# Trophic complexity, limits on predictability, and emergent ecosystem structure and function in a new size-spectral plankton model

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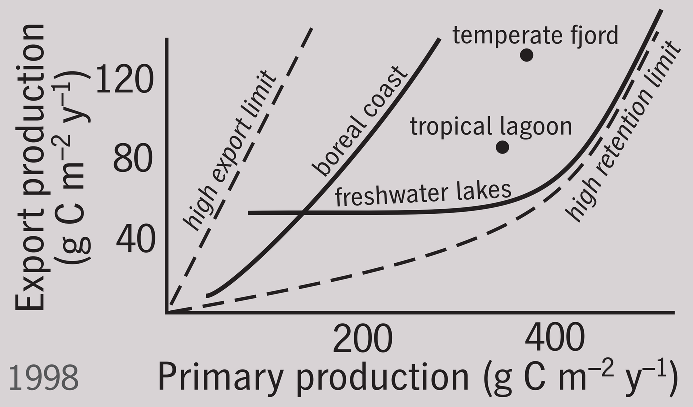
poster, paper, and interactive model at
**http://faculty.washington.edu/banasn/astrocat/**

## 1 · Background



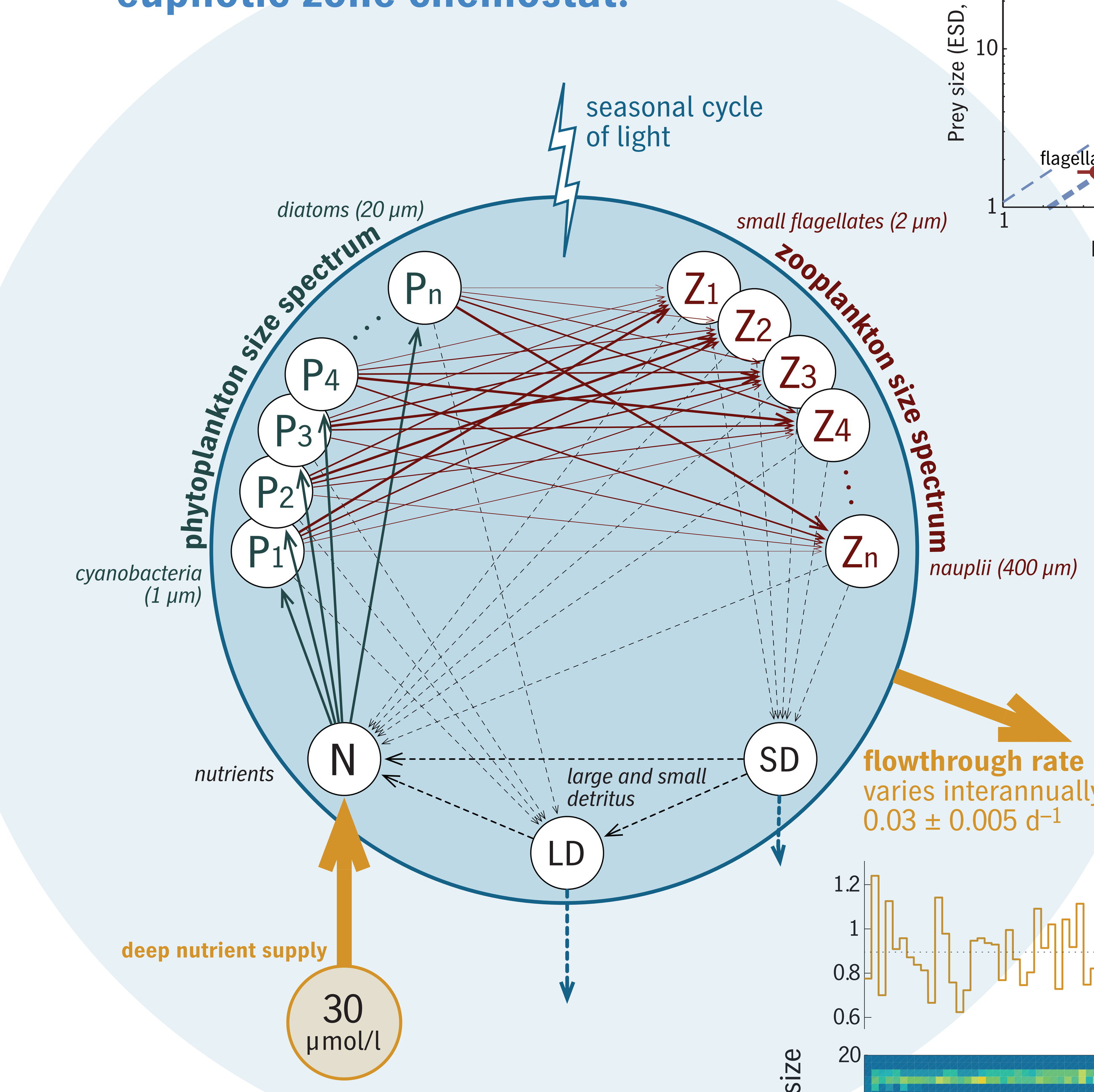

Relationships among production, recycling, and export fluxes vary widely across aquatic ecosystems. Plankton community structure plays a huge role in this, but current marine biogeochemical models lack the flexibility to reproduce this diversity in ecosystem function, or to confidently relate community structure to net fluxes.

