Nutrients, their cycling, and upwelling

• Nitrogen cycling
  – Living is easy when there is upwelling
  – But when the going gets tough… cycle!

• Silica is THE upwelling nutrient
  – Has a deep ocean cycle

Taking the story from the oligotrophic to eutrophic systems.
Biolimiting constituents (a.k.a. nutrients)

Nitrate ($\text{NO}_3^-$) Does not limit growth of bluegreen algae (cyanobacteria) they fix nitrogen.

Silicate ($\text{H}_2\text{SiO}_4$) Limits the growth of diatoms

Phosphate ($\text{HPO}_4^{2-}$) the ultimate limiting nutrient for plant growth
Vertical distribution of nutrients

Phosphate $10^{-6}$ mol/liter

Nitrate $10^{-6}$ mol/liter

Silicate $10^{-6}$ mol/liter

Libes, 1992

Nutrients become fully depleted during stratification.
Nutrient distribution varies among oceans

- Mixed layer is deeper in Atlantic than in Pacific
- Remineralized nutrients accumulate in deep water, transported by ocean conveyor belt
Light and nutrients determine where the productivity is.
Seasonal evolution of mixed layer (physics) sets up the annual cycle of the biology....
Productivity follows the nutrient availability.

- Phytoplankton
- Zooplankton
- Nutrients
- Mixing
- Light
- Temperature
- Stratified
- Spring bloom
- Fall mini-bloom

Relative increase

Seasonal variations:
- Spring bloom
- Fall mini-bloom

Graph depicting nutrient availability and its impact on productivity.
Oligotrophic ocean:

- The nutrient point of view
- The underlying chemistry
- The controlling chemistry
New versus regenerated production

Note: the biggest arrow is upwelled NO$_3^-$
Cycling of nitrogen in the ocean

Uptake and use is the dominant part....
Nitrogen limitation and low oxygen

- “Leaks” in the simple nutrient story
- Nitrogen fixation ↑
- Denitrification ↓
The simple Nitrogen cycle

NITROGEN CYCLE

Denitrification

Nitrification

N2-Fixation

Assimilation

Mineralization

Organic Matter

$\text{NO}_2^+$

$\text{NH}_4^+$

$\text{NO}_3^−$
**Different oxidation states of nitrogen**

<table>
<thead>
<tr>
<th>Species</th>
<th>Molecular Formula</th>
<th>Oxidation Number of Nitrogen</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrate ion</td>
<td>NO$_3^-$</td>
<td>+ V</td>
</tr>
<tr>
<td>Nitrite ion</td>
<td>NO$_2^-$</td>
<td>+ III</td>
</tr>
<tr>
<td>Nitrous oxide gas</td>
<td>N$_2$O</td>
<td>+ I</td>
</tr>
<tr>
<td>Nitric oxide gas</td>
<td>NO</td>
<td>+ II</td>
</tr>
<tr>
<td>Nitrogen gas</td>
<td>N$_2$</td>
<td>0</td>
</tr>
<tr>
<td>Ammonia gas</td>
<td>NH$_3$</td>
<td>− III</td>
</tr>
<tr>
<td>Ammonium ion</td>
<td>NH$_4^+$</td>
<td>− III</td>
</tr>
<tr>
<td>Organic amine</td>
<td>RNH$_2$</td>
<td>− III</td>
</tr>
</tbody>
</table>
The Nitrogen cycle - reality

NITROGEN CYCLE

\[ \text{Denitrification} \rightarrow \text{N2-Fixation} \rightarrow \text{Assimilation} \rightarrow \text{Organic Matter} \]

\[ \text{Nitrification} \rightarrow \text{Mineralization} \rightarrow \text{Denitrification} \]

\[ \text{NO}_2^{-} \rightarrow \text{NH}_4^{+} \rightarrow \text{NO}_3^{-} \]

\[ ^0 \rightarrow ^{+III} \rightarrow ^{+V} \]

\[ N_2 \]
Recycling of nutrients at its peak... and nutrients at a minimum productivity slows down, respiration picks up....
The Nitrogen cycle… when nutrients are low the saviors come along.
Cycling of nitrogen in the ocean

Uptake and use is the dominant part....
The Nitrogen cycle... when things get tough

You see the other half of the cycle

NITROGEN CYCLE

The spoilers
Anaerobic

The saviors
Energy intensive

Denitrification
N2-Fixation

N2

NO₂

NH₄⁺

NO₃⁻

Assimilation
Mineralization
Organic Matter

Nitrification
Low oxygen and the "spoilers"

Figure 5.6
The distribution of $O_2$ and $CO_2$ with depth. Changes in $O_2$ concentration may exceed 400% from the surface to depth, while $CO_2$ concentrations change by less than 15%.
The Nitrogen cycle... the spoilers

Nitrogen Cycle

- **Anaerobic respiration**
- Denitrification
- Nitrification
- N2-Fixation
- Assimilation
- Mineralization
- Organic Matter

Lost to the system
The Nitrogen cycle... the whole story

- **Anaerobic respiration**
- Input to the system
- Lost to the system
- **Energy intensive**

**NITROGEN CYCLE**

- **N2 Fixation**
- **Denitrification**
- **Nitrification**
- **Mineralization**
- **Assimilation**
- **Energy intensive**

**Input to the system**

**Lost to the system**

**NO3^−** -> **NO2** -> **NH4^+** -> **N2**
Aerobic versus anaerobic

The Marine nitrogen cycle
The Eutrophic ocean

• In the open ocean upwelling is the eutrophic endmember...

