Rethinking the critical depth: Nonlinear mortality required to model wintertime phytoplankton growth

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The wintertime period is important because it sets the biological conditions for the spring bloom.

Understanding this period is important for predicting how phytoplankton blooms might change in response to climate change (e.g. increased temperatures, shallower mixed layers).

What can we learn about phytoplankton loss terms through modeling wintertime phytoplankton stocks?

**Traditional theory (Sverdrup 1953)** assumes constant loss rates so phytoplankton stocks begin to increase in the spring when the mixed layer shoals.

**Recent observations (Behrenfeld 2010, Mignot et al 2018)** show increasing phytoplankton stocks in the wintertime.

One hypothesized mechanism for biomass accumulation is decreasing loss rates as the mixed layer deepens due to a reduction in grazing rates at low prey concentration (“dilution-recoupling hypothesis”). The mathematical model proposed here confirms that this is a plausible mechanism.

Both the traditional theory and the dilution-recoupling hypothesis posit that loss terms are dominant in the wintertime.

What can we learn about phytoplankton loss terms through modeling wintertime phytoplankton stocks?

**Nonlinear mortality**

- Dilution alone does not necessarily decrease phytoplankton loss rates.
- With a linear functional response, assuming that the natural phytoplankton mortality is small, if zooplankton and phytoplankton stocks are in equilibrium, they will remain in equilibrium even as the mixed layer deepens.
- With a type III functional response, the grazing rate decreases as the mixed layer deepens.

Grazing rate $g(p)$ as a function of phytoplankton concentration for Holling’s Type I, II, and III functional responses.

**Modeling the winter-spring transition**

Dilution decreases the concentration of both phytoplankton and zooplankton while the mixed layer is deepening.

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Grazing rate $g(p)$ as a function of phytoplankton concentration for Holling’s Type I, II, and III functional responses.

When implemented in a full NPZ model, a grazing function with an inflection at low phytoplankton concentration is sufficient to reproduce both wintertime biomass accumulation and a spring bloom.

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