Macro- and micronutrient limitation of phytoplankton standing stock in the southern California Current System

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MODIS chlorophyll $\alpha$ satellite image July 2003
California Cooperative Oceanic Fisheries Investigations station plan since 1984, California Current Ecosystem LTER since 2005

- ~191,000 km²
- 66 stations
- 4 cruises/yr
- 500m CTD casts
- Chlorophyll $a$
- Macronutrients
- Salinity
- Temperature
- Oxygen
- Plankton nets
- 1° production

- *NEW* 1 “process cruise” every 2 years and much more…

~350 km

~700 km
Phytoplankton standing stock is generally limited by nitrate.

- $y$-intercept = 0.34 µM phosphate
- $y$-intercept = 2.4 µM silicic acid
CalCOFI June 2000 cruise - 10 m

- Temporal lag in phytoplankton growth with respect to nitrate supply (e.g. MacIsaac et al., 1985)
- Proximate grazing control, reducing nitrate utilization (e.g. Miller et al., 1991)
- Limitation by a physical process or nutrient other than nitrate; iron? (e.g. Martin and Fitzwater, 1988)
High nutrient (>10 \( \mu M \) nitrate), low chlorophyll (<1 \( \mu g \) chl a \( L^{-1} \))

**Nitrate (\( \mu mol \))**

- 10-15 \( \mu M \)
- 10 \( \mu M \)
- 20-25 \( \mu M \)

**Remotely-sensed chlorophyll \( a \) (\( \mu g \) L\(^{-1} \))**

- <1 \( \mu g \) L\(^{-1} \)
- <1 \( \mu g \) L\(^{-1} \)
- <1 \( \mu g \) L\(^{-1} \)

Levitus (1994)
July 2003
μM nitrate

July 2003
μg chl a L⁻¹

July 2004
μM nitrate

July 2004
μg chl a L⁻¹
Fe addition grow-out experimental protocol

- teflon pump system
- trace metal-clean methods
- >0.7 μm chlorophyll $a$
- macronutrients
- particulate organic C/N
- HPLC pigments
- samples for microscopy

Unamended control replicates

+5 nM Fe replicates
July 2003
µM nitrate

July 2003
µg chl a L⁻¹

July 2004
µM nitrate

July 2004
µg chl a L⁻¹
Expt 1 - July 2003
~50 km offshore

<table>
<thead>
<tr>
<th></th>
<th>t = 0</th>
<th>t = 3 d</th>
</tr>
</thead>
<tbody>
<tr>
<td>µg chl a</td>
<td>0.65</td>
<td>0.55 1.85</td>
</tr>
<tr>
<td>µM nitrate</td>
<td>3.5</td>
<td>1.9   0.0</td>
</tr>
<tr>
<td>µM phosphate</td>
<td>0.5</td>
<td>0.5   0.4</td>
</tr>
<tr>
<td>µM silicic acid</td>
<td>1.5</td>
<td>0.5   0.4</td>
</tr>
<tr>
<td>nM Fe</td>
<td>0.2</td>
<td>-     -</td>
</tr>
</tbody>
</table>

19-but = pelagophytes, chrysophytes
fuc = diatoms
19-hex = prymnesiophytes, diatoms
chl c3 = prymnesiophytes, diatoms
neox = chlorophytes
Expt 2 - July 2004
~200 km offshore

<table>
<thead>
<tr>
<th>t = 0</th>
<th>t = 2 d</th>
<th>control</th>
<th>+Fe</th>
</tr>
</thead>
<tbody>
<tr>
<td>µg chl a</td>
<td>0.36</td>
<td>0.94</td>
<td>2.91</td>
</tr>
<tr>
<td>µM nitrate</td>
<td>2.0</td>
<td>1.2</td>
<td>0.1</td>
</tr>
<tr>
<td>µM phosphate</td>
<td>0.3</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td>µM silicic acid</td>
<td>0.5</td>
<td>0.3</td>
<td>0.2</td>
</tr>
<tr>
<td>nM Fe</td>
<td>0.2</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

carotenoid pigments @ t = 2 d

19-but = pelagophytes, chrysophytes
fuc = diatoms
19-hex = prymnesiophytes, diatoms
ch1 c3 = prymnesiophytes, diatoms
neox = chlorophytes
July 2003
nM diss Fe

July 2004
nM diss Fe

July 2003
µM nitrate:nM diss Fe

July 2004
µM nitrate:nM diss Fe

HNLC nitrate:Fe ≈ 100-1000!!
Biomass-limited by nitrate, growth rate-limited by Fe.

Expt 1 - July 2003

- Growth rate-limited by Fe
- Control

Expt 2 - July 2004

- Control
- +Fe

Graphs show changes in chlorophyll-a (µg chl a L⁻¹) and nitrate (µM) concentrations over days.
Significance of growth rate-limitation by iron

In both “nitrate/iron replete” and “nitrate replete/iron growth rate-limiting”, new production should be comparable

BUT, this could result in variability (both spatial and temporal) in macronutrient biogeochemistry and phytoplankton community structure and distribution
We observed iron limitation in a non-HNLC regime, in relatively close proximity to the continent.

In general, the high nitrate, high iron nearshore is biomass-limited by nitrate. The medium nitrate, low iron transition zone is biomass-limited by nitrate and growth rate-limited by iron. There is some evidence to support Fe-limitation during spring-time as well.

Assessing nitrate and iron limitation adds to the understanding of phytoplankton distribution and nutrient biogeochemistry in the southern California Current System (not to discount other limiting or controlling processes).

The alteration to the supply of micronutrients such as iron could have potentially important effects on phytoplankton and nutrient biogeochemistry.