I. Ocean Circulation

II. Water Column Production
   A. Coastal Oceans
   B. Open Oceans
   E. Micronutrients
   F. Harmful Algal Blooms

III. Zooplankton and Nekton

The water column is also important to benthic production over a great part of the ocean.
Cold to Hot

What are the important primary producers in the water column?
- Diatoms
- Cyanobacteria
- Coccolithophorids
- Cryptomonads

Dinoflagellates
All microscopic and mostly as single cells or short chains

Production by phytoplankton is generally lower than that of bottom plants

<table>
<thead>
<tr>
<th>Environment</th>
<th>Rate of production (g e- C m-2 d-1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arctic Ocean</td>
<td>0.7-1</td>
</tr>
<tr>
<td>Southern Ocean</td>
<td>40-200</td>
</tr>
<tr>
<td>Subpolar ocean</td>
<td>30-180</td>
</tr>
<tr>
<td>Temperate ocean</td>
<td>70-180</td>
</tr>
<tr>
<td>Tropical and Subtropical</td>
<td>100-200</td>
</tr>
<tr>
<td>Coral reef</td>
<td>4-40</td>
</tr>
<tr>
<td>Euphotic zone</td>
<td>70-180</td>
</tr>
<tr>
<td>Coastal upwelling areas</td>
<td>100-200</td>
</tr>
</tbody>
</table>

Global Pattern of Marine Primary Productivity

May
High Nutrient Low Chlorophyll regions (HNLC)
Intense Herbivory or Trace Metal Limitation? (iron, manganese, zinc, cobalt)

Forcing agents for Phytoplankton Production

Ocean Nitrogen Cycle
Aquatic Nitrogen Cycle

Productivity of phytoplankton also influenced by mixing in the water column:
- Delivery of nutrients
- Vertical movement of algae

Seasonal Temperature profile, coastal Maine

Cycles of productivity are influenced by changes in the light compensation depth that are a function of incident light and absorption

The Compensation depth is a physiological concept: The depth at which the rate of photosynthesis for an individual plant equals the rate of respiration by that plant.

The Critical depth is an ecological concept applied to the whole community of plants and related to vertical mixing of the water:
The Compensation depth is a physiological concept: The depth at which the rate of photosynthesis for an individual plant equals the rate of respiration by that plant.

The Critical depth is an ecological concept applied to the whole community of plants and related to vertical mixing of the water:

It is the depth to which the total phytoplankton biomass may be circulated and still spend sufficient time above the compensation depth to have the total production equal the total respiration for a given time period. Thus the depth of vertical mixing is another important determinant of productivity.

**Ecology of the Water Column (Biological Oceanography)**

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Lenes et al.
Upwelling along the California coast has different effects on productivity depending on river inputs and width of the continental shelf margin (Ken Bruland and Colleagues).

Iron Limitation of Ocean Phytoplankton

**Observations**
- Tropical Pacific Ocean near the equator, rich in N and P but low in plant life.
- Light levels are plentiful
- What limits plant biomass?

**Iron Experiments**
- Multiple additions of dissolved iron to attain 2 nM (225 kg in 80 km²). Sulphur Hexafluoride used as tracer.
- Control area with no iron added, only SF6 and acid solution.
- Navigate ship following buoys that mark the water masses.
- Measure light, chlorophyll a, nutrients, biomass, CO2 pp.
Photosynthetic capacity: immediate and sustained increases.
- Phytoplankton growth rate: doubled, abundance increased 20x.
- Nitrate concentrations: declined by half.
- Shift dominance to larger diatoms; release control by herbivory.

Iron Ex Experiments

- Results of iron enrichment experiments taken from the US JGOFS (Joint Global Ocean Flux Study) newsletter

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Date</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>IronExI</td>
<td>1993</td>
<td>3-fold increase in chlorophyll</td>
</tr>
<tr>
<td>IronExII</td>
<td>1996</td>
<td>10-fold increase in chlorophyll, 90µatm drawdown in CO2</td>
</tr>
<tr>
<td>SOGREE</td>
<td>1999</td>
<td>6-fold increase in chlorophyll, 25µatm drawdown in CO2</td>
</tr>
<tr>
<td>EisenEx</td>
<td>2000</td>
<td>4-fold increase in chlorophyll</td>
</tr>
<tr>
<td>SEEDS</td>
<td>2001</td>
<td>40-fold increase in chlorophyll</td>
</tr>
<tr>
<td>SOFeX (N)</td>
<td>2002</td>
<td>Greater than 10-fold increase in chlorophyll, Greater than 40µatm drawdown in CO2</td>
</tr>
<tr>
<td>SOFeX (S)</td>
<td>2002</td>
<td>Greater than 10-fold increase in chlorophyll, Greater than 40µatm drawdown in CO2</td>
</tr>
<tr>
<td>SERIES</td>
<td>2002</td>
<td>Greater than 10-fold increase in chlorophyll</td>
</tr>
</tbody>
</table>

What happens to the Carbon Produced during these Blooms?

A small proportion of organic carbon falls to the sea floor, where it may get buried under sediment.

Iron Ex Experiments

This graph shows the difference in the rate of carbon assimilation and drawdown in the Equatorial Pacific and the Southern Ocean.

Explosions from 1995-2000: Synthesis and Future Directions

Boyd et al., 2007
Science 315
Pg. 312
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The principal herbivores of phytoplankton in the ocean are the copepods which feed by creating currents, and capturing algae using a "feeding basket" made by appendages.

Others use filters to remove food from the water.

Predatory Zooplankton

Many Phytoplankton and Zooplankton are bioluminescent; they account for most of the bioluminescence in the sea.
Many Phytoplankton and Zooplankton (and fish) undergo daily vertical migrations of a meter to tens of meters.

The nekton consists mostly of Larger, predatory type animals.

IV. The Nekton

V. Water Column Food Web (Simplified)

The microbial food web, an important component of water column trophic dynamics

Water Column Food Web (traditional view)

Water Column Food Web (modern view)