Plankton Biomass and Food Web Structure

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Food Web Structure is Central to Elemental Cycling
“Microsystems”

In every liter of seawater there are all the organisms for a complete, functional ecosystem.

These organisms form the fabric of life in the sea - the other organisms are embroidery on this fabric.
Important things to know about ocean ecosystems

- **Population size and biomass** (biogenic carbon): provides information on energy available to support the food web

- **Growth, production, metabolism**: turnover of material through the food web and insight into physiology.

- **Controls on growth and population size**
In a “typical” liter of seawater...

- Fish: None
- Zooplankton: 10
- Diatoms: 1,000
- Dinoflagellates: 10,000
- Nanoflagellates: 1,000,000
- Cyanobacteria: 100,000,000
- Prokaryotes: 1,000,000,000
- Viruses: 10,000,000,000
High abundance does not necessarily equate to high biomass. Size is important.
Why are pelagic organisms so small?

Consider a spherical cell:

\[ SA = 4\pi r^2 \]
\[ V = \frac{4}{3} \pi r^3 \]

The smaller the cell, the larger the SA:V. Greater SA:V increases their ability to absorb nutrients from a dilute solution. This may allow smaller cells to outcompete larger cells for limiting nutrients.
• “Typical” concentrations of inorganic nutrients in the open sea:
  – Subtropical North Pacific:
    • Nitrate+nitrite 1-10 nM (0.001-0.01 µM)
    • Phosphate 10-40 nM (0.01-0.04 µM)

• “Typical” concentrations of inorganic nutrients in soils:
  • Nitrate+Nitrite 5-100 µM
  • Phosphate 5-30 µM
Why do we care about biomass?

- Information on biologically stored energy
- Quantify the amount of carbon held in marine biota (carbon budgeting purposes)
- Identify how much “material” is available at each step of the food chain.
The way biomass is distributed among trophic levels in the food web provides clues to the efficiency of energy transfer through the ecosystem.

Note: this is a static depiction—it does not provide information on how fast biomass turns over within each trophic level.
Why carbon?

- Common “currency” among all organisms.
- Carbon serves as a proxy for ecosystem energy

\[ \text{AN} = 6 \ (6\text{P}/6\text{N}) \]
\[ \text{AW} = 12.011 \]
Oxidation: -4 to +4
Electrons: 1s^22s^2p^2
Isotopes: ^{11}\text{C}, ^{12}\text{C}, ^{13}\text{C}, ^{14}\text{C}
Forms: oxides, hydrides, sulfides and halides
All living organisms utilize the same molecular building blocks.

- **Carbohydrates**: sugars and sugar polymers (mono- and polysaccharides). Monosaccharides used for energy and nutrients (carbon), polysaccharides are used for energy storage (starch), cell structure (chitin).

- **Lipids**: long-chained hydrocarbons; includes fatty acids, phospholipids, pigments, steroids.

Hydrophobic hydrocarbon and hydrophilic phosphate-containing functional group makes phospholipids ideal membranes.
Molecular constituents of cells (cont.)

- **Proteins**: amino acid polymers used for regulation of metabolism (enzymes), cell structure, nutrient/energy storage, solute transport, signaling, defense.

- **Nucleic acids**: polymers of nucleotides that comprise DNA and RNA. Store and transmit hereditary information (also structural RNAs).
The elemental composition of a typical bacterium

<table>
<thead>
<tr>
<th>Element</th>
<th>% dry</th>
<th>Substrate Source</th>
<th>Cellular Components</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>55</td>
<td>DOC, CO₂</td>
<td>Main constituent of cellular material</td>
</tr>
<tr>
<td>O</td>
<td>20</td>
<td>O₂, DOM, CO₂</td>
<td>Constituent of cell material and cell water; O₂ primary electron acceptor in aerobic respiration</td>
</tr>
<tr>
<td>N</td>
<td>10</td>
<td>NH₃, NO₃⁻, NO₂⁻, DON, N₂</td>
<td>Constituent of amino acids, nucleic acids, nucleotides, and coenzymes</td>
</tr>
<tr>
<td>H</td>
<td>8</td>
<td>DOM, H₂</td>
<td>Main constituent of organic compounds and cell water</td>
</tr>
<tr>
<td>P</td>
<td>3</td>
<td>PO₄³⁻, DOP</td>
<td>Constituent of nucleic acids, nucleotides, phospholipids, LPS</td>
</tr>
<tr>
<td>S</td>
<td>1</td>
<td>SO₄²⁻, H₂S, HS, DOM</td>
<td>Constituent of cysteine, methionine, glutathione, several coenzymes</td>
</tr>
<tr>
<td>K</td>
<td>1</td>
<td>Potassium salts</td>
<td>Main cellular inorganic cation and cofactor for certain enzymes</td>
</tr>
<tr>
<td>Mg</td>
<td>0.5</td>
<td>Magnesium salts</td>
<td>Inorganic cellular cation, cofactor for certain enzymatic reactions</td>
</tr>
<tr>
<td>Ca</td>
<td>0.5</td>
<td>Calcium salts</td>
<td>Inorganic cellular cation, cofactor for certain enzymes</td>
</tr>
<tr>
<td>Fe</td>
<td>0.002</td>
<td>Iron salts, DOM</td>
<td>Component of cytochromes and Fe-proteins; cofactor for many enzymes</td>
</tr>
</tbody>
</table>
The Struggle for Composition

