Primary Production

Primary Producers
• Largely photosynthetic
  – Conversion of light energy into chemical energy
  – Need light, CO₂ and photosynthetic pigment
  – Produces O₂ and glucose
  – Pigments include chlorophylls, xanthophylls (particularly fucoxanthin),
    carotenes and phycobilins
  \[ \text{CO}_2 + \text{H}_2\text{O} + \text{light} \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + \text{O}_2 \]

More Primary Producers
• Several important roles
  – Capturing energy and making it available for living organisms
  – Manufacturing O₂ for respiration
  – Recycling of carbon (CO₂) following respiration

Trophic Level Energy Transfer (graphic)
• 5-20% (average of 10%) of energy passed to next level
• Creates pyramid

Photosynthesis & Respiration (graphic)
Carbon Recycling (graphic)

Taxa of Primary Producers
• Includes all three Domains
  – Bacteria – Some bacteria photosynthetic (other autotrophic bacteria are
    chemosynthetic), Cyanobacteria
  – Archaea – Primarily chemosynthetic
  – Eukaryota –
    • Kingdom Protista – singled celled organisms
      – Plant-like - Bacillariophyta, Dinoflagellata, Chrysophyta
      – Animal-like – Foraminafera, Polycystina, Ciliophora
    • Kingdom Plantae: Phyla Chlorophyta, Phaeophyta, Rhodophyta, Magnoliophyta

Taxa of Primary Producers (graphic)

Measuring Primary Productivity (graphic)
• Amount of organic material produced per m² of surface area

Measuring Primary Production
• Gross PP - total amount of organic material produced
  – gC/m²/unit time (day or yr) - based on sea surface
• Net PP - Gross minus the amount needed for cellular respiration of the primary
  producers
• Light - Dark bottle technique
  – Use of O₂ measurements - problem due to zooplankton utilizing oxygen too
  – Use of C¹⁴ (bicarbonate labeled with C¹⁴)
Global Primary Production (graphic)
Global Primary Productivity (graphic)
Other Measures
• Standing stock (crop) - a measure of the existing amount of living photosynthetic material
  – Typically used for terrestrial measurements
  – Seaweeds more reasonable to measure than phytoplankton
  – However, phytoplankton play greater role in primary production
  – Thus not a good measure
  – More recent technique of using amount of chlorophyll as an indicator of standing stock

More Other Measures
• Use of satellites - coastal zone color scanner (CZCS) monitoring chlorophyll concentration, both distribution and abundance

Other Measures (graphic)
Variation in Primary Production
• Dependent on physical, chemical, and biological characteristics of environment
• Theoretically populations can grow unchecked (exponential growth)
• However, biological systems always have some “limiting factor”
  – For phytoplankton - light, nutrients and/or grazing

Effects of Limiting Factors (graphic)
Light
• Light - depth of photic zone dependent on sun’s position, atmospheric and water characteristics (absorption and transparency)
  – May be a few meters (coastal) to 200 m
  – Critical depth - rate of photosynthesis balanced by cellular respiration (no net photosyn.) - less than the photic zone

Effect of Light Intensity on Rate of Photosynthesis (graphic)
Photosynthetic Response of Two Phytoplankton Species (graphic)
Photosynthesis
• Light reaction requires the pigment to absorb light energy and convert it to a chemical form (ATP or NADPH$_2$)
• Dark reaction utilizes chemical form of energy to manufacture carbohydrate compounds
• Chlorophyll $a$ absorbs light in reds (700nm) and blues (400nm)
• Problem for marine photosyn. since red is absorbed by water quickly

More Photosynthesis
• Need for accessory pigments which absorb energy and pass it chlorophyll
  – Fucoxanthin (xanthophyll) - in Phaeophyta, Chrysophyta and Dinoflagellata (550nm)
– Phycoerythrin (pcobilins) in Rhodophyta and Cyanobacteria - blues (400nm)
• Marine green algae and grasses (dependent on chlorophyll) have large amounts of pigment and supplement with chlorophyll $b$

**Nutrients**
• Need components for photosynthesis and for structural components
  – Include C, H, O, N, P and trace elements
• C, H, O readily available as carbonate (CO$_3^{2-}$), bicarbonate (HCO$_3^-$) and water (H$_2$O)
• N available as nitrate (NO$_3^{-}$), nitrite (NO$_2^{-}$), ammonium (NH$_4^+$) and N$_2$
  – N$_2$ requires nitrogen fixation
• P available as phosphate (PO$_4^{3-}$)

**More Nutrients**
• General loss of nutrients from photic zone through sinking
  – Requires vertical mixing - wind, wave and tidal mixing vs. upwelling
  – Upwelling caused by offshore winds, coastal currents, and equatorial Coriolis effect of water moving N & S from equator
  – Langmuir cells (parallel with wind direction) may hold nutrients near surface

**Even More Nutrients**
• El Niño - normal weather based on weather pattern that brings warm surface current from N along Peruvian coast in their summer - causes rainy, humid, warm weather and blocks typical upwelling in the area
  – If El Niño goes further S or stays longer, there’s a dramatic effect on marine productivity in the region (also known as the El Niño Southern Oscillation or ENSO)
  – La Niña is the more normal form of southern oscillation

**Global Upwelling Areas (graphic)**
**Vertical Distribution of Nitrate (graphic)**

**Grazing**
• Grazers are herbivores
• Herbivore population dependent on presence and numbers of phytoplankton/primary productivity
• Populations of both vary in a dependent fashion (can be cyclical activity of overgrazing and starvation)

**Global Zooplankton Populations (graphic)**
**Effects of Grazing (graphic)**

**More Grazing**
• Movements of grazers follow phytoplankton (sometimes a preferred species)
  – Copepods and their "red" and "blue dance"
    • Red - move vertically (when chlorophyll in phytoplankton above absorbs blue light)
    • Blue - move horizontally (when little phytoplankton above)
Seasonal Variations

• Dependent on light, nutrients and grazing
• No activity when there is no/little light - may be in cyst form during absence
• Nutrient supply dependent on mixing - when thermocline or pycnocline is absent (and other special sources)
• Finally affected by population of grazers
• Temperate example

Limiting Factors of Photosynthesis (graphic)
Seasonal Variations in Thermocline (graphic)
Seasonal Population Variations (graphic)
Effects of Seasonal Light Conditions (graphic)
More Seasonal Variations (graphic)