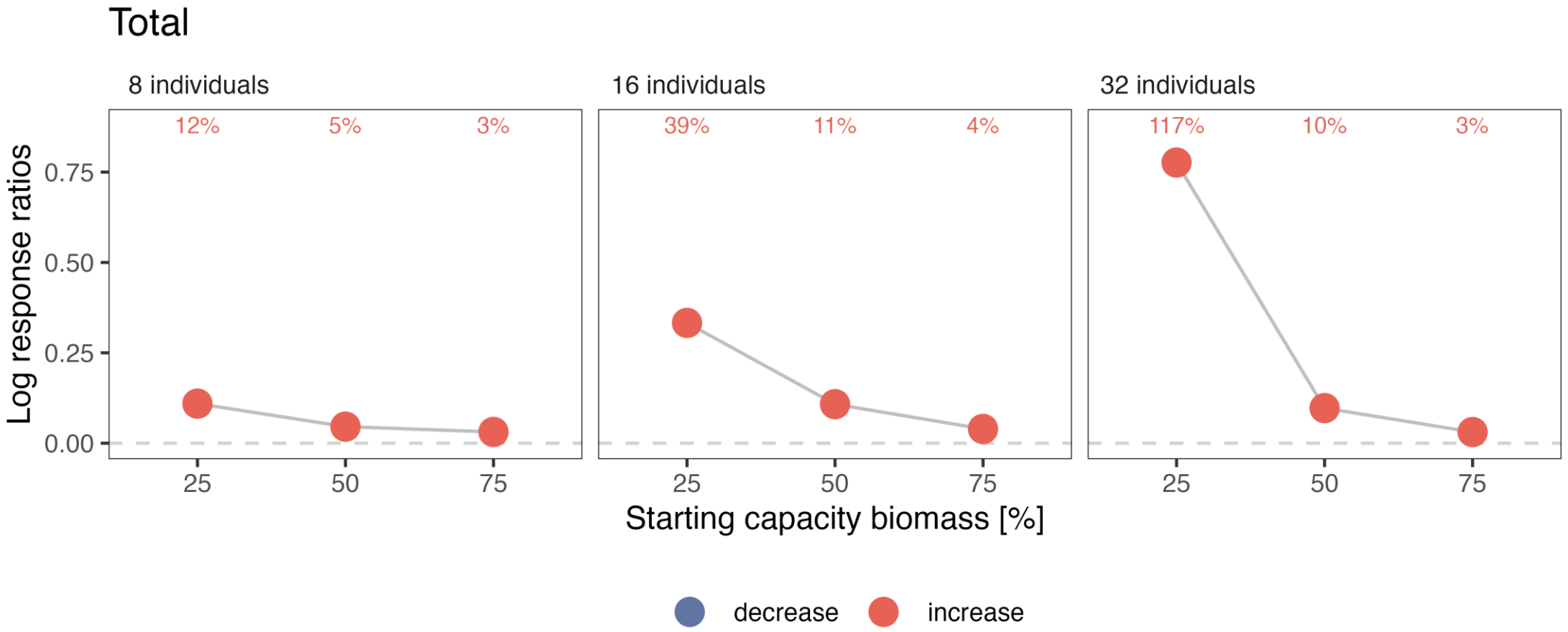
Ecosystem primary production



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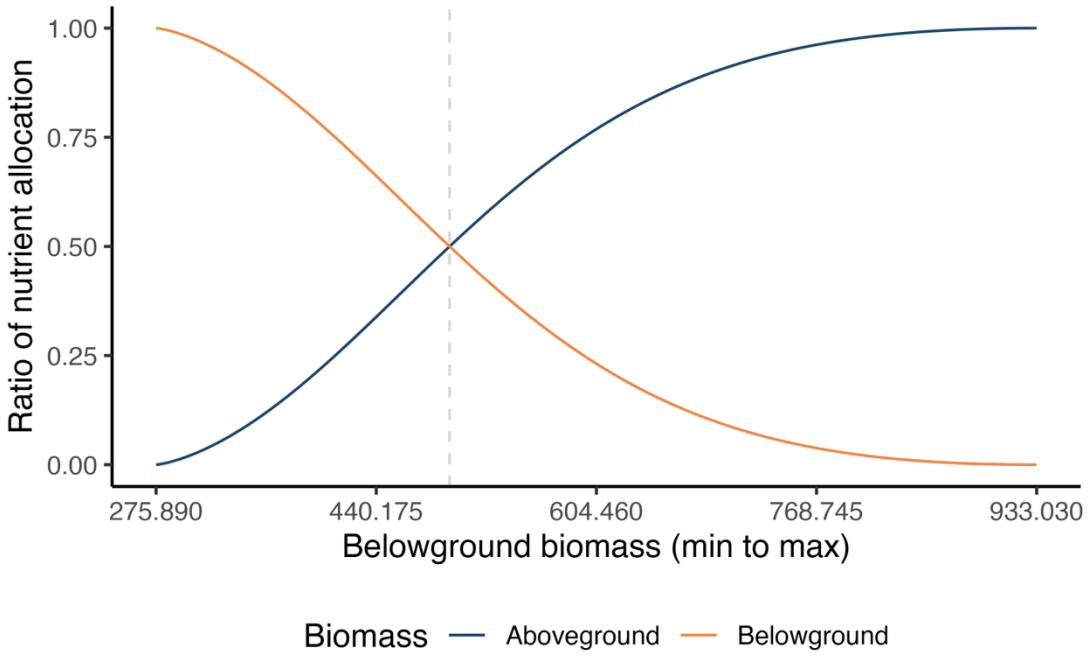
