From observation to prediction: Identifying patterns in microbial dynamics
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Marine Microplankton Ecology
OCN 626
What do we want to understand?

- What processes control plankton population dynamics in differing marine ecosystems?
- Are there predictable relationships between picoplankton growth and the processes that control growth (top down and bottom up)?
- Over what time/space scales do these controlling processes act?
Phytoplankton biomass and biogeography

Note the patchy variability in the subtropical gyres – what controls these patterns?

Note the clear seasonal progressions in both the temperate and polar regions.

Are there similar dynamics associated with bacterial populations in the world’s oceans? Are bacterial dynamics regulated on similar time and space scales?
Are there predictable patterns in microbial oceanography?

Bird and Kalff (1984) and Cole et al. (1988) - relationships in volumetric determinations of bacterial abundance and Chl a across diverse aquatic ecosystems. For every 10-fold increase in Chl a, bacterial abundance increases 3-8 fold. Two implications: 1) at low concentrations of Chl a, bacterial abundance becomes increasingly important, and 2) bacterial abundance increases more slowly than phytoplankton along gradients in productivity. The relationship between bacteria and their DOM source was used to infer that in general, bacteria are controlled by bottom up factors.
Gasol and Duarte (2000)

The slopes defined by these relationships range from 0.3-0.8. Across large trophic gradients, changes in bacterial abundance appear dampened relative to phytoplankton.

Fig. 1. Relationships between chlorophyll concentration and bacterial abundance as published in the literature. Each equation is drawn from the minimum to the maximal value in the original data set used to create it. Sources of the equations can be obtained via anonymous ftp at ftp.icm.csic.es/pub/gasol.
Cross ecosystem comparisons of bacterial biomass

• Over wide range of aquatic ecosystems, bacterial biomass appears correlated with phytoplankton biomass.

• Bacterial abundance appears to vary less than phytoplankton biomass across large gradients in productivity.

• With increasing oligotrophy, bacterial biomass appears relatively more important to total plankton biomass.
Comparative relationships between bacterial and primary production

Across diverse aquatic ecosystems, bacterial production and primary production are positively correlated, with ~40% of the variance in BP explained by PP. Over this wide range of ecosystems, BP accounted for ~20% of the volumetric and 30% of the areal rates of PP.
Cross ecosystem comparisons of bacterial production

- Over wide range of aquatic ecosystems, bacterial production is positively correlated with primary production.

- The variability between bacterial and primary production are approximately equal across large gradients in productivity.

- Across diverse ecosystems, bacterial production is equivalent to 20-30% of primary production.
Microbial food webs and carbon flow

<table>
<thead>
<tr>
<th>Ecosystem</th>
<th>BP:PP</th>
<th>BB:PB</th>
<th>Carbon Export from upper ocean (% PP)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ross Sea</td>
<td>0.04</td>
<td>0.02</td>
<td>12-&gt;50%</td>
</tr>
<tr>
<td>Subtropical North Pacific</td>
<td>0.20</td>
<td>0.7</td>
<td>4-10%</td>
</tr>
<tr>
<td>Sargasso</td>
<td>0.18</td>
<td>1.2</td>
<td>&lt;10%</td>
</tr>
</tbody>
</table>
What controls the distributions, activities and diversity of plankton in the ocean?

- **Physics**
  - Mixing
  - Light
  - Temperature
  - Advection

- **Chemistry**
  - Nutrients, including trace metals (Fe)

- **Biology**
  - Physiology/competition
  - Predation
  - Viruses
Bottom up and top down controls

- Bottom up: light, nutrients, temperature
- Top down: predation, viruses, and competition

- When the two types of controls are closely coupled, plankton biomass is relatively stable in time and space and little material leaves the food web (via sinking).
- When the two controls are loosely coupled, biomass can fluctuate widely and the ecosystem exports a greater proportion of fixed carbon.
HSS theory:
“The world is green”

COMMUNITY STRUCTURE, POPULATION CONTROL, AND COMPETITION

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The purpose of this note is to demonstrate a pattern of population control in many communities which derives easily from a series of general, widely accepted observations. The logic used is not easily refuted. Furthermore, the pattern reconciles conflicting interpretations by showing that populations in different trophic levels are expected to differ in their methods of control.