- Plankton are relatively enriched in P, N, C, Fe compared to the surface seawater.

- Energy must be expended to acquire and maintain intracellular concentrations of these elements.
How do we measure plankton biomass?

- Count and measure individuals and calculate carbon
- Weigh (either dry or wet) cells and calculate biomass
- Estimate living carbon using some biomolecule proxy (DNA, ATP, chlorophyll)
Particulate carbon

- Technique: combust (oxidize) organic material and measure resulting CO$_2$.
- Need to concentrate cells: typically glass filters (usually ~0.7 $\mu$m pore size) or tangential flow (Fukuda et al. 1998)
- Measurements include living cells and detritus.
Zooplankton

• Small zooplankton are usually enumerated by microscopy and converted to cell carbon

• Larger zooplankton can be weighed for approximation of carbon.

Primary consumers (herbivores)

Secondary consumers (carnivores)
Phytoplankton carbon

- Phytoplankton carbon determinations are most often derived from measurements of chlorophyll; this requires a conversion factor.
- Phytoplankton carbon can also be estimated based on cell size and abundances (microscopy and/or flow cytometry).
Chlorophyll is frequently estimated by satellite remote sensing.
Carbon to Chlorophyll Conversions

- Chlorophyll concentrations can vary depending on physiological and environmental history of the cells.
In the ocean gyres, chlorophyll concentrations are low in the surface water, greater at depth (80-150 m). In contrast, most of the production (=synthesis of biomass) occurs in the well-lit upper ocean.
ATP as an indicator of biomass

- All living cells contain ATP
- ATP degrades rapidly after cell death
- ATP:C ratio appears well conserved
- ATP:C ~250:1 (mg : mg)
- Non-discriminate, includes all living material

Fig. 2. Relationship of ATP (adenosine triphosphate) content of planktonic organisms to their carbon content. Units are picograms ($10^{-12}$ g), for bacteria (▲), phytoplankton algae (●) and two zooplanktonic copepods (■). (From Holm-Hansen.42)
Euphotic zone typically ~30-75% of particulate material contains ATP.
Determining Biomass by Microscopy

- Filter seawater onto polycarbonate filter or concentrate cells by settling (large phytoplankton)
- Stain cells
- Visualize cells by light and/or fluorescence microscopy
- Count cells and measure cell sizes
- Use conversion factors to calculate carbon
Application of flow cytometry to abundance/cell sizing
Planktonic biomass generally declines with increasing depth—why?
Important exceptions to the logarithmic decline in biomass with depth
Biomass pyramids in large areas of the open ocean appear inverted, with secondary producers comprising a major fraction of ecosystem biomass.

Gasol et al. (1997)
An inverted food web in low productivity ecosystems?

How is this biomass pyramid sustained?
Rapid turnover of phytoplankton biomass.
Plant Biomass and Productivity in Marine and Terrestrial Ecosystems

<table>
<thead>
<tr>
<th>Ecosystem</th>
<th>Biomass ($10^{15}$ g)</th>
<th>Net Primary Production ($10^{15}$ g year$^{-1}$)</th>
<th>Turnover time (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marine</td>
<td>1-2</td>
<td>45-55</td>
<td>0.02-0.06</td>
</tr>
<tr>
<td>Land</td>
<td>600-1000</td>
<td>55-70</td>
<td>9-20</td>
</tr>
</tbody>
</table>

The main punch line:
Despite low biomass, plankton biomass turnover is rapid – implies rapid cycling of bioelements in the sea.