Driving factor: Non-linear mechanism



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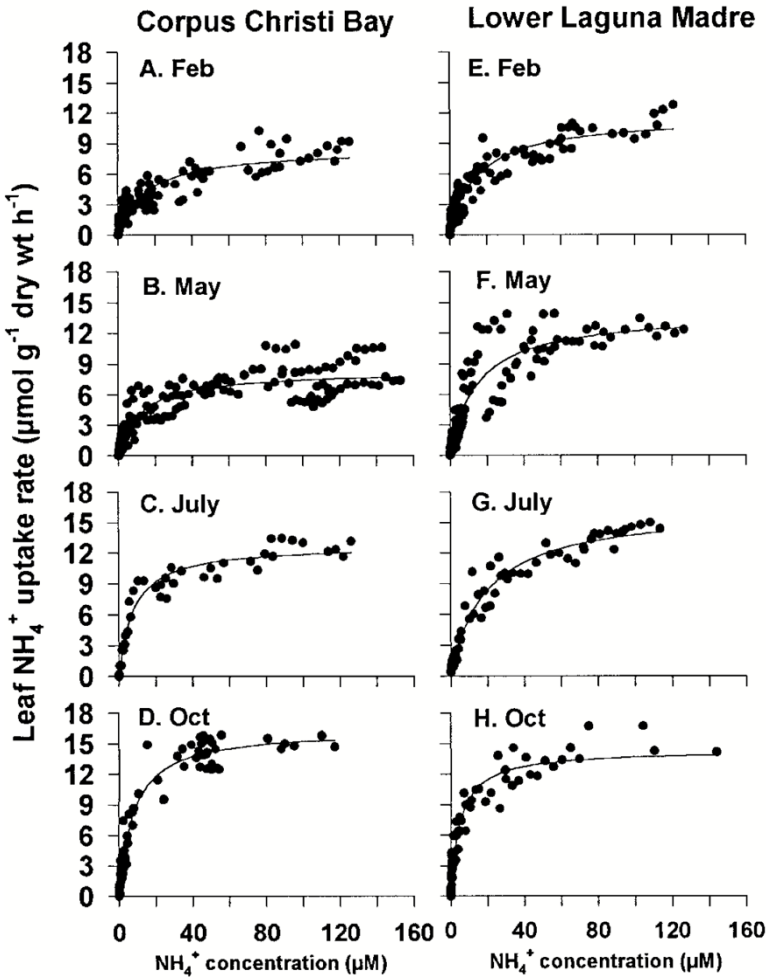


