Marine Ecology I: Phytoplankton and Primary production

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Phytoplankton, biogeochemistry & climate I

• Uptake of $CO_2$ through photosynthesis

• Calcification

\[
Ca^{+2} + CO_3^{2-} \rightleftharpoons CaCO_3
\]

- Can affect the infrared radiative properties of the atmosphere

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Phytoplankton, biogeochemistry & climate II

- Production of dimethyl sulphide (DMS)

  - Source of cloud condensation nuclei, which change the reflectance (albedo) of clouds

  - Can affect the shortwave radiative properties of the atmosphere

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Phytoplankton, biogeochemistry & climate III

• Modulation of the absorption of shortwave (visible) radiation in the surface ocean

  – Can affect absorption and the transport of heat in the ocean

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Biological (organic) pump

\[ \text{CO}_2 + \text{H}_2\text{O} + \text{Nutrients} + \text{Light} \quad \overset{\text{Phytoplankton}}{\leftrightarrow} \quad \text{Organic matter} + \text{O}_2 \]
Diatoms

– Eukaryotes
– Major primary producers
– Commonly form chains or colonies
– Have external “skeletons” made of silica
– Can sink fast

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Dinoflagellates

– Eukaryotes
– Usually exist as single cells
– Have two flagella
  i.e., they can swim weakly
– Alkenones are used for reconstruction
  of paleo-temperatures
– Red tides producers
Coccolithophorids

– Eukaryotes
– Have two flagella but only at certain life stages
– Spherical organisms covered with plates of calcium carbonate
– Blooms increase water albedo
– Fossils are used to make chalk

\[ \text{Ca}^{+2} + \text{CO}_3^{2-} \rightleftharpoons \text{CaCO}_3 \]
Phytoflagellates

– Eukaryotes
– Single cells or can form large (up to 1 cm) hollow, gelatinous colonies
– Producers of DMS
– Decaying remains can cause foam on the sea shore
Cyanobacteria I

*Trichodesmium*

- Exist as single filaments, trichomes (10’-100’s of cells), or colonies (visible to the naked eye; 1-10 mm in length)
- **Nitrogen fixers** (i.e., contribute to new production)
- Have gas vacuoles
- Tropical and subtropical distribution
Cyanobacteria II
Marine N\textsubscript{2}-fixing unicellular cyanobacteria

- Small unicellular prokaryotes
- Spherical
- Size: 2-20 µm in diameter
- Different species (e.g. *Cyanothece, Myxosarcina, Gloeoethece, Synechocystis*)
- Important N\textsubscript{2}-fixers (contribute to new production)


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**Cyanobacteria III**

**Synochococcus**

- Small unicellular prokaryotes (ca. 1 μm)
- Contain phycobilisomes
- Orange-yellow fluorescence under blue light
- Some motile strains
- Global distribution, throughout euphotic zone
- Up to $10^4$ - $10^5$ cells mL$^{-1}$

Discovered in the late 70’s (Waterbury et al., *Nature* 772: 293, 1979).

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Cyanobacteria IV

Prochlorococcus

- Small unicellular prokaryote
- Size: 0.5 to 0.7 µm in diameter
- Main photosynthetic pigments are divinyl chlorophyll a (Chl \text{a}_2) and divinyl chlorophyll b (Chl \text{b}_2)
- Most abundant phytoplankton (50° N-50° S)
- Genomic size ca. 2 Mbp. Smallest of all known oxyphotobacteria

Discovered in the 80’s (Chisholm et al., Nature 344: 340, 1988).

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**Picophytoeukaryotes**

(< 2 - 3 µm)

- Ubiquitous and significant members of the plankton
- Phylogenetically very diverse
- New clades very different from known organisms
- Abundance: $10^3$-$10^4$ cells mL$^{-1}$


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Flow Cytometry II

Typical cytograms from marine samples

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Flow Cytometry III


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Chlorophyll-\(a\): an index of phytoplankton biomass, \(B\)

Main photosynthetic pigment
Present in all - and only in - phytoplankton

Dimensions: \(M \, L^{-3}\)

Units: \(mg \, m^{-3}\) (or \(\mu g \, L^{-1}\))

Methods: Colorimetric
Fluorometric (\textit{in vivo}, on extracts)
HPLC (High Performance Liquid Chromatography)
Remote sensing
Phytoplankton absorption spectrum

Chlorophyll-a

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Primary production, $P$

*$\text{CO}_2 + \text{H}_2\text{O} \rightarrow \text{Organic matter} + \text{O}_2$

Carbon fixation (photosynthesis) per unit volume per unit time

Dimensions: $\text{M L}^{-3} \text{T}^{-1}$
Units: $\text{mg C m}^{-3} \text{h}^{-1}$

Daily water-column primary production:

$$P_{T,Z} = \iiint P(z,t) \, dz \, dt$$

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Phytoplankton blooms: Sverdrup’s model

Fig. 4. Schematic diagram showing critical depth and compensation depth

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Which are the factors controlling primary production?

<table>
<thead>
<tr>
<th>External</th>
<th>Internal</th>
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<tbody>
<tr>
<td>• Light</td>
<td>• Pigments</td>
</tr>
<tr>
<td>• Nutrients (macro &amp; micro)</td>
<td>• Nutrient pool</td>
</tr>
<tr>
<td>• Grazing by zooplankton</td>
<td>• Enzyme concentration</td>
</tr>
<tr>
<td>• Temperature</td>
<td>• Cell size</td>
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<tr>
<td>• ...</td>
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• Most of the variability in the photosynthetic rate of phytoplankton can be attributed to variations in light

• After light, most of the variability in primary production measurements can be explained in terms of variability in biomass
A useful approach

a) To establish a quantitative description of the relationship between biomass-normalised primary production and light

a) To study the effect of other variables (e.g., nutrients, $T$, cell size, etc.) on the photosynthetic parameters

\[ P(I) = P^B(I) \times B \]

$P^B = \text{Biomass-normalised primary production}$
$I = \text{Irradiance (Photosynthetically Active Radiation 400–700 nm)}$
$B = \text{Biomass}$
Photosynthesis-light curve

\[ P^B = f(I; \alpha^B, P^B_m) + R^B \]

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Photosynthetic parameters

\[ P^B_m = \text{assimilation number} \]

Information about the dark reaction of photosynthesis, i.e., enzymatic reactions

\[ \alpha^B = \text{Initial slope} \]

\[ \alpha^B = a^* \Phi \]

\[ a^* = \text{Specific absorption coefficient} \]

\[ \Phi = \text{Quantum yield (mol C / mol quanta)} \]

Related to the efficiency of photosynthesis. Information about the photochemical reaction

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Wavelength dependence of photosynthesis at low light intensities

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Spectral composition of light changes with depth

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Phytoplankton biomass

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Global primary production

Global NPP is ~105 Pg C yr\(^{-1}\) : 48.5 Pg C yr\(^{-1}\) (46%) in the oceans and 56.4 Pg C yr\(^{-1}\) (54%) on land

Global primary production II

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NPP global annual = $104 \times 10^{15}$ g C

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Global primary production III

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