Allometry in large-scale models of ocean biogeochemical cycling: Underlying patterns and processes

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Outline

- Allometry in marine ecosystems- a cautionary tale from fisheries science
- Allometry in phytoplankton-What do we know
- Allometry in models- how do we handle it?





Fundamental assumption often made in ecology...

As a class of animals gets bigger, they slow down and get more efficient at using energy



77 W/kg



2 W/kg







Classic mathematical model Pütter (1920) $\frac{\partial X}{\partial t} = a * X^n - b * X^m$

Where X is some variable of interest that changes over time (mass, length, volume)

Time variation depends on five parameters (a,b,n,m,X₀)

Equilibrium depends essentially on two parameters (a/b, n-m, with m>n)

Versions of this equation $\frac{\partial X}{\partial t} = a * X^{2/3} - b * X$

Growth of individuals (Von Bertalanffy, 1957) X=L³

$$3L^{2} \frac{\partial L}{\partial t} = a * L^{2} - b * L^{3} \rightarrow \frac{\partial L}{\partial t} = \frac{a}{3} - \frac{b}{3} * L$$
$$b = \frac{a}{L} \approx \frac{a}{V^{1/3}}$$

 L_{∞}

Note: (West et al. scaling can be transformed into exactly the same framework by using L^4)

Result: Exponential approach of fish towards a maximum size

- Fisheries community spends a great deal of time defining these parameters.
 - Fishbase dataset at UBC quantifies this across 2,497 (!) species.

Vincenzi et al. Ecological Applications, 2016

500

400

300

200

100

Length (mm)





But...

- What about the sink term?
- Is basal metabolism the only thing we care about?
- As organisms get bigger, they devote more resources to reproduction



A second example of the equation

$$\frac{\partial X}{\partial t} = r * X^1 - r/K * X^2$$

Logistic growth (Verhulst, 1838) m=2, n=1, a=r, b=r/K r=intrinsic growth K=carrying capacity

YFT Atlantic production model (1969-1992)

Fishing rate

Gaertner et al., 2001

Underlies ideas of maximum sustainable yield in fisheries- density dependent mortality means one can remove biomass and increase net productivity.



Age

In this framework, catching fish at the top of the curve just pulls off the one that are hogging resources and can result in a healthier, more productive population.











In this framework, removing the matriarchs results in a disproportionate impact on reproduction.







Key lessons from Section 1

- Allometry can serve as a powerful tool for data reduction but requires...
- Understanding balance between growth and loss.
- Understanding mechanisms underlying growth and loss









Section 2: Allometry amongst the plankton -What have we learned?











May also be spatially variable











How are these ideas implemented in large-scale models?

Summ





Most models have a structure that is generically like the following

Change of phyto = Growth – Grazing

$$\frac{\partial P}{\partial t} = \mu * P - \lambda \left(\frac{Z}{Z_*}\right) * P$$

Change of zoo = incorporation of phyto – grazing of zoo

$$\frac{\partial Z}{\partial t} = \epsilon \lambda \left(\frac{Z}{Z_*}\right) * P - \gamma \left(\frac{Z}{Z_*}\right) Z$$



Quasi-equilibrium solution

Then at equilibrium

Both classes go as growth rate.

Small plankton dominate at low nutrients because of lower half-saturation coefficient (higher growth)

 $Z \sim \frac{\mu}{\lambda}, P \sim \frac{\mu}{\lambda^2}$

Large plankton dominate at high concentrations because of lower grazing rates.









But when we implement this...



Alternative implementation (GFDL BLING, miniBLING, TOPAZ)

$$\frac{\partial Z}{\partial t} = \epsilon \lambda \left(\frac{Z}{Z_*}\right) * P - \gamma \left(\frac{Z}{Z_*}\right)^3 Z$$

Implies that grazers on large plankton are much more highly controlled by grazing.

Result is that

 $P \sim \mu^3$, $Z \sim \mu$





Result





However...



Limited data from the MareDAT database suggests that microzooplankton actually track nanoplankton.

Does this suggest that grazing on picoplankton is too strong?





Conclusions

- We ought to include allometry as a constraint on our models.
- But we need to be cognizant that mechanisms matter.
- Scaling grazing with higher trophic level biomass especially important.
- Mixotrophy?
- Patchiness?



LIBERAL-ARTS MAJORS MAY BE ANNOYING SOMETIMES, BUT THERE'S NOTHING MORE OBNOXIOUS THAN A PHYSICIST FIRST ENCOUNTERING A NEW SUBJECT.