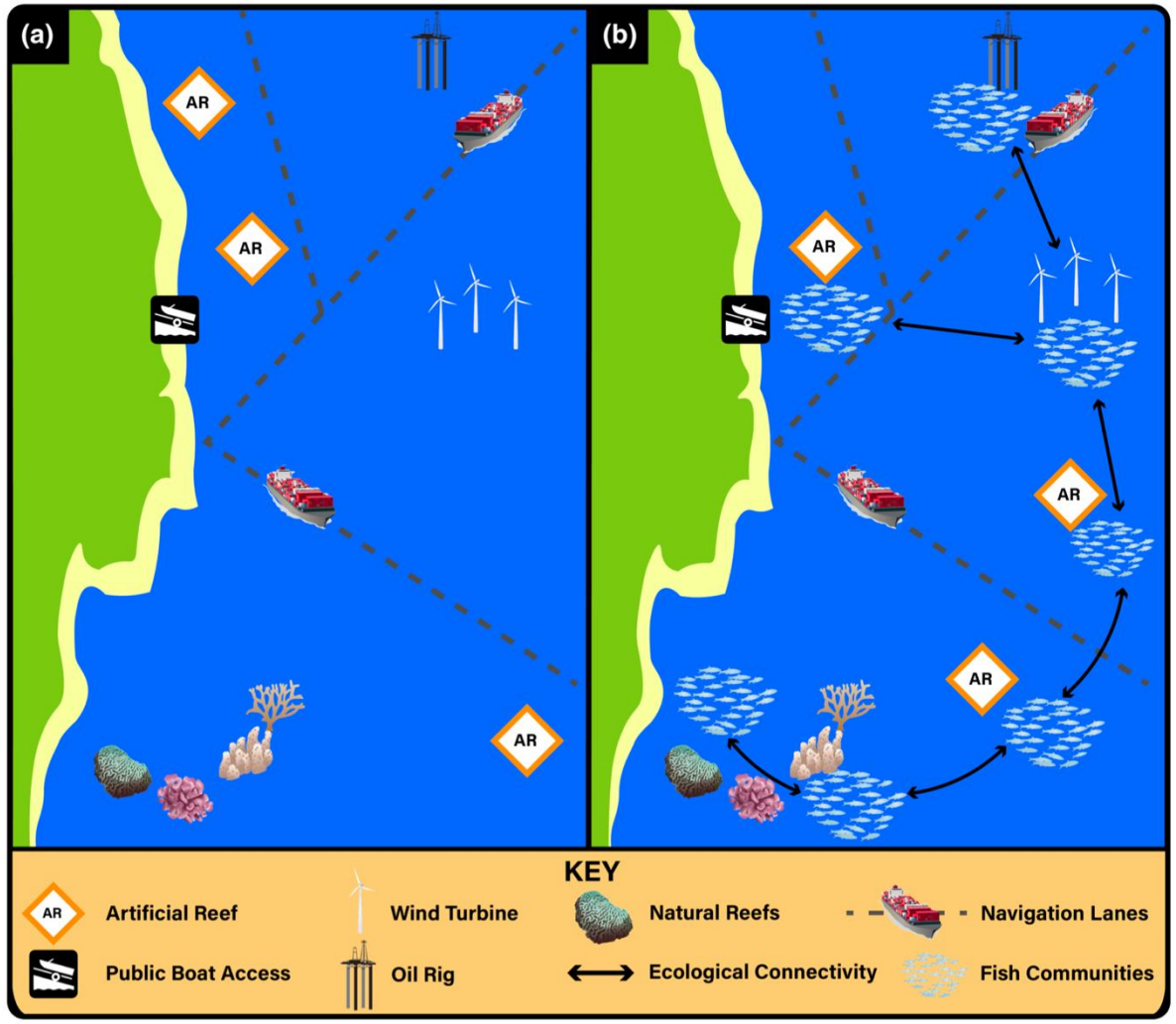
Lee, K.-S., Dunton, K.H., 1999. Inorganic nitrogen acquisition in the seagrass Thalassia testudinum: Development of a whole-plant nitrogen budget. Limnol. Oceanogr. 44, 1204–1215. https://doi.org/10.4319/lo.1999.44.5.1204