Most recent efforts to better include planktonic diversity in biogeochemical models have focused on phytoplankton diversity and adaptive strategies for maximizing primary production (see Smith et al. 2011 for a recent review, including exceptions). This poster describes theoretical experiments in a model chemostat that explore a parallel question:

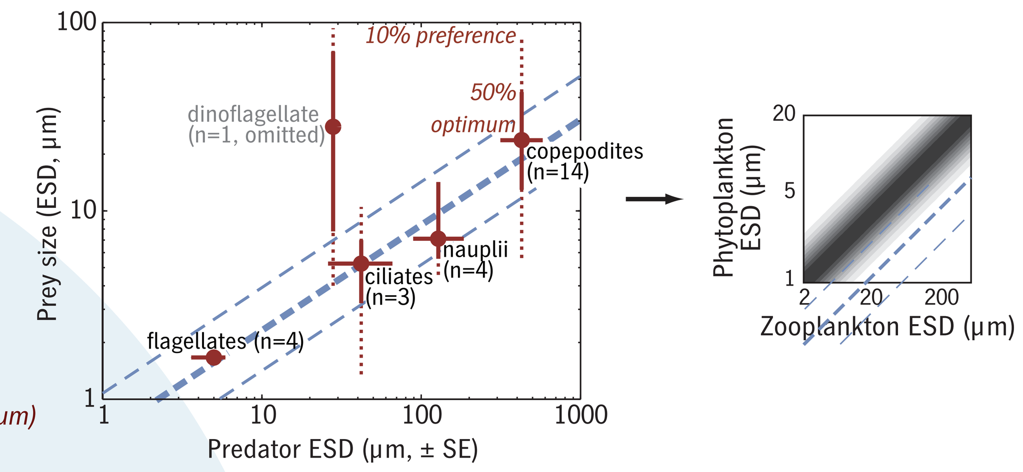
How does **resolving diversity in trophic interactions**—turnover time, prey preference, phytoplankton defensive ability—change a model's representation of community structure and ecosystem function?

## 2 · Adding a *size-based* growth-grazing tradeoff

**ASTroCAT** (Allometric/Stochastic Trophic Complexity Analysis Tool: Banas, *Ecol. Modelling*, 2011) is a framework for systematically adding diversity to the trophic interactions in a planktonic nutrient-cycling model. The experiments described here were run in a **euphotic zone chemostat.**