SUMMARY

In summary, then, our general conclusions are: (1) Populations of producers, carnivores, and decomposers are limited by their respective resources in the classical density-dependent fashion. (2) Interspecific competition must necessarily exist among the members of each of these three trophic levels. (3) Herbivores are seldom food-limited, appear most often to be predator-limited, and therefore are not likely to compete for common resources.

General theory of population regulation resting on the idea of trophic cascades:

1.) Plants (phytoplankton) and decomposers (bacteria) are abundant and thus tend to be resource limited (bottom up).

2.) Herbivores appear limited by predation (top down).

3.) Predators control herbivores, thus predators are controlled by the availability of prey (bottom up).

Whether a population is limited by resources or predation depends on its trophic level.

American Naturalist 94: 421-425
What controls export?

- Temperature?
- Community structure?
- Nutrient availability?
Physical controls on plankton

- Mixing
- Light
- Temperature
- Advection

These processes act over different time and space scales
LARGER CELLS
HIGHER BIOMASS
SLOWER TURNOVER
SELECTIVE PRESSURE
TO SEQUESTER NUTRIENTS
AND MINIMIZE LOSSES
(e.g., NOXIOUS/TOXIC BLOOMS)

SMALLER CELLS
HIGH TURNOVER
COMPETITION FOR NUTRIENTS
RETENTION BY RECYCLING
(MICROBIAL LOOP)

LARGER CELLS
HIGHER BIOMASS
TRANSIENT & SELF-LIMITING
SELECTION FOR
RAPID GROWTH
(DIATOMS)

LOW BIOMASS
SLOW TURNOVER
ADAPTATIONS FOR
EFFICIENT USE OF
LIGHT&NUTRIENTS
(HIGH-LATITUDE
“HNLC”)

Cullen et al. 2002,
The Sea
# Putting big boxes around ocean ecosystems

<table>
<thead>
<tr>
<th>Ecosystem</th>
<th>Stratification</th>
<th>New nutrient input</th>
<th>Primary production per unit area*</th>
<th>Processes regulating production</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Coastal upwelling</strong></td>
<td>Patchy</td>
<td>High</td>
<td>Advection</td>
<td>Medium to high</td>
</tr>
<tr>
<td><strong>Low latitude gyre</strong></td>
<td>Strong</td>
<td>Low</td>
<td>Mixing, N₂ fixation</td>
<td>Low to medium</td>
</tr>
<tr>
<td><strong>Equatorial upwelling</strong></td>
<td>Strong</td>
<td>High</td>
<td>Advection</td>
<td>Medium</td>
</tr>
<tr>
<td><strong>Subarctic gyre</strong></td>
<td>Strong</td>
<td>High</td>
<td>Mixing</td>
<td>Medium (low in winter)</td>
</tr>
<tr>
<td><strong>Southern Ocean</strong></td>
<td>Weak</td>
<td>Very high</td>
<td>Mixing</td>
<td>High (low in winter)</td>
</tr>
<tr>
<td><strong>Eastern boundary current</strong></td>
<td>Medium</td>
<td>Medium</td>
<td>Advection</td>
<td>Grazing and nutrient supply</td>
</tr>
</tbody>
</table>

*Nutrient input level relative to plankton uptake (i.e. high: concentration always saturating uptake rate; low: concentration always rate limiting).

*Measures of production include, low: <0.1 g C m⁻² d⁻¹; medium: ~0.5 g C m⁻² d⁻¹; high: > 1 g C m⁻² d⁻¹.

From: Barber (1988)
Four primary ecological biomes in the world’s oceans: Polar, Westerlies, Trades, Coastal

These biomes are largely defined by physical forcing of the upper ocean.

**Polar**: Mixed layer is constrained by salinity changes driven by sea-ice melt (>60° latitude).

**Westerlies**: Mixed layer depth is forced by local winds and seasonal warming (30-60° latitude).

**Trades**: Mixed layer is forced by basin scale geostrophic adjustment to local or distant wind forcing.
These biomes can be further subdivided in provinces based on satellite-derived measurements of chlorophyll.

51 biogeochemical zones within the 4 biomes
The Polar Biome

Surface ocean chlorophyll around the Arctic and Antarctic

Polar: Physically energetic, very deep winter mixing. Mixed layer is largely constrained by salinity changes during sea-ice melt and formation (>60° latitude). Strong seasonality in light with large biological responses.

