How top-down effects influence predator:prey ratios and planktonic community diversity in a size-structured model of phyto- and microzooplankton

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Introduction
Many fundamental characteristics of plankton are strongly modulated by cell size in predictable and meaningful ways.
The size-dependency of properties also simplifies modeling the detailed diversity of planktonic assemblages.
In this study we:
I. Describe allometrically scaled rates and properties in a nutrient-phytoplankton-microzooplankton model
II. Examine planktonic community structure and predatory-prey size ratios in a zero- and one-dimensional model
III. Analyse solutions for grazing preference

Many studies assume a fixed 1:1 predator:prey size ratio, and here we investigate if we can recreate that ratio using a trait-based approach

Ia. Model equations

Phytoplankton

\[
dP(t) = P(t) \left( \mu P(t) \frac{N}{N + k} - m P(t) - \frac{1}{h} \frac{P(t)}{P(t) + k} \right) + Z(t)
\]

Microzooplankton

\[
dZ(t) = Z(t) \left( \gamma P(t) - R(t) - \frac{m Z(t)}{R(t) + 1} \right)
\]

Nutrients

\[
N = N + \sum P(t) \frac{Z(t)}{h}
\]

Ib. Phytoplankton parameterization

- Empirical relationships were used to determine allometric relationships for phytoplankton parameters
- Maximum growth rate and nutrient half-saturation constant were allometrically scaled

Ic. Microzooplankton parameterization

- Empirical and theoretical relationships were used to determine the microzooplankton size scalings
- Maximum grazing rate and grazing half saturation constant were formulated using an analogy from enzyme kinetics, using the following equations:

\[
\gamma \propto \frac{1}{s^2} \\
R \propto \frac{1}{s^3}
\]

- Many of these parameters are dependent on the size of both the predator and the prey

IIa. Model results: planktonic size spectra, biomass values, and prey size classes grazed

- The allometric parameters were implemented in a zero-dimensional nutrient-phytoplankton-microzooplankton model
- The simulations were run separately for three different sized microzooplankton and also in a multi-grazer system with all three predators
- Microzooplankton were allowed to graze the prey that led to the greatest intake
- For all simulations, there was not a consistent predator:prey size ratio
- The larger the microzooplankton, the more advantageous to consume a wide prey size range
- The greater the phytoplankton size range consumed, the greater the resulting prey size diversity
- The largest microzooplankton outcompeted the smaller grazers in the multi-grazer system

IIb. Model results: planktonic biomass values for one-dimensional model

- The biological nutrient-phytoplankton-microzooplankton model was coupled with a one-dimensional biogeochemical model
- As in the zero-dimensional case, the same set of single and multi-grazer systems were run
- Each model was run for 5 years, with the last two years shown

Qualitatively similar results to the zero-dimensional model, with the addition of seasonal cycles, emerged

Conclusions
- Consistent with field data and previous modeling efforts, small phytoplankton were relatively more abundant than larger microzooplankton in all model simulations
- Microzooplankton consumed a wide variety of prey sizes, including prey larger than the grazers
- Larger microzooplankton are able to increase the size diversity of the phytoplankton by consuming a wider size range of prey
- Several key size relationships are still unconstrained, which have a strong influence on the model results, such as the exclusion of small predators