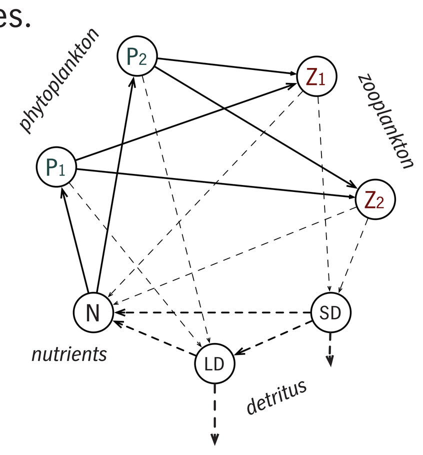


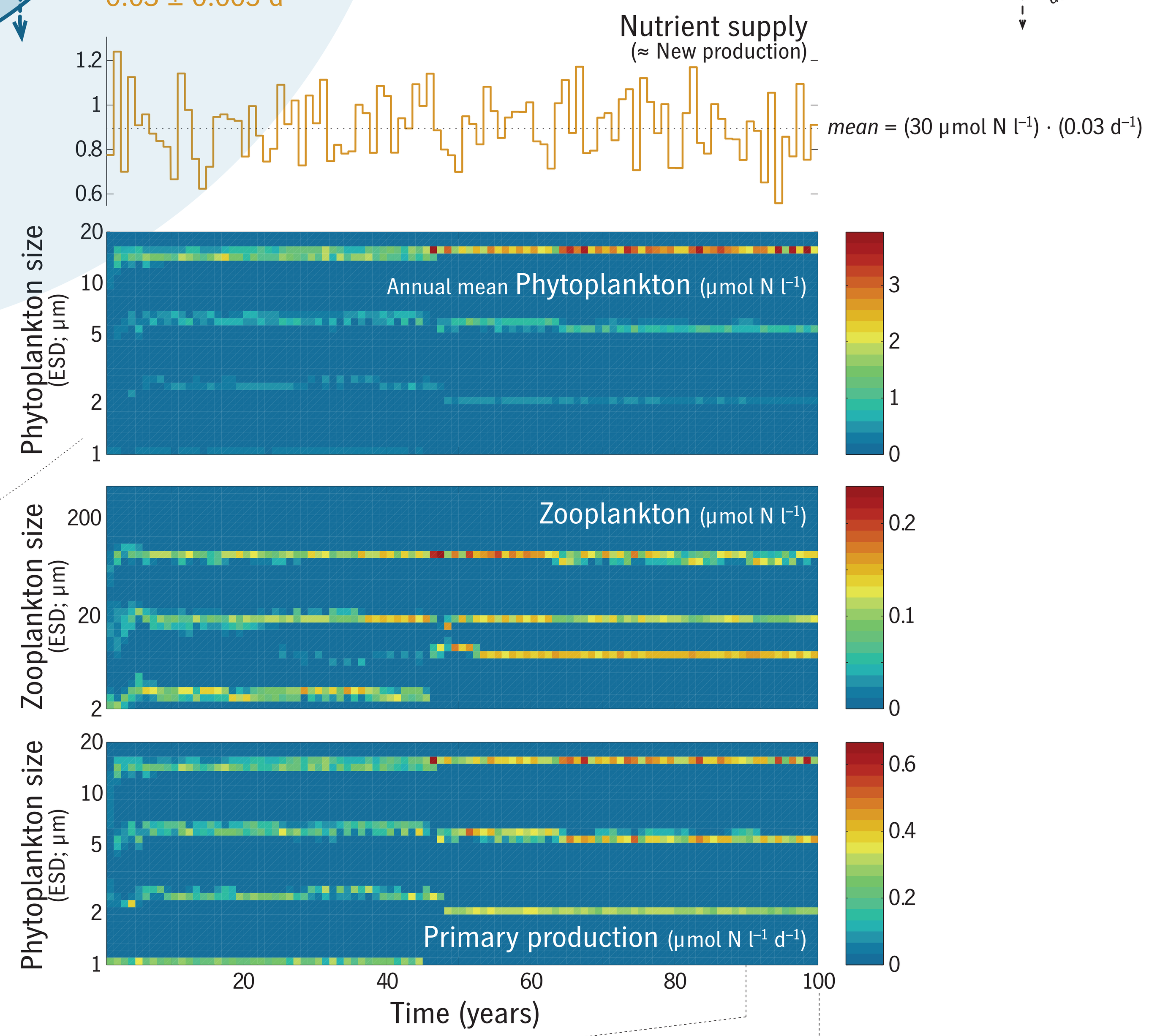

Grazing preferences parameterized using lab-based allometry (Hansen et al., *L&O*, 1994)

