Lecture 19
Regulation of Productivity and Limiting Factors
March 21, 2007

- Global distribution of Primary Productivity
- What Limits Terrestrial Productivity
  - light, water, temperature
- Who are the aquatic Primary Producers (the invisible forest)?
- What regulates their growth?
  - light, nutrients
- Limiting Nutrients
Terrestrial Primary Production

Productivity ranges (g/m²/yr):

- **< 100**
- **100 - 600**
- **> 600**

*NASA satellite image*
Limits to terrestrial productivity
Distribution of primary production, standing biomass, and radiation input relative to rainfall and temperature

How will global climate change influence these boundaries?

P = Primary Production (tn/ha)
B = Biomass (tn/ha)
R = Solar Radiation (kcal/m²/yr)

Marine Primary Production

Higher in Zones of Upwelling

Productivity ranges (g/m²/yr):

- < 40
- 40 - 90
- > 90

NASA satellite image
Phytoplankton: A tour

- Over 20,000 species
- Occur wherever there is water
- Range from 0.5 to 1000 $\mu$m in diameter
- There is as much genetic information in a liter of seawater as in the entire human genome
From Round et al 1990 ‘The diatoms’
From Round et al. 1990 'The diatoms'
From Canter-Lund & Lund 1996, ‘Freshwater Algae’
Coccolithophores
From Winter & Siesser 1994, 'Coccolithophores'
Cyanobacteri

Courtesy D. Karl
Cyanobacteria import nitrogen into the oceans from the atmosphere

Nitrogen Fixation

$\text{N}_2 \rightarrow \text{NH}_4$
Prochlorococcus

- 0.7µm in diameter
- Smallest and simplest photosynthetic cell
- Most abundant
- “The essence of life”
What regulates Aquatic Primary Production?

Productivity ranges (g/m²/yr):
- < 40
- 40 - 90
- > 90

NASA satellite image
The Biological Pump

- $CO_2$
- Large phytoplankton
- Small phytoplankton
- Zooplankton
- Microzooplankton
- Bacteria
- Surface ocean
- Deep ocean
- Deep consumers
- Sea floor
- Regenerated $NH_4^+$, urea, orgP,
- $NO_3^-$, $PO_4^{3-}$, etc.
- Upwelling
- Mixed Layer
- $H_2O$
- Density
- Depth

Upwelling brings nutrient-rich water to the surface, which is then used by phytoplankton to grow. The phytoplankton then die or are consumed, enriching the water with nutrients, which are then reused by microorganisms. The cycle continues, regulating the nutrient balance in the ocean.
Seasonal Temperature & Mixing Cycles in a Temperate Lake

**SUMMER**
*(Thermocline, No deep mixing, Nutrient Depletion in Surface Waters)*

**FALL**
*Surface Layers Cool and Sink (Mixing, Nutrient-Rich Waters Rise)*

**WINTER**
*Low Temperatures (Low Mixing, Low Solar Radiation)*

**SPRING**
*Spring Overturn, Spring Bloom (Winds, Deep Mixing, Nutrients Mix to Surface, Solar Radiation)*

See also Fig. 58.3 in text.
Coastal Upwelling

Ocean Currents and Upwelling

West Wind Drift

Continents Deflect Ocean Current

Equatorial Upwelling

Ocean Currents and Upwelling

Coastal Upwelling
nutrients: N, P, etc
Wind upwelling
Phytoplankton bloom

$\text{CO}_2$

$\text{O}_2$
Coastal Upwelling
Global Ocean Circulation
West Wind Drift
Continents Deflect Ocean Current
Equatorial Upwelling
Prevailing El Nino
Global Ocean Circulation
Coastal Upwelling
The Experimental Lakes Area - Ontario
SERIES Fe Fertilization
Experiment 2002
Sub-arctic Pacific

More on this in the last lecture!

Take Home Messages

- Land – water, sunlight, nutrients
- Ocean – sunlight and nutrients
- Biosynthesis and nutrient regeneration along gradients
- Upwelling in oceans critical
- Limiting factors/Law of the minimum – Redfield Ratio