Conclusions (I)

- Increased primary production at the ecosystem-scale
- ARs could be a useful tool for conservation by increasing primary production

- So far closed model environment
- Only one artificial reef modelled

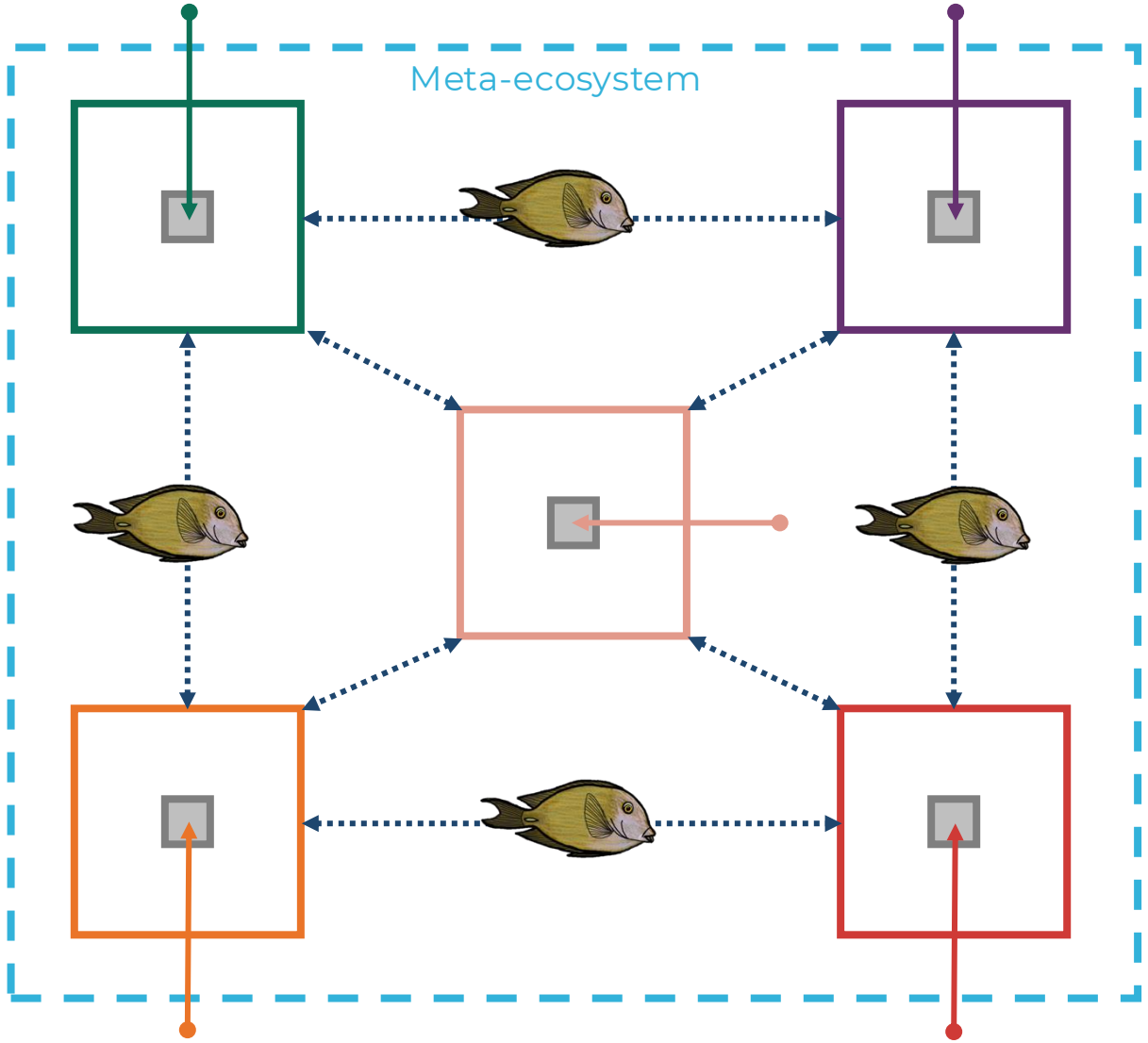
Connectivity and distribution of artificial reefs (AR)

