Announcements

• Quiz on the fish paper (Ware and Thompson) after break
• Nutrient budget assignment

What happens when the top predators disappear?

Nutrients, etc. → Phytoplankton → Zooplankton → Fish, Birds, Mammals

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
Zooplankton nutrition

- 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 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.

Microzooplankton grazing:

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

Dilution method:
\[ \ln \left( \frac{P_t}{P_0} \right) / t = \mu - gD \]

- \( \ln \left( \frac{P_t}{P_0} \right) / t \) = prey net growth rate (‘apparent’ growth rate, d\(^{-1}\))
- \( \mu \) = prey specific growth rate, d\(^{-1}\) (density independent)
- \( g \) = community grazing rate, d\(^{-1}\) (density dependent)
- \( D \) = dilution

\[ \text{Intercept} = \mu, \text{specific growth rate (d}^{-1}\text{) of prey} \]
\[ \text{Slope} = g, \text{community grazing rate (d}^{-1}\text{)} \]

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

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

- Strom et al. 2001
Small phytoplankton grazed at higher rates than large phytoplankton

Could grazing contribute to diatom dominance in Puget Sound?

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

\[ \text{Re} = \frac{L \cdot \nu}{\nu} \]  
(length)(velocity)  
(kinematic viscosity)

Re < 10: Laminar  
Re > 10^4: Turbulent  
10 < Re < 10^4: Transitional  
(dependents upon geometry)

For pipes, transitional flow: ~2000 < Re < ~4000

Zooplankton feeding at low Reynolds numbers

Reynolds number: \( \text{Re} = \frac{\text{length} \cdot \text{velocity}}{\text{viscosity}} \)  
[m] * [m/s] / [m^2/s]

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

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

Flow around a zooplankter:

Feeding: \( \text{Re} = 20 \times 10^{-6} \frac{[\text{m}]}{50 \times 10^{-3} \frac{[\text{m/s}]}{10^{-6} \frac{[\text{m}^2/\text{s}]}{= 1 \text{ (laminar)}} \)} \)

Swimming: \( \text{Re} = 1 \times 10^{-3} \frac{[\text{m}]}{0.1 \frac{[\text{m/s}]}{10^{-6} \frac{[\text{m}^2/\text{s}]}{= 100 \text{ (transitional)}} \)} \) (bursts)

Examples of Reynolds numbers of flow around organisms

<table>
<thead>
<tr>
<th>Description</th>
<th>( \text{Re} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>A large whale swimming at 10 m s^-1</td>
<td>300,000,000</td>
</tr>
<tr>
<td>A tuna swimming at the same speed</td>
<td>30,000,000</td>
</tr>
<tr>
<td>A duck flying at 20 m s^-1</td>
<td>300,000</td>
</tr>
<tr>
<td>A large dragonfly going 7 m s^-1</td>
<td>30,000</td>
</tr>
<tr>
<td>A copepod in a pulse of 20 cm s^-1</td>
<td>300</td>
</tr>
<tr>
<td>Flight of the smallest flying insects</td>
<td>30</td>
</tr>
<tr>
<td>An invertebrate larva, 0.3 mm long, moving at 1 mm s^-1</td>
<td>0.3</td>
</tr>
<tr>
<td>A sea urchin sperm advancing the species at 0.2 mm s^-1</td>
<td>0.03</td>
</tr>
</tbody>
</table>
Movies of copepod feeding and feeding currents

http://www.youtube.com/watch?v=Ggk2O7p4vWQ&feature=endscreen
http://www.youtube.com/watch?v=p0Ze5KZS00

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

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

Re generated production

New production

Deep water mixing

CO₂ enters ocean and equilibrates with carbonates (\(\rightarrow\) HCO₃⁻)

Phytoplankton production converts HCO₃⁻ to particulate organic C

Zooplankton grazing

CO₂ returns to atmosphere via gas exchange

Dissolved organic carbon (DOC)

Loss of particulate organic C from surface water

Size matters