Patterns of Productivity

Limitation by Light and Nutrients

OCN 201 Biology Lecture 8
Primary Production - the production of biomass by **autotrophs**

Secondary Production - the production of biomass by **heterotrophs**

The production of heterotrophs depends upon the production of autotrophs

What controls the production (growth) of autotrophs?
Resource Limits on Primary Productivity

\[ 6\text{CO}_2 + 6\text{H}_2\text{O} \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2 \]

- Light
- Nitrate
- Phosphate
- Trace Metals

Cell
The Pelagic Divisions
(By Light availability)

- **EUPHOTIC**
  - "Good" Light
  - 20 to 100 m
  - Photosynthesis!

- **DISPHOTIC**
  - Twilight
  - about 600 m

- **APHOTIC**
  - No Light
  - About 600 m
Photosynthesis

\[ 6\text{CO}_2 + 6\text{H}_2\text{O} \xrightarrow{\text{Light Energy}} \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2 \]
Photosynthesis

$6\text{CO}_2 + 6\text{H}_2\text{O} \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2$

Phytoplankton Cell

Light Energy
Respiration

\[ 6\text{CO}_2 + 6\text{H}_2\text{O} \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2 \]

Phytoplankton Cell

Energy
Photosynthesis vs Respiration

- Phytoplankton have to do both
- Photosynthesis has to be greater than respiration for phytoplankton to grow

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<tr>
<th>In the Sunlight</th>
<th>Photosynthesis &amp; Respiration</th>
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| In Darkness    | Respiration                 |
Light Decreases with Depth
Light Decreases with Depth

EUPHOTIC ZONE
Depth Effects on PP

Photosynthesis declines strongly with Depth

Respiration more constant with depth
Depth Effects on PP

The depth at which photosynthesis and respiration (production and consumption of organic matter) are EQUAL is not necessarily at 50 m!! It varies.

**Compensation Depth**

Not necessarily at 50 m!! It varies.
Depth Effects on PP

Carbon Fixed or Respired

0  25  50  75  100

Depth (m)

Surface

Compensation Depth

Below Comp. Depth

Productivity

Respiration
Depth Effects on PP

The compensation depth also marks the base of the euphotic zone. Not necessarily at 50 m!! It varies.
Key Concepts

Primary productivity by phytoplankton is restricted to the surface ocean (that’s where the light is)

The **euphotic zone** refers to the zone above the **compensation depth**. Anywhere above that depth, photosynthesis exceeds respiration

This means that phytoplankton have extra organic carbon they can use to grow and reproduce
Net Solar Radiation (average)
Phytoplankton chlorophyll
Nutrient Limitation

- With sufficient light, growth will continue until a critical nutrient runs out.
- Whichever nutrient runs out first is called the limiting nutrient.
Limits on Primary Productivity

\[ 6\text{CO}_2 + 6\text{H}_2\text{O} \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2 \]
Heterotrophs Break down organics and release Nutrients

Heterotrophic Organism

Food C, N, P

O₂
Heterotrophs break down organics and release nutrients.

- **Energy**
  - \( \text{CO}_2 + \text{H}_2\text{O} \)
  - Respiration & Remineralization

- **Growth**
  - Nutrients

- **Food**
  - C, N, P

- **O_2**
Cycling of Matter

Nutrients

SUN

Heterotroph

Autotroph
Cycling of Matter

Nutrients

SUN

Heterotroph

Autotroph

C

N

P
CO$_2$ & Nutrients (Inorganic)

Euphotic Zone

Deeper Ocean
Euphotic Zone

Deeper Ocean

Recycle (decompose)

Reuse

CO₂ & Nutrients (Inorganic)

Uptake

Export

Phytoplankton (Primary Production)

Zooplankton (Herbivores)

Zooplankton (Carnivores)

Fishes

Reuse

Reuse

Reuse

Euphotic Zone

Deeper Ocean
Decomposers (bacteria) recycle (decompose) CO$_2$ & Nutrients (Inorganic) in the Deeper Ocean and export it back to the Euphotic Zone. Phytoplankton (Primary Production) uptakes CO$_2$ & Nutrients (Inorganic) from the Euphotic Zone and recycles (decompose) it through the food web, which includes Zooplankton (Herbivores) and Zooplankton (Carnivores), and eventually reaches Fishes.
Nutrient Concentration

- Nutrients depleted in euphotic zone
- Nutrients enriched in deep water
Concentration

Nutrients Accumulate in deep ocean, because there is no sunlight to drive primary production.
• Most biomass in the sea is in the upper 200 meters

• Nutrients become depleted in most surface waters because of primary production

**Concentration**

**NET PRODUCTION**
(low nutrients, high biomass)

**NET DECOMPOSITION**
(high nutrients, low biomass)

Nutrients Accumulate in deep ocean, because there is no sunlight to drive primary production
Decomposers (bacteria)

Euphotic Zone

Deeper Ocean

Recycle (decompose)

Inorganic

CO$_2$ NO$_3$ PO$_4$

Uptake

Reuse

Reuse

Reuse

Export

Mixing and Upwelling

CO$_2$ NO$_3$ PO$_4$

(Inorganic)

(Inorganic)
Sources of Nutrients to Surface Water

- **Mixing** by storms, high winds
  - Strong density stratification inhibits mixing
  - Stratification greatest in the tropics

- **Upwelling** (coastal or equatorial)
Equatorial Upwelling

[Diagram showing ocean currents and trade winds at the equator, indicating upwelling of cooler, nutrient-rich water.]

http://www.youtube.com/watch?v=EjlIeQFxdlE
Coastal Upwelling
• Nutrients are stripped from surface waters by photosynthesis and lost to deep water

• Areas with upwelling or deep mixing by storms are very productive because nutrients are returned to the surface - but productivity depends on light

• Areas with little mixing or upwelling become nutrient limited and have low productivity EVEN IF THERE IS LOTS OF LIGHT
Global Patterns of Productivity

Suptropical Gyres
High Light
Low Nutrients
Global Patterns of Productivity

Equatorial Upwelling
High Light
High Nutrients
Global Patterns of Productivity

Subtropical Coastal Upwelling
High Light
High Nutrients
Global Patterns of Productivity

Temperate Seasonal Light
Seasonal Nutrients from winter mixing
Global Patterns of Productivity

- Polar
- Strong Seasonal Light
- High Nutrients
Seasonal Productivity

- Tropical Gyres
- North temperate
- North polar
- Tropical (Equatorial Upwelling)

Phytoplankton biomass

Month:
- J F M A M J J A S O N D J

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Productivity Patterns

- Tropics (except equator): Lots of sunlight, but low nutrients due to strong thermal stratification = persistently low productivity

- Equatorial upwelling: strong upwelling and lots of sunlight = persistently high productivity

- Temperate: Seasonal deep mixing of nutrients plus moderate sunlight = spring bloom, small fall bloom

- Polar: High nutrients, but light limited except during summer = one major summer bloom