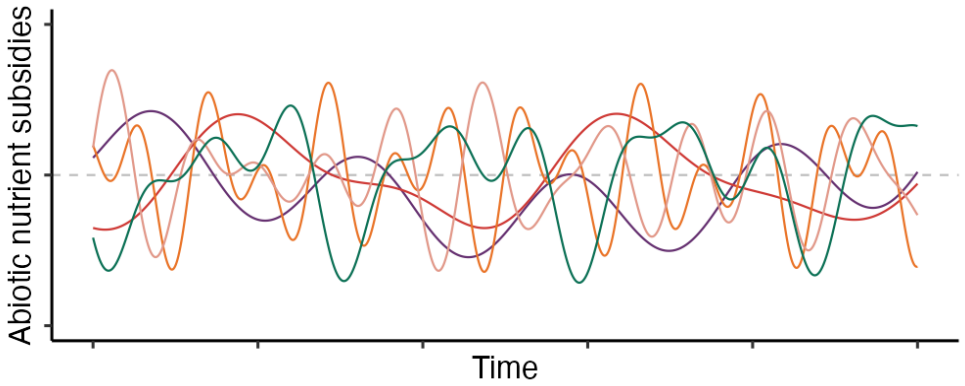


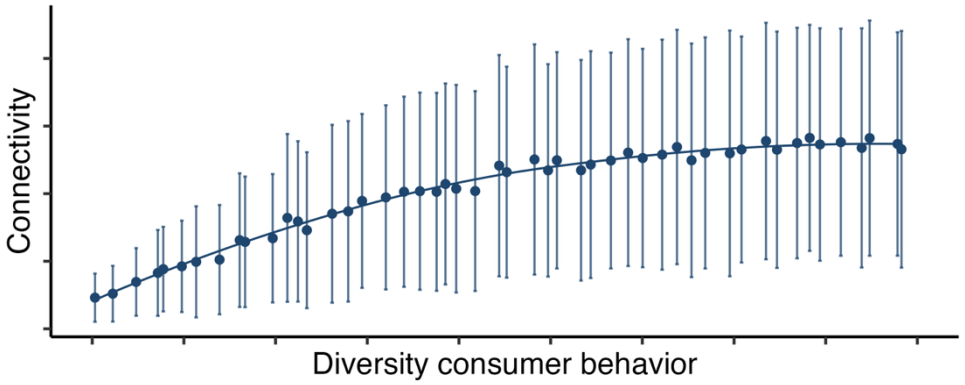
Paxton, A.B., Steward, D.N., Harrison, Z.H., Taylor, J.C., 2022. Fitting ecological principles of artificial reefs into the ocean planning puzzle. Ecosphere 13. https://doi.org/10.1002/ecs2.3924