Longhurst (2007)

Fig. 9.3 ARCT: seasonal cycles of monthly surface chlorophyll and depth-integrated autotrophic production for the years 1997–2002 from SeaWiFS data together with characteristic seasonal cycles of mixed-layer depths from Levitus climatological data and photic depths computed from characteristic irradiance and the archive of chlorophyll profiles discussed in Chapter 1.
The coastal biome

Amazon River plume
Large source of terrestrial materials (including Fe and Si)

Gulf of Mexico
Very shallow, nutrient enriched from runoff

Upwelling off Peru

Upwelling off the NW coast of Africa

Coastal: diverse coastal processes modify mixing, light, and nutrient inputs.
Trade wind and westerlies

**Trades:** relatively stable; mixing largely dependent on basin-scale physics with weak local wind forcing.

**Westerlies:** Seasonally modified; local wind forcing plays important roles in convective exchange.
Trades regions are dominated by the subtropical oligotrophic gyres; westerlies contain 2 of the large HNLC regions (subarctic N. Pacific and northern regions of the Southern Ocean); polar regions (in the summer) are HNHC.
Frontal Systems

- Physical boundaries partly define biogeographical partitioning of plankton biomass.

- Fronts are zones of sharp discontinuity that form leaky boundaries between habitats; however, frontal regions also create unique habitats.
Note the absence of temporal information from polar biomes.
<table>
<thead>
<tr>
<th>Location</th>
<th>Biome</th>
<th>Province</th>
<th>Depth (m)</th>
<th>T (°C)</th>
<th>$\text{NO}_3^-+\text{NO}_2^-$ (µM)</th>
<th>Chl a (µg L$^{-1}$)</th>
<th>Chl a (mg m$^{-2}$)</th>
<th>Primary production (mgC m$^{-2}$ d$^{-1}$)</th>
<th>$C$ export (mgC m$^{-2}$ d$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BATS</td>
<td>Westerlies</td>
<td>NAST</td>
<td>10-300</td>
<td>19-29</td>
<td>&lt;0.05-0.5</td>
<td>0.05-0.3</td>
<td>20.5±8.8</td>
<td>416±178</td>
<td>27.2±13.9</td>
</tr>
<tr>
<td>DYFAMED</td>
<td>Westerlies</td>
<td>MED</td>
<td>10-500</td>
<td>12-25</td>
<td>0.1-2</td>
<td>0.02-1.5</td>
<td>27.1±13.9</td>
<td>427±70</td>
<td>11.5±4.5</td>
</tr>
<tr>
<td>ESTOC</td>
<td>Trades/Coastal</td>
<td>Canary</td>
<td>35-150</td>
<td>17-24</td>
<td>&lt;0.05</td>
<td>0.05-0.4</td>
<td>29.4±5.7</td>
<td>456±98</td>
<td>4.5±2.9</td>
</tr>
<tr>
<td>HOT</td>
<td>Trades</td>
<td>NPTG</td>
<td>20-100</td>
<td>22-30</td>
<td>0.01-0.03</td>
<td>0.05-0.1</td>
<td>22.5±4.5</td>
<td>480±129</td>
<td>28.3±9.9</td>
</tr>
<tr>
<td>KERFIX</td>
<td>Westerlies</td>
<td>ISSG</td>
<td>&lt;50-250</td>
<td>1.5-4.5</td>
<td>23-28</td>
<td>0.3-1.5</td>
<td>18-80</td>
<td>189±110</td>
<td>1.9-2.9</td>
</tr>
<tr>
<td>KNOT</td>
<td>Westerlies</td>
<td>KURO</td>
<td>15-60</td>
<td>3-7.5</td>
<td>10-23</td>
<td>-</td>
<td>28.6±2.9</td>
<td>663±86</td>
<td>-</td>
</tr>
<tr>
<td>OSP</td>
<td>Westerlies</td>
<td>OCAL</td>
<td>40-120</td>
<td>5.5-13</td>
<td>8.5-16</td>
<td>0.2-0.4</td>
<td>13.5-20</td>
<td>589</td>
<td>18.2±7.2</td>
</tr>
</tbody>
</table>

Main points: Despite large differences in mixing and temperature, these regions have broadly similar rates of primary production and phytoplankton biomass (note the exceptions often lie in physically energetic regions).

From: Karl et al. (2003)
Note the generally lower variability in Chl relative to primary production; this likely reflects tight top down control in these ecosystems.

From: Karl et al. (2003)
From: Karl et al. (2003)