• The ecosystem is different and so is the controlling nutrient.
Vertical distribution of nutrients

Phosphate $10^{-6}$ mol/liter

Nitrate $10^{-6}$ mol/liter

Silicate $10^{-6}$ mol/liter

Libes, 1992

Nutrients become fully depleted during stratification
Hydrocast gear

Niskin bottle
“rosette” with 36 bottles for collecting sub-surface water
Deploying the CTD

CTD preparation and deployment at night
https://www.youtube.com/watch?v=wO_Dh97v4QM

CTD Rosette System, Deployment and Retrieval
https://www.youtube.com/watch?v=f_SHCc5Ton4

Underwater view of a CTD cast
https://www.youtube.com/watch?v=LEn2qxSrPm0
Rigging the bottles
Drawing samples from the bottles
Processing the samples
Silica the upwelling nutrient

Silicate ($\text{H}_2\text{SiO}_4$) Limits the growth of diatoms

$\text{SiO}_2$ (Silica) is an important nutrient only for diatoms
Siliceous plankton make siliceous oozes

Diatoms

Shells are composed of silicon (Si)-(glass)

Form silica deposits on ocean floor (siliceous oozes)

silicoflagellates

radiolaria
Vertical distribution of nutrients

Phosphate $10^{-6}$ mol/liter  nitrate $10^{-6}$ mol/liter  silicate $10^{-6}$ mol/liter

In upwelling zones/during upwelling phosphorous and nitrate are generally not fully depleted

Libes, 1992
The silica cycle (global view)

Silica is undersaturated and dissolves… it only forms deposits under major productivity areas.
The biological pump....

Not only controls carbon but the nutrients including silica.
And thermohaline circulation moves through the system…
Horizontal distribution of Silicate

We see a dramatic difference in distribution between the Atlantic and the Pacific.

Figure 1.5. Vertical profiles of silicic acid (A) and calcium (B). These elements are released to the dissolved phase of seawater on the dissolution of opal and carbonate tests. (The silicic acid profile was plotted by using Ocean Data View from WOCE data; Ca data are from de Villiers (1994).)
Silica the upwelling nutrient

Silicate ($\text{H}_2\text{SiO}_4$) Limits the growth of diatoms

$\text{SiO}_2$ (Silica) is an important nutrient only for diatoms

Upwelling zones are areas with high diatom productivity because silica is plentiful

This is because silica from deep water is upwelled there.
Coastal Upwelling zones in the world ocean

Fig. 5.01 Major coastal upwelling regions of the world, adapted from Thompson (1977). Arrows indicate prevailing winds.

Mann and Lazire
Open ocean zones of upwelling ....

**Fig. 5.01** Major coastal upwelling regions of the world, adapted from Thompson (1977). Arrows indicate prevailing winds.
Distribution of siliceous sediments

BIOGENIC SEDIMENTS: Distribution & percent concentration of biogenic silica in surface sediments of the world ocean on a CaCO$_3$ free basis.

Distribution of siliceous sediments largely aligns with upwelling zones
Silica cycling in an upwelling zone

1. Dissolved silica is present in deep waters.
2. Silica upwells
3. Silica is fixed in the mixed layer
4. Diatoms die and the silica tests sink to the sediments while dissolving and may begin to release SiO$_2$
5. Silica dissolves in the sediments releasing SiO$_2$ to the overlying water:
   This replenishes the SiO$_2$ content of the water locally and can enhance its silica content.
Silica cycling in a coastal upwelling zone

1. Dissolved silica is present in deep waters.

2. Silica upwells.

3. Silica is fixed in the mixed layer.

4. Diatoms die and the silica tests sink to the sediments while dissolving and may begin to release SiO$_2$.

5. Silica dissolves in the sediments releasing SiO$_2$ to the overlying water:
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Siliceous phyto plankton

Diatoms, radiolarians, silicoflagellates

Diatoms - plants

Cell walls are composed of silicon (Si)- essentially glass
Fixed this lecture

- Fix this lecture:
- The video is broken find a new one
- The Silica portion needs revision so that it goes logically through global and then to local/coastal upwelling rather than back and forth