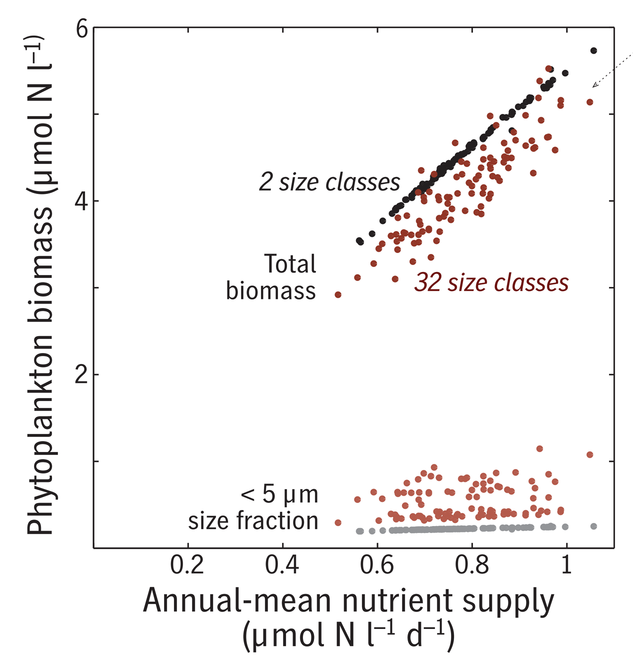


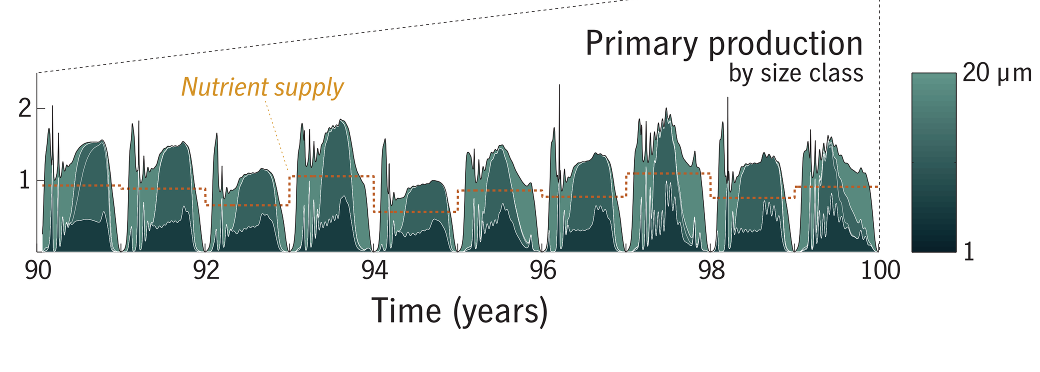

There is a **single tradeoff** along the phytoplankton size spectrum: small phytoplankton grow faster and have lower nutrient requirements than large ones, but have grazers with faster turnover times.

This tradeoff could also be expressed in a simple 2P, 2Z model; this experiment tests the effect of **resolution**.




All organisms in this model have growth rates on the order of 1 d$^{-1}$ or faster, but resolving a continuum of competitors and trophic interactions introduces **long-term time evolution that makes the ecosystem's response to slow (seasonal to interannual) changes in forcing partially unpredictable**, in a pragmatic sense.

Banas (*Ecol. Modelling*, 2011) explored this in more depth, using a simpler version of this testbed, and found that the level of interannual unpredictability is a strong function of prey selectivity: less selective grazers = more interannual variation = lower correlation between annual-mean N supply and biomass (as low as $r^2 = 0.6$).

Resolving the spectrum of trophic interactions also **shifts the mean.**

Phytoplankton biomass: –9% (32 size-class – 2 size-class)

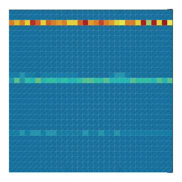
Zooplankton biomass: +16%

Primary production: +13%

Export efficiency: –9%
(export ÷ primary production)

Resolving *mesozooplankton* as a third size spectrum (cf. Baird and Suthers 2007) would likely amplify these effects.

## 3 · Adding a *defense-based* growth-grazing tradeoff



The discontinuities in the biomass spectra suggest that too much competitive exclusion is taking place. Giving the phytoplankton greater adaptive ability allows them to fill more niches, producing a higher level of coexistence and a more continuous size spectrum.

