OCN621: Biological Oceanography-Microbial Ecology II

Zackary Johnson
MSB614
zij@hawaii.edu

<http://www.soest.hawaii.edu/oceanography/zij/ocn621.html>

\[ \mu = \frac{\mu_{\text{max}}[N]}{K_N + [N]} \]
Phytoplankton Production

2: Quantifying Primary Production: incubations with tracers

photosynthesis: \( CO_2 + H_2O \rightarrow CH_2O + O_2 \)

carbon incorporation

\( ^{14}CO_2 \) uptake: dark bottle / light bottle technique
Phytoplankton Production

2: Quantifying Primary Production (cont). – incubation technique problems:

Recycling:
- minimized in $^{18}$O method although some $^{18}$O$_2$ may be used inside the cell before it enters the external O$_2$ pool
- O$_2$ method can not measure photorespiration
- net community production $<$ $^{14}$C primary production $<$ gross PP (dependent on length of incubation)
Phytoplankton Production

2: Quantifying Primary Production (cont). – incubation technique problems:

**dark bottle corrections**
- \( \text{O}_2 \) method – necessary to account for respiration
- \(^{14}\text{C} \) method – desirable to account for chemosynthesis

**bottle confinement** - stress effects on community structure and process rates
- solid surfaces \( f(\text{bottle size}) \), unnatural light, temperature shock, vigorous mixing (filling bottles)

**contamination**
- trace metals in \(^{14}\text{C} \) or \(^{18}\text{O} \) stocks and incubation bottles
- sample collection gear: metal fittings and wire, rubber closures, etc.
Phytoplankton Production

2: Quantifying Primary Production (cont.) – comparison of techniques

Photorespiration:
RUBISCO functions in both carbon fixation and oxidation reactions, not all reductate (NADPH) is used for CH₂O production. If other compounds need to be reduced, then more O₂ is produced than CO₂ consumed.

PQ = Photosynthetic Quotient
= moles O₂ produced / moles CO₂ consumed

- carbohydrates \( \text{PQ} = 1.0 \)
- lipids \( \text{PQ} = 1.4 \)
- proteins \( \text{PQ} = 1.05 \text{ NH}_4^+ \)
  \( \text{PQ} = 1.6 \text{ NO}_3^- \)
- phytoplankton \( \text{PQ} = 1.1 \pm 0.1 (\text{NH}_4^+) \)
  \( \text{PQ} = 1.4 \pm 0.1 (\text{NO}_3^-) \)
Phytoplankton Production

2: Quantifying Primary Production (cont). – fluorescence
absorbed excitation energy has three fates: heat, energy production or fluorescence (re-emission of light)

modulated fluorescence can be used to probe the state of PSII and thus be used as a gauge of photosynthetic rate

\[ F_o = \text{initial fluorescence (dark adapted, low)} \]
\[ F_m = \text{light saturated fluorescence (maximal, high)} \]
\[ F_v = F_m - F_o = \text{variable fluorescence} \]
\[ F_v/F_m = \text{photochemical conversion efficiency of photosystem II} \]
\[ \tau = \text{turnover rate} \]
\[ n = \text{number of photosynthetic units} \]
\[ \sigma_{PSII} = \text{antenna size of photosystem II} \]
\[ E = \text{light} \]

photosynthetic rate \( \approx f(n, E, F_v/F_m, \tau, E, \sigma_{PSII}) \)

for example, photosynthetic rate = 
\[ \frac{n(F_v/F_m)}{\tau} \left( 1 - \exp\left( \frac{E \sigma_{PSII}}{\tau} \right) \right) \]
Phytoplankton Production

2: Quantifying Primary Production (cont.) – fluorescence
notes: assumes primary production controlled by PSII
(fluorescence only from PSII)
not possible to measure all parameters fluorometrically
analytical theory not well developed, but observations match C-14, O₂
fast, non-destructive, no incubations, potential for remote sensing
Phytoplankton Production

2: Quantifying Primary Production (cont). – areal production

- surface or near surface maximum
- when normalized to differences in light field, profiles all essentially look the same
2: Quantifying Primary Production (cont). – areal production
direct quantification: trapezoidal integration

- does not assume functional form
- can be used for both stocks and rates
- can be modified to integrate to a given % light

\[ \sum PP = z_1 P_1 + \sum_{i=1}^{i_{\text{max}}} (z_i - z_{i-1})(P_i + P_{i-1})/2 \]

Remember:
- volumetric rate = rate m^{-3} (or rate L^{-1})
- areal rate = rate m^{-2}

Because depth distribution can vary substantially based on light and mixing, areal calculation useful for calculating inventories, basin-wide processes, comparing between ecosystems, etc.
Phytoplankton Production

2: Quantifying Primary Production (cont). – estimation of areal production using different models:

I. Wavelength-resolved models (WRMs)

\[ \sum PP = \int_{\lambda=0}^{\lambda=0.00} \int_{t=0}^{t=\text{max}} \int_{z=0}^{z_{eu}} \Phi(\lambda, t, z) \times \text{PAR}(\lambda, t, z) \times a^*(\lambda, z) \times \text{Chl}(z) \ d\lambda \ dt \ dz - R \]