Fish illustrations by K.S. Munsterman

Using a meta-ecosystem framework

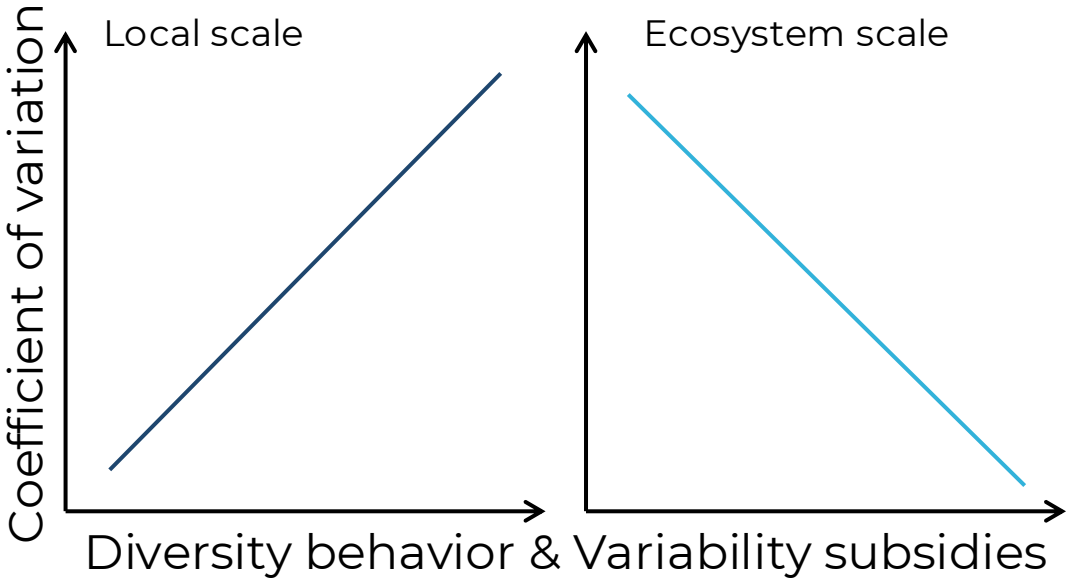


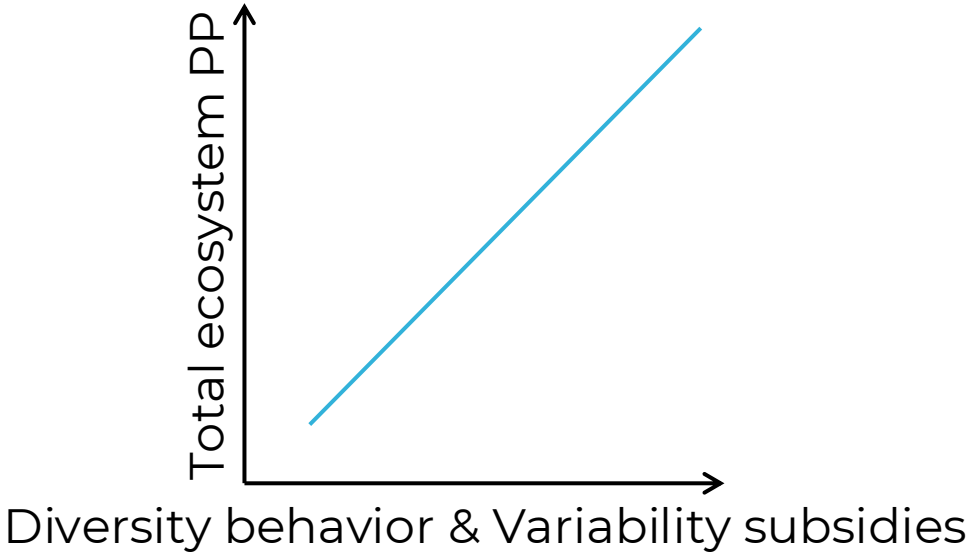




Hypotheses

2) How are consumer behavior and abiotic subsidies affecting the total primary production on meta-ecosystem scale?





Measures of stability

- Stability local scale:

  σ_i^2 = variance of each local ecosystem primary production
  μ_M = mean of the total meta-ecosystem production

$$cv_\alpha = \frac{\sum\sqrt{\sigma_i^2}}{\mu_M}$$

- Stability meta-ecosystem scale:

  σ_M^2 = variance of meta-ecosystem primary production
  μ_M = mean of the total meta-ecosystem production

$$cv_\gamma = \frac{\sqrt{\sigma_M^2}}{\mu_M}$$

- Linear regressions:

  1) $\mathrm{cv}_{\alpha/\gamma} \sim diversity_{behavior} * variability_{subsidies}$