Smith et al. (2009) models optimal nutrient uptake kinetics by allowing phytoplankton to adjust the fractions of their nutrient quota dedicated to

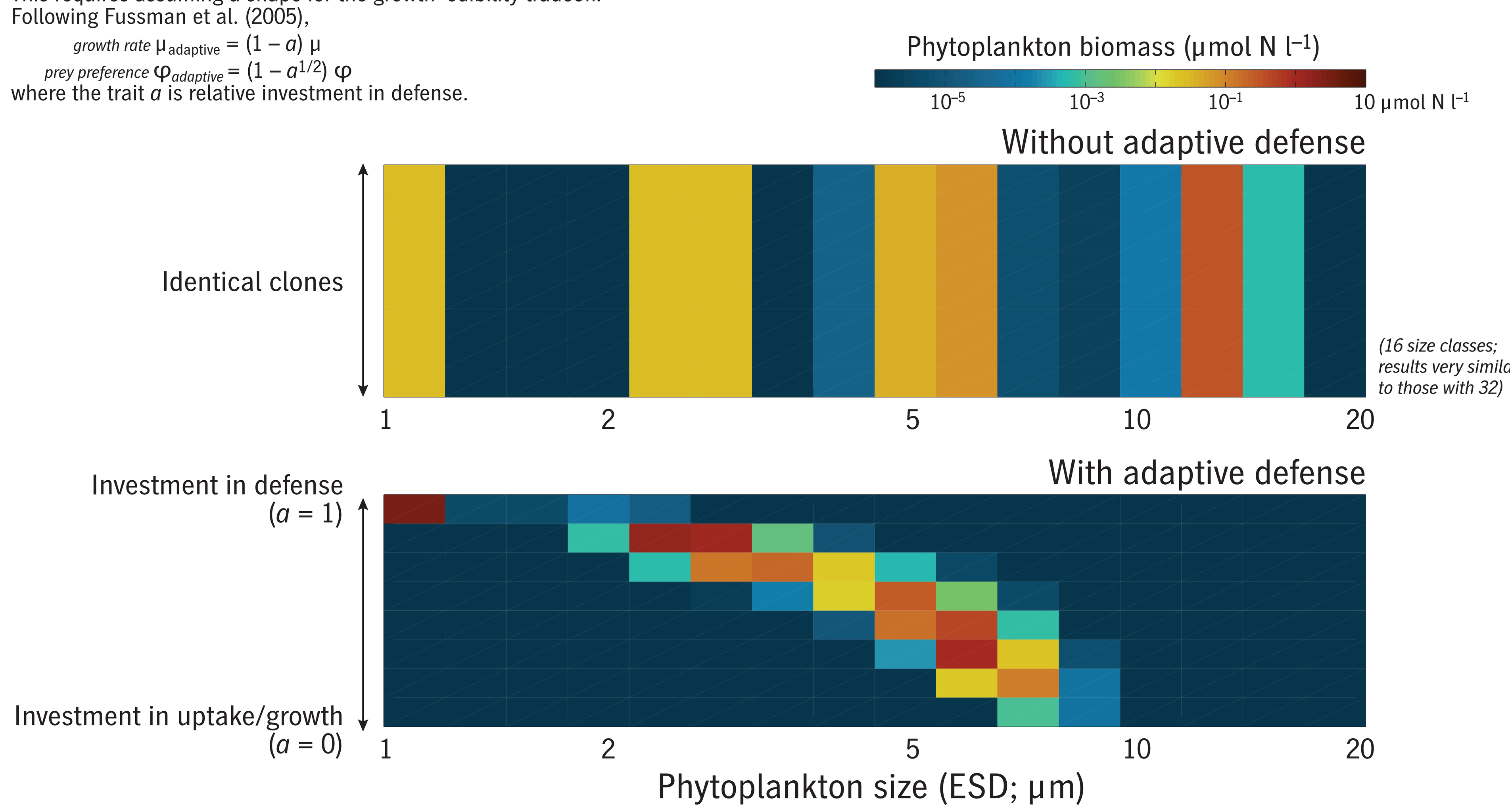

Here I've followed the same framework, but allowed a three-way optimization that includes defensive ability (albeit with no physiological detail).

This requires assuming a shape for the growth–edibility tradeoff. Following Fussman et al. (2005),

*growth rate* $\mu_{\mathrm{adaptive}} = (1 - a)\,\mu$

*prey preference* $\varphi_{adaptive} = (1 - a^{1/2})\,\varphi$

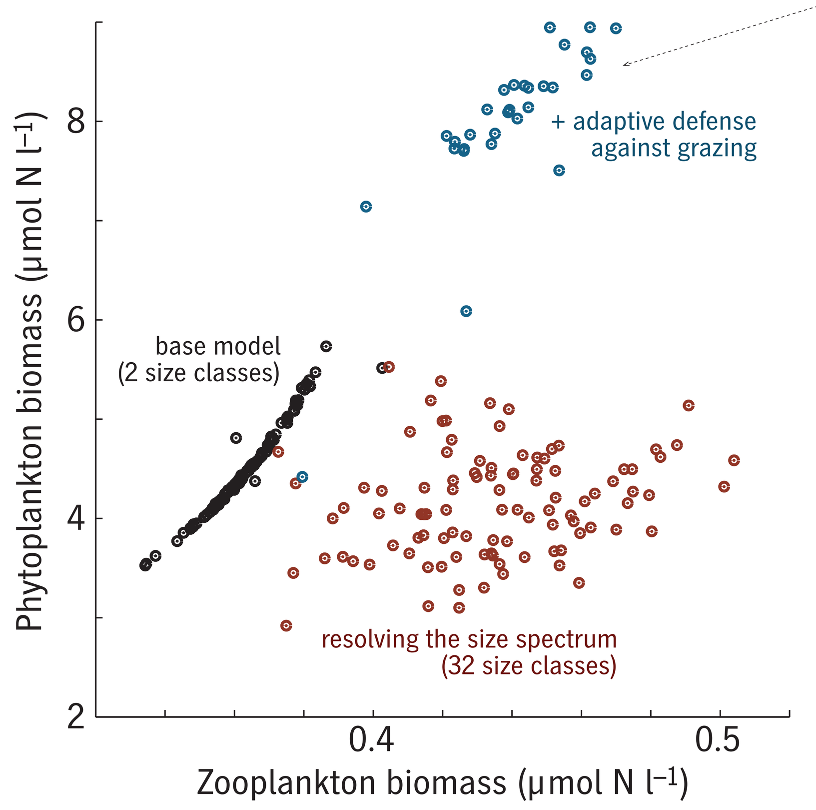
where the trait $a$ is relative investment in defense.




Small phytoplankton invest almost entirely in defense; larger ones invest progressively more in growth. Total biomass **increases**.

The monotonic pattern suggests that the combination of size- and adaptive-defense-based dynamics could be efficiently represented in trait-based or optimality-based form, for inclusion in large-scale biophysical models.

However, it is unclear whether the simplicity of this pattern would persist in a model that resolved mesozooplankton (especially omnivorous mesozooplankton).




Resolving a **second** axis of diversity shifts the mean community structure further.

## Conclusions

Resolving two tradeoffs between phytoplankton growth and grazing—one defined by the allometry of growth rates, nutrient requirements, and prey preferences, the other based on a more theoretical model of optimal investment in defense against grazing—has several effects on a simple model plankton community. Phytoplankton and zooplankton biomass increase, primary production increases, and export efficiency decreases. (This last result in particular might well be different if the model resolved a spectrum of mesozooplankton along with microzooplankton.) The relationship between even very slow changes in forcing and the ecosystem response becomes very noisy.

Transient predator-prey interactions (a.k.a. blooms and "ecosystem weather") play the same role in biogeochemistry that eddies play in ocean circulation or decadal oscillations play in the climate system. Instead of designing biogeochemical models to eliminate them, we could focus instead on resolving them, quantifying their contribution to mean fluxes, and quantifying the unpredictability associated with them through ensemble methods.

This work was supported by NSF and the NOAA Coastal Ocean Program as part of the PNWTOX (Pacific Northwest Toxin) project. The statements, findings, conclusions, and recommendations are those of the author and do not reflect the views of NSF, NOAA or the Department of Commerce.

Many thanks to Kai Wirtz, Mark Baird, Jorn Bruggeman, and Evelyn Lessard for helpful discussions.

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