Chapter 18

PRIMARY PRODUCTION AND ENERGY FLOW

Chapter Concepts

- Terrestrial Primary Production is generally limited by temperature and moisture
- Aquatic Primary Production is generally limited by nutrient availability
- Consumers can influence rates of primary production in terrestrial and aquatic ecosystems
- Energy losses limit the number of trophic levels found in ecosystems

Fundamental Concepts

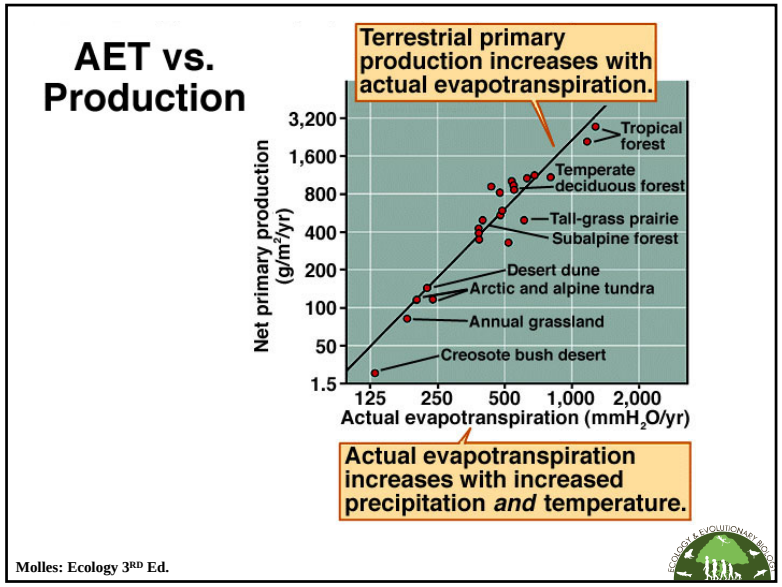
- Primary Production – fixation of energy by autotrophs in an ecosystem
- Rate of Primary Production – amount of energy fixed over a given period of time
  - Gross – Total amount of energy fixed by autotrophs
  - Net – Amount of energy leftover after autotrophs have met their metabolic needs

Fundamental Concepts

- Trophic Level – Position in a food web determined by number of energy transfers from primary producers to current level:
  - Primary producers occupy first level
  - Primary consumers occupy second level
  - Secondary consumers occupy third level
  - Tertiary consumers occupy fourth level

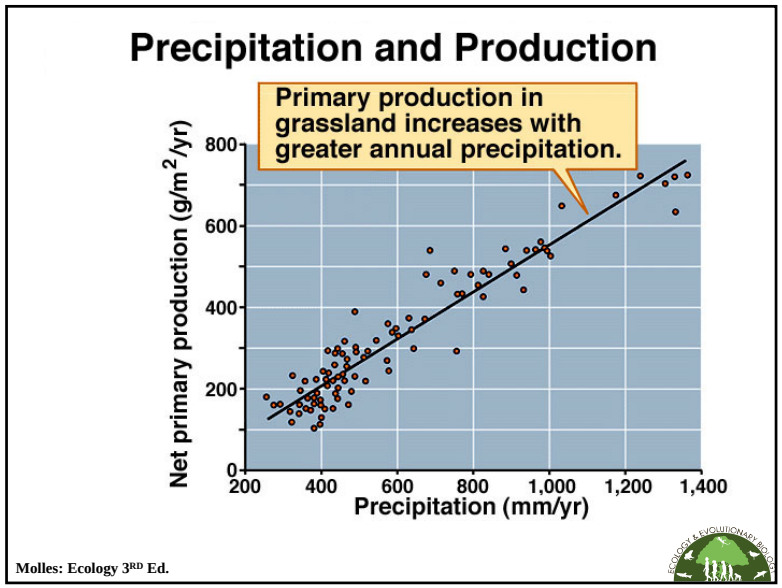
Evapotranspiration and Terrestrial Primary Production

- *Rosenzweig* estimated influence of moisture and temperature on rates of primary production by plotting relationship between annual net primary production and annual actual evapotranspiration (AET)
  - ❖AET – annual amount of water that evaporates and transpires off a landscape
    - Cold dry ecosystems tend to have low AET



Evapotranspiration and Terrestrial Primary Production

- ❖Generally, there is a positive relationship between net primary production and AET
  - *Sala* found east-west variation in primary production correlated with rainfall



Soil Fertility and Terrestrial Primary Production

- Significant variation in terrestrial primary production can be explained by differences in soil fertility
- *Shaver and Chapin* found arctic net primary production was twice as high on fertilized plots compared to unfertilized plots
- *Bowman* suggested N is main nutrient limiting net primary production in a dry tundra meadow, and N and P jointly limit production in a wet meadow

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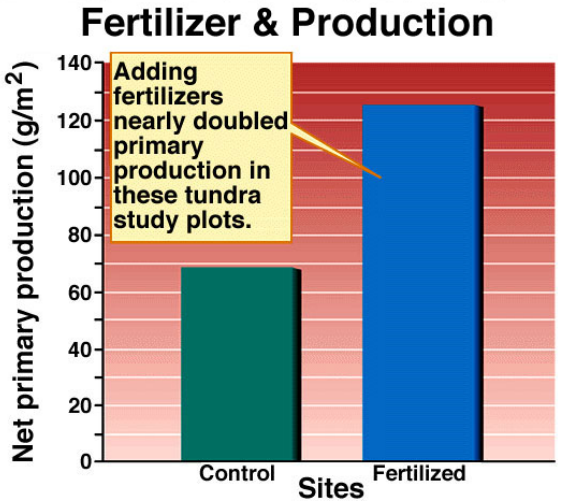

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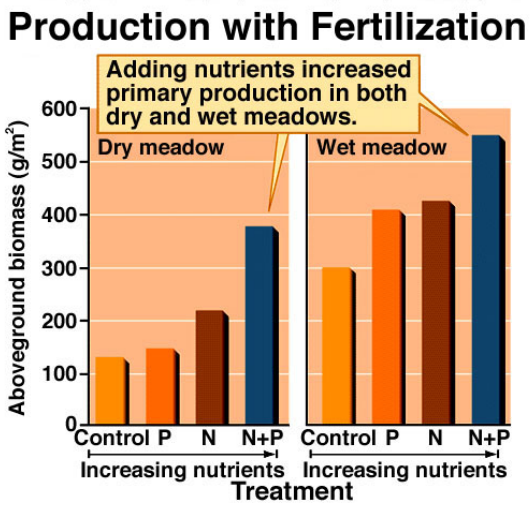

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Patterns of Aquatic Primary Production

- Several studies have found quantitative relationship between phosphorus and phytoplankton biomass
- Several studies support generalization that nutrient availability controls rate of primary production in freshwater ecosystems

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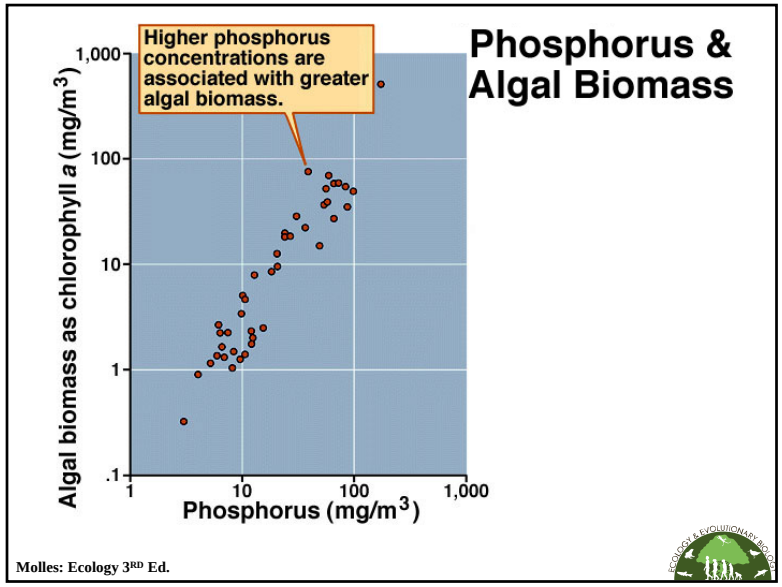

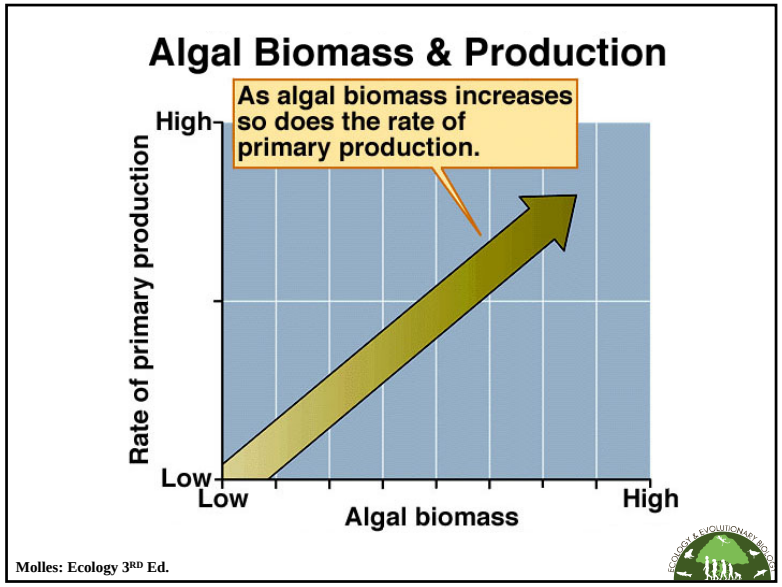

Whole Lake Experiments

- Founded in 1968
- In northwestern Ontario, Canada
- The Experimental Lakes Area

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