Ocean biology and carbon export
Photosynthesis:

\[ \text{CO}_2 + \text{H}_2\text{O} \rightarrow \text{O}_2 + \text{CO}_2 + \text{H}_2\text{O} + \text{O}_2 \]

Decomposition:

\[ \text{CO}_2 + \text{H}_2\text{O} \rightarrow \text{CO}_2 + \text{H}_2\text{O} \]
# The Elements of Microbial Life

<table>
<thead>
<tr>
<th>Component</th>
<th>Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nucleus (DNA)</td>
<td>C-N-P</td>
</tr>
<tr>
<td>Ribosome (RNA)</td>
<td>C-N-P</td>
</tr>
<tr>
<td>Membranes</td>
<td>C-P</td>
</tr>
<tr>
<td>Cell wall</td>
<td>C-N</td>
</tr>
<tr>
<td>Proteins/enzymes/flagellum</td>
<td>C-N</td>
</tr>
<tr>
<td>Storage bodies:</td>
<td></td>
</tr>
<tr>
<td>• PHB</td>
<td>C</td>
</tr>
<tr>
<td>• Poly-P</td>
<td>P</td>
</tr>
</tbody>
</table>
Fixed biochemical stoichiometry:
Average composition of plankton cells
106C : 16N : 1P (mol : mol : mol)
Production and remineralization

**Organic matter production by photosynthesis:**

\[
106 \text{ CO}_2 + 16 \text{ HNO}_3 + \text{H}_3\text{PO}_4 + 122 \text{ H}_2\text{O} \Rightarrow (\text{CH}_2\text{O})_{106} (\text{NH}_3)_{16} (\text{H}_3\text{PO}_4) + 138\text{O}_2
\]

- Consumes inorganic nutrients
- Produces oxygen

**Aerobic remineralization of organic matter:**

\[
(\text{CH}_2\text{O})_{106}(\text{NH}_3)_{16}\text{H}_3\text{PO}_4 + 138\text{O}_2 \Rightarrow 106\text{CO}_2 + 122\text{H}_2\text{O} + 16\text{HNO}_3 + \text{H}_3\text{PO}_4
\]

- Consumes \(O_2\)
- Remineralizes inorganic nutrients
The biological carbon pump

The graph shows the total inorganic carbon (µmol C kg⁻¹) with depth (m) and total inorganic carbon (µmol C kg⁻¹) across different depths. The graph compares the carbon levels in different biological conditions: no biology and biology. The carbon dioxide (CO₂) is depicted with arrows indicating the upward movement from the surface to deeper depths. The graph highlights the significant role of biology in sequestering carbon in the ocean depths.
• Regional differences due to age of the water mass
• Determines “potential productivity” of the basin
As water ages during ocean circulation from N. Atlantic to N. Pacific, continuous particle rain and microbial decomposition results in increases in inorganic nutrients and subsequent decreases in $O_2$. 
Export - vertical attenuation of particles

Mixed layer

Carbon flux - 100m

Carbon uptake

Carbon flux - 1000m

Carbon burial

U.S. JGOFS

<5 to 10%

~1-5%

~0.1%
SEDIMENT TRAPS

- Glass buoyancy
- Sediment trap
- Current meter + transmissometer
- Acoustic Release
- Anchor (scrap chain)
VERTEX program - late 70's – mid 80's
Extensive upper ocean trap studies

**“Martin OOC curve”**
Martin et al., 1987

\[ F = F_{100} \left( \frac{z}{100} \right)^b \]
\[ F_{100} = 1.53 \text{ (mol m}^{-2}\text{ y}^{-1}) \]
\[ b = 0.86 \]
Sinking particles do not sink vertically
• sinking velocity = 10’s - >500 m/day
• horizontal velocity = 1 - 10’s cm/sec

Avg. “sinking” particle:
4 m vertical drop & 540 m horizontal trajectory during 60 min talk
Thorium-234 approach for estimating particle export

Calculate $^{234}\text{Th}$ flux from the measured $^{234}\text{Th}$ activities

- low $^{234}\text{Th} = $ high flux
- need to consider non-steady state and physical transport

half-life = 24.1 days

source = $^{238}\text{U}$ parent is conservative

sinks = attachment to sinking particles and decay
No simple relationship between primary production and export.
Factors controlling Export fluxes

Particle size
Particle composition
Particle geometry
Particle sinking rate

Many of these processes are biologically-mediated and controlled by food web dynamics.
Foodwebs control particle transformations in the sea. Growth Efficiencies matter!
DIRECT ALGAL SINKING

U.S. JGOFS
TRACKING ALGAL AGGREGATION WITH

*Chaetoceros messanensis*

Honjo and Manganini (1993)
Impact of direct algal sinking

Flux of labile phytodetritus to the deep North Atlantic
Feeding by salps can reduce algal biomass and repackage carbon biomass into fast sinking fecal pellets.

*Biomass of Salpa fusiformis of up to 360 mg C m$^{-3}$*

*Herbivory during diatom bloom in North Atlantic terminated the bloom before nutrients had run out.*

Sedimentation of diatom-rich salp fecal pellets

> 1 mm long, 350 µm wide, 10 µg C per pellet---these things sink FAST...

*BATHMANN (1988)*
Agents of mineral ballast – opal and calcite
Organic matter production by photosynthesis:

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- Consumes inorganic nutrients
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Aerobic remineralization of organic matter:

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- Consumes O₂
- Remineralizes inorganic nutrients
New and regenerated production

Dugdale and Goering (1967) identified 2 forms of primary production:

1) new production supported by external input of N (e.g. NO$_3^-$ and N$_2$),

2) recycled or regenerated production, sustained by in situ recycling of N.

- Over short time scales, input of new N supports higher trophic levels and maintains carbon export.
- Why do these generalizations apply to the open sea but not near shore environments?
New production

New production has two components:
1. Accumulation of organic matter in the euphotic zone
2. Export of organic matter from the euphotic zone

New production fueled by exogenous sources of nitrogen introduced to the upper ocean (typically considered nitrate).

This production must be balanced by removal of nitrogen from the upper ocean. Thus, new production is equivalent to export of N from the surface ocean. Over sufficiently long
The f-ratio

\[ f = \frac{V_{NO_3^-}}{V_{NO_3^-} + \sum N_R} \]

Assumptions:
1) \( N_2 \) fixation is low
2) Steady state system
3) Euphotic zone nitrification is low

Note \( N_R \) includes regenerated forms of N uptake (historically thought to include urea and \( NH_4^+ \))

Mathematical description linking new production and organic matter export. At steady state, nitrogen input is balanced by nitrogen export.

Under steady state (i.e. nitrate input balanced by export/grazing loss), if export is less than input, biomass accumulates. This biomass must eventually be exported to keep the system in steady state.
Wind-driven convective mixing of the upper ocean is a critical pathway for introducing nutrients to the euphotic zone.
Seasonal variations in mixing and temperature in the Sargasso Sea—note winter time deepening of the mixed layer coincides with seasonal cooling.
Deepening of the mixed layer introduces nutrients to the upper ocean, resulting in seasonal increases in new production.

Figure 3. (a) Nitrate concentrations in the euphotic zone at the Bermuda Atlantic Time-series Study (BATS) site from 1989 to 1998. (b) The ratio values over the same interval calculated from measured nitrate concentrations using the Platt and Harrison [1985] relationship.
Upwelling provides new nutrients for phytoplankton growth

“new water” = new production
Fig. 5.01 Major coastal upwelling regions of the world, adapted from Thompson (1977). Arrows indicate prevailing winds.
Primary nitrogen sources supporting plankton growth

Eukaryotes

Prochlorococcus

Diazotrophs

Heterotrophs

Not all nutrients are created equal…