Stoichiometry of consumer-driven nutrient cycling: Background and theory

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TRIGGER WARNING

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Stoichiometry

Mass balance of multiple conserved substances in ecological interactions
There are stoichiometric stories across all levels of organization – and they relate!

I’ll be spending most of my time around the organism level.
How do we unpack this box?

What are the functional couplings?

How do we overlay multiple cycles?

Finkel et al. JPR 2010

A highly multidimensional problem!
Consumers are important as nutrient recyclers (Ketchum 1962, Lehman 1980, Vanni, Atkinson and others).

Might we build up an understanding species by species, “wiring” in measured values.
The P released per biomass ingested varied with P:C of food, and became zero at low food P levels.

Animals were actively maintaining their P balance by adjusting C vs. P budgets.

Y. Olsen et al. L&O 1986
Dominance by larger grazers was associated with P instead of N limitation.

Food web shifts result in biogeochemical adjustments.

Elser et al. L&O 1988
Homeostasis “inflected” the relationships, depressing N:P released at low food N:P and increasing N:P released at high food N:P.

At the time of this paper, open Q was what was best value for zooplankton N:P. So calculated model with a range of values.

**Fig. 3.**—Under the model of strict homeostasis, the ratio of nitrogen to phosphorus (N:P) released and therefore resupplied to algae (s) is predicted to vary with the N:P in the algal pool (f) according to the curvilinear relationships pictured. Shown are solutions to equations (9) using $L = 0.5$ (left) and $L = 0.9$ (right) when $b = 5$ (left curve), 10, 15, 20, and 25 (right curve).
Andersen and Hessen L&O 1991

Not all crustacean zooplankton have same C, N, P. Daphnia high P, low N. Copepods high N, low P.

Andersen and Hessen L&O 1991
Used Sterner’s recycling model and Andersen/Hessen measurements of zooplankton N:P to retroactively “predict” biogeochemical shifts observed by Elser et al. 1988.

Linked food web shifts to biogeochemical cycling through stoichiometrically explicit modeling.

Sterner et al. Biogeochem 1992
Stoichiometric building blocks

1. Species in ecosystems have multiple roles and affect biogeochemical cycling of multiple substances including the primary limiting nutrients.
2. We might predict some complex ecosystem dynamics with relatively simple mass-balance relationships.
3. Organisms are biodiverse and ALIVE! They don’t fit into food webs/OCB like passive, linear transducers.
Implications of stoichiometric mismatches
One species of zooplankton herbivore, consuming one species of algae, had very different growth dynamics depending on how algae were grown. Only years later did we learn that *D. obtusa* had very high body P and thus high P demands.
Variation in nutrient content of algae affects zooplankton growth.
Biodiversity as a challenge, made more acute by advances in barcoding, etc.

Do we need a “new theory” for every subspecies of consumer?

http://dna-barcoding.blogspot.com/2014/03/from-puffins-to-plankton.html

“Rules of Life”? (J. Olds, NSF-BIO)
Unexpectedly high variation in elemental content of freshwater zooplankton while intraspecific variation was comparatively small.

Hypothesized that high P was related to high RNA and thus there was a tradeoff between high growth with good food and good growth on poor food.
Mineral form of P: Apatite

\[ \text{Ca}_5\text{F(PO}_4\text{)}_3 \]
\[ \text{Ca:}P = 5:3 = 2.3 \]

chlorine, hydroxyl, or carbonate
often replacing the fluoride


Stoichiometry of nutrient recycling by vertebrates in a tropical stream: linking species identity and ecosystem processes
Promising! A simple measure (P content of animal) was associated with something potentially very complicated – how fast that animal grows on different living foods.
There have been some great successes in applying stoichiometric relationships to organism growth and nutrient cycling.

But not all studies that attempt this find high predictive power with stoichiometry.
More on the importance of growth
Fig. 3 Growth rates of the rotifer *Brachionus rubens* as a function of food quantity and quality (redrawn from original data provided by K.-O. Rothhaupt, published originally in Rothhaupt, 1995).
Carbon and phosphorus linkages in *Daphnia* growth are determined by growth rate, not species or diet

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Fig. 2. Diet P strongly influences growth rates ($F_{0.14} = 36.32, P < 0.001$) and P contents ($F_{0.14} = 5.45, P < 0.001$). Mean dry mass growth (day $^{-1}$; a) and percent P (b) for all seven species grown on three diets (L = low P, S = switch treatment and H = high P). Error bars are 1 standard error. Letters represent significant differences within a species among diets (Tukey HSD, $P < 0.05$). Species are sorted by $\mu_{GM}$ in the HP treatment.
Q: What determines the sensitivity of growth to P limitation? Are “high P” species more sensitive?

Fast growing species more susceptible to P limitation.

Growth:efficiency tradeoff.

“No” relation with P content at HP algae:

Plus relation with growth at HP algae:
A perhaps universal relationship linking C and P additions associated with growth: As more P is added to body, relatively more C is added but not proportionately. Works across species and across treatment.

Species with low max growth, small scope for change in C:P.

Species with high max growth, large scope for change in C:P.
Take Homes

Ecological stoichiometry is based on rules for linking elements during organism growth. These then feed back on production dynamics and ecosystem properties.

The art of making things just complicated enough to explain patterns but not more so remains a challenge.
Thank you!

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