Grazing phytoplankton: Size matters

I. Microzooplankton grazing
II. Types of mesozooplankton
III. Zooplankton grazing at low Reynolds numbers
IV. Zooplankton food webs
V. Zooplankton, phytoplankton, and biogeochemistry

Herbivorous zooplankton: Grazers

- Herbivores: feed primarily on phytoplankton
- Carnivores: feed primarily on other zooplankton (animals)
- Detrivores: feed primarily on dead organic matter (detritus)
- Omnivores: feed on mixed diet of plants and animals and detritus

Zooplankton nutrition
Zooplankton size classifications

- **Microzooplankton**: Single celled (protists) that eat phytoplankton and bacteria (< 0.2 mm)
  - Microzooplankton: Ciliates – eat flagellates
  - Nanozooplankton: dinoflagellates and flagellates – eat bacteria and small phytoplankton
  - Amoebas: Radiolaria and foraminifera
- **Mesozooplankton**: 0.2 mm to 30 mm (averaging about the size of a rice grain). These include all nutritional modes
- **Macrozooplankton**: > 1 cm. All nutritional modes.

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Microzooplankton grazing:

How can you determine rates of grazing by microbes in the sea?

Dilution method:

\[
\ln\left(\frac{P_t}{P_0}\right)/t = \mu - g D
\]

- \(\mu\) = prey specific growth rate, \(d^{-1}\) (density independent)
- \(g\) = community grazing rate, \(d^{-1}\) (density dependent)
- \(D\) = dilution

**Graph**:

![Graph showing dilution vs. apparent growth rate](image)

**Equations**:

\[
\text{Slope} = g, \text{ community grazing rate} \ (d^{-1})
\]

**Intercept** = \(\mu\), specific growth rate \(d^{-1}\) of prey

Grazing rates high during blooms (periods with high growth rates)

**References**:

- Strom et al. 2001

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**Phytoplankton growth and grazing at a station in the San Juan Islands**

**Graph**:

![Graph showing growth and grazing comparison](image)

**Legend**:

- Growth or grazing rate \(d^{-1}\)
- Months: Nov, Feb, May, Aug

**Fig. 3** Seasonal cycle in phytoplankton growth (solid bars) and microzooplankton grazing (open bars) in northern Puget Sound data (for total chlorophyll only). Compilation of data from two different years.

**Strom et al. 2001**

Grazing rates high during blooms (periods with high growth rates)

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**Small phytoplankton grazed at higher rates than large phytoplankton**

**Graph**:

![Graph showing small vs. large phytoplankton grazing rates](image)

**Legend**:

- Total, >5 µm, <8 µm
- Months: Nov, Feb, May, Aug

**Strom et al. 2001**

Could grazing contribute to diatom dominance in Puget Sound?
Visualizing copepod grazing

- https://www.youtube.com/watch?v=5RZwLbRd3b4

Zooplankton grazing on phytoplankton (copepods)

Old view:  Copepods fed with “sieves”
           Collected algae by filter feeding

New View:  Copepods pick individual cells out of the water
           Locate cells by following chemical “plumes”

          Zooplankton feed at low Reynold’s numbers:
          Impossible to “sieve” water at this scale
Reynolds numbers and fluid flow

\[ \text{Re} = \frac{L \cdot v}{\nu} \]

(length)(velocity)
(ynamic viscosity)

\[ \text{Re} < 10: \text{Laminar} \]
\[ \text{Re} > 10^4: \text{Turbulent} \]
\[ 10 < \text{Re} < 10^4: \text{Transitional} \]

(depending upon geometry)
For pipes, transitional flow: \( \sim 2000 < \text{Re} < \sim 4000 \)

Zooplankton feeding at low Reynolds numbers

Reynolds number: \( \text{Re} = \frac{\text{length} \cdot \text{velocity} \cdot \text{viscosity}}{\nu} \)

[m] \( \times \) [m/s] / [m^2/s]

Seawater kinematic viscosity = 10^-6 m^2/s (at 20 °C)

Flow around a phytoplankton cell:
\( \text{Re} = 10 \times 10^{-6} \text{[m]} 1 \text{[m/s]} / 10^{-6} \text{[m}^2\text{/s]} = 10 \) (laminar)

Flow around a zooplankter:
Feeding: \( \text{Re} = 20 \times 10^{-6} \text{[m]} 50 \times 10^{-3} \text{[m/s]} / 10^{-6} \text{[m}^2\text{/s]} = 1 \) (laminar)
Swimming: \( \text{Re} = 1 \times 10^{-3} \text{[m]} 0.1 \text{[m/s]} / 10^{-6} \text{[m}^2\text{/s]} = 100 \) (~transitional) (bursts)

Examples of Reynolds numbers of flow around organisms

\[ \text{Re} \]

A large whale swimming at 10 m s^-1 300,000,000.
A tuna swimming at the same speed 30,000,000.
A duck flying at 20 m s^-1 300,000.
A large dragonfly going 7 m s^-1 30,000.
A copepod in a pulse of 20 cm s^-1 300.
Flight of the smallest flying insects 30.
An invertebrate larva, 0.3 mm long, moving at 1 mm s^-1 0.3.
A sea urchin sperm advancing the species at 0.2 mm s^-1 0.03.

From Vogel 1981
Predacious copepods: Euchaeta
Impales prey with modified feeding appendages
Locates prey by sensing vibrations

Movies of copepod feeding and feeding currents
http://www.youtube.com/watch?v=Ggk2O7p4yWQ&feature=endscreen
http://www.youtube.com/watch?v=s0Zc15KZS00

Diel vertical migration of zooplankton
Example: *Euchaeta* in Puget Sound
(Ohman 1990)
Phytoplankton, zooplankton, and nitrogen cycling in the open sea

Phytoplankton production

Zooplankton grazing

Regenerated production

NH$_4^+$, NO$_3^-$

NH$_4^+$

New production

Deep water mixing

Vertical migration by zooplankton efficiently delivers nutrients to deep water

Zooplankton contribution to carbon cycling and the biological pump

CO$_2$ enters ocean and equilibrates with carbonates (→ HCO$_3^-$)

Phytoplankton production converts HCO$_3^-$ to particulate organic C

Zooplankton grazing

CO$_2$

Return of CO$_2$ to atmosphere via gas exchange

HCO$_3^-$

Dissolved organic carbon (DOC)

Loss of particulate organic C from surface water

Vertical migration by zooplankton

Size matters