  2) $PP_M \sim diversity_{behavior} * variability_{subsidies}$

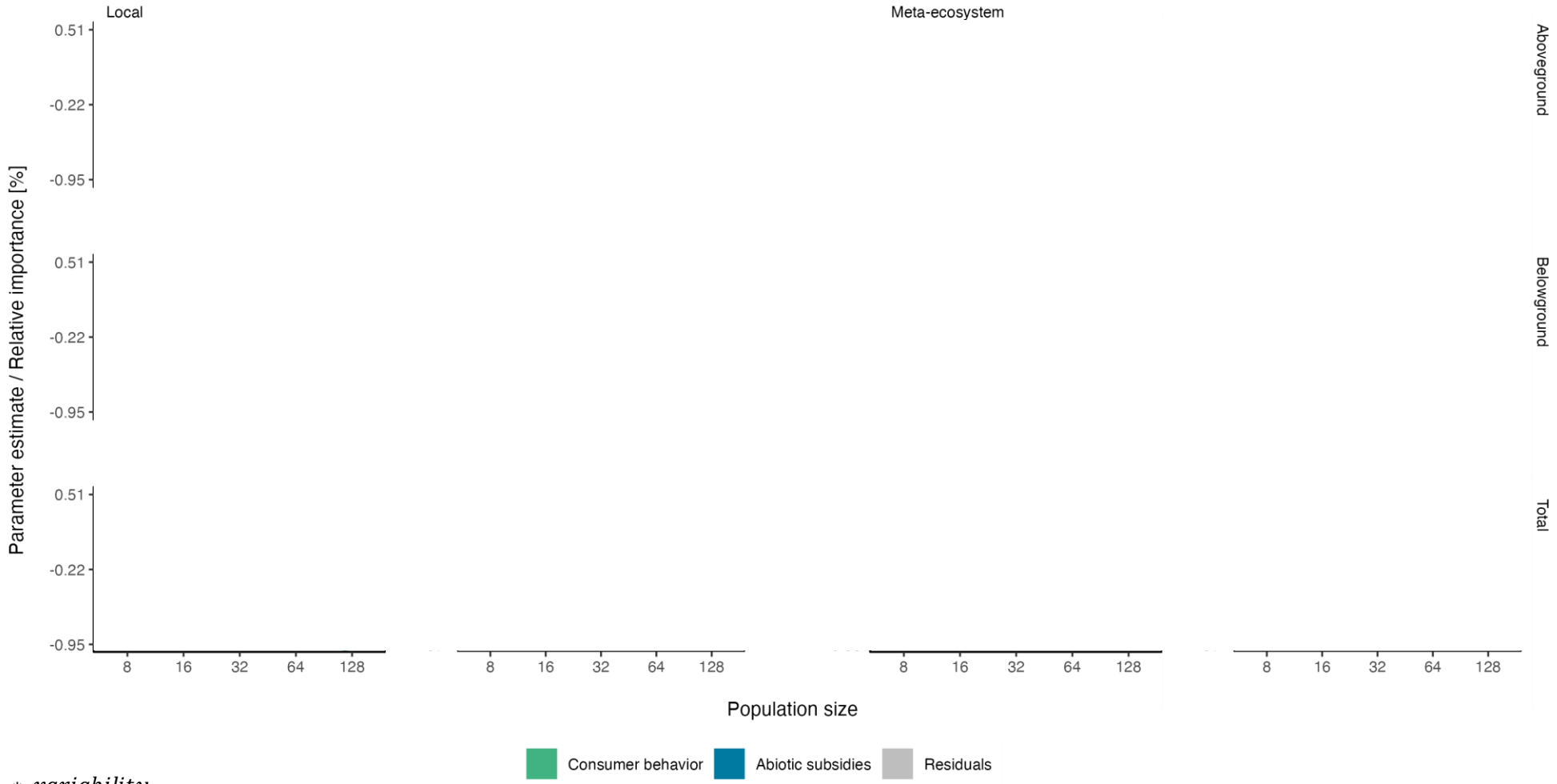
  PP_M = cumulative meta-ecosystem primary production

- Relative importance R^2 of $diversity_{behavior}$ and $variability_{subsidies}$

Wang, S., Loreau, M., 2014. Ecosystem stability in space: α, β and γ variability. Ecol Lett 17, 891–901. https://doi.org/10.1111/ele.12292
Wang, S., Loreau, M., 2016. Biodiversity and ecosystem stability across scales in metacommunities. Ecol Lett 19, 510–518. https://doi.org/10.1111/ele.12582

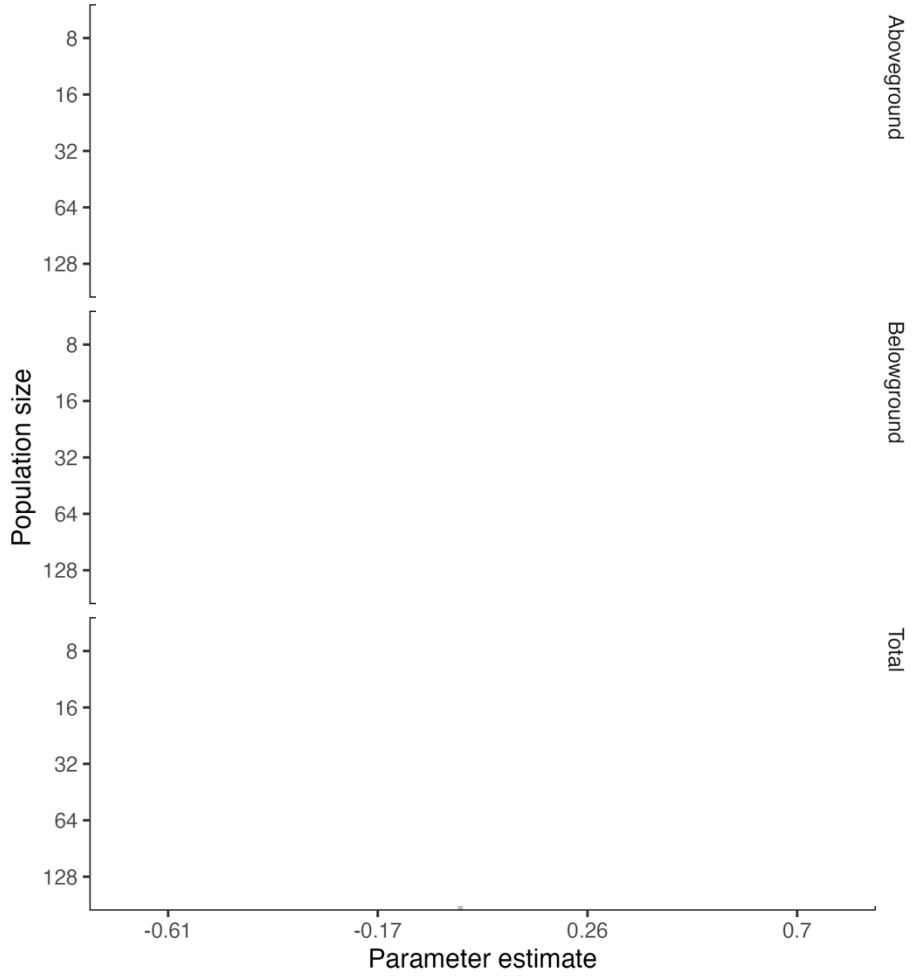
Grömping, U., 2006. Relative importance for linear regression in R: the package relaimpo. J. Stat. Soft. 17. https://doi.org/10.18637/jss.v017.i01

1) How are consumer behavior and abiotic subsidies affecting the stability of primary production on local and meta-ecosystem scale?



$cv_{\alpha/\gamma} \sim diversity_{behavior} * variability_{subsidies}$

2) How are consumer behavior and abiotic subsidies affecting the total primary production on meta-ecosystem scale?



$PP_M \sim diversity_{behavior} * variability_{subsidies}$

Conclusions (II)

- Driving factors and emerging stability patterns differed between local and meta-ecosystem scale
- Stability and cumulative primary production affected by different processes
- Potentially important when evaluating management actions

…how to move on from here…

- Introducing spatially explicit connectivity
- Testing intra- and interspecific behavioral variability
- Simulating multi-species populations

Katrina Munsterman

Sean Richards

Acknowledgments

Jacob Allgeier

Kenzo Esquivel

Katrina Munsterman

Bridget Shayka

Samantha Iliff

Sean Richards

Thank you for your attention!

Any questions?

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