II. Wavelength-integrated models (WIMs)

\[ \sum PP = \int_{t=\text{min}}^{t=\text{max}} \int_{z=0}^{z_{eu}} \eta(t, z) \times \text{PAR}(t, z) \times \text{Chl}(z) \ dt \ dz - R \]

II. Time-integrated models (TIMs)

\[ \sum PP = \int_{t=0}^{t_{eu}} P^b(Z) \times \text{PAR}(z) \times DL \times \text{Chl}(z) \ dz \]

IV. Depth-integrated models (DIMs)

\[ \sum PP = P_{opt}^b \times f[\text{PAR}(0)] \times DL \times \text{Chl} \times z_{eu} \]

\[ \sum PP = C_{surf} \times Z_{eu} \times P_{opt}^b \times DL \times f(E_o) \]

\[ C_{surf} = \text{surface chlorophyll}, \ Z_{eu} = \text{depth of euphotic zone (assumed 1% light level)}, \ P_{opt}^b = \text{maximum chlorophyll normalized photosynthesis, DL=day length, } f(E_o) = \text{“shape” of primary production curve} \]

because (1) no net photosynthesis is assumed to occur <1% light level, and (2) \( f(E_o) \) is relatively constant, \( \Sigma PP \) becomes a sole function of \( C_{surf}, DL, \) and \( P_{opt}^b \). The first two can be remotely estimated.
Phytoplankton Production: Distribution and Variability

1. Major bottom-up factors affecting primary production/biomass
   - temperature
   - nutrients
   - light (diel, seasonal, latitude, mixing)

2. Spatial
   - depth, on-off shore (coastal/oligotrophic), mesoscale (ex. eddies), global (meridional)

3. Temporal
   - day (diel)
   - seasonal (annual)
   - inter-annual (ex. El Nino)
   - decadal (ex. PDO)
   - glacial (ex. Milankovitch cycles)
   - epoch
Temperature
- temperature affects enzymatic processes
  * excess temperatures can lead to protein denaturation and instability
  * low temperatures slow kinetics
- phytoplankton are adapted to specific temperature ranges
- closely related phytoplankton can have markedly different temperature response curves (ex. Prochlorococcus strains)
- because open ocean temperatures are relatively constrained (~<32°C), there is little evidence that high temperatures limit primary production
- because low temperatures waters are often associated with high nutrient waters, it is unclear if temperature per se limits production in situ - in the field there is often an inverse relationship with temperature and biomass / production
Temperature: Atlantic Ocean

Integrated Biomass Abundances

- Prochlorococcus
- Synechococcus
- Eukaryotes

Fluorescence

Temperature

Integrated Biomass Abundances

- Prochlorococcus
- Synechococcus
- Eukaryotes

N Latitude

μm³/mm²

°C

Red Fls

1e+6

1e+5

1e+4

1e+3

0

1.5

1.0

0.5

0.0
Nutrient limitation of phytoplankton

- growth rate is affected by nutrient concentrations and generally follows a Michaelis-Menten curve

\[ \mu = \frac{\mu_{\text{max}} [N]}{K_N + [N]} \]

- \( \mu \) = growth rate
- \( \mu_{\text{max}} \) = maximum growth rate
- \([N]\) = nutrient concentration
- \( K_N \) = half saturation constant

So, if nutrients are less than the \( K_N \), then they are limiting. “High” nutrients are >\( K_N \), “low/limiting” nutrients are <\( K_N \)

This is a simplified expression with assumptions.

More complex equations can be used to describe growth rate as a function of nutrients. Especially for nutrients that require significant “processing” within the cell (ex. nitrate) or co-limitation.

ex. \[ \mu = \frac{\mu_{\text{max}} Q}{A + Q} \]

\( \frac{\text{uptake rate}}{\text{growth rate of cells}} = Q \)

\( A \)= half saturation constant for intracellular process governing uptake
## Nutrient limitation of phytoplankton

### Range of maximum growth rates ($\mu_{\text{max}}$)

<table>
<thead>
<tr>
<th>$\mu_{\text{max}}$</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1-0.7</td>
<td>Oligotrophic, tropical waters</td>
</tr>
<tr>
<td>0.4-1.0</td>
<td>Temperate, eutrophic, coastal waters</td>
</tr>
<tr>
<td>1.0-3.0</td>
<td>Tropical upwelling, and picoplankton under eutrophic conditions at higher temperatures</td>
</tr>
</tbody>
</table>

### Half saturation constants ($K_N$) in ($\mu$M)

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>$K_N$</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>NO$_3$ or NH$_4$</td>
<td>0.01-0.1</td>
<td>Oligotrophic</td>
</tr>
<tr>
<td></td>
<td>0.05-2.0</td>
<td>Eutrophic oceanic waters</td>
</tr>
<tr>
<td></td>
<td>2.0-10.0</td>
<td>Eutrophic coastal waters</td>
</tr>
<tr>
<td>Silicate</td>
<td>0.5-5.0</td>
<td>General range for diatoms</td>
</tr>
<tr>
<td>Phosphate</td>
<td>0.02-0.5</td>
<td>General range for oligotrophic to eutrophic waters</td>
</tr>
<tr>
<td>Iron</td>
<td>0.0000001</td>
<td>Oligotrophic</td>
</tr>
</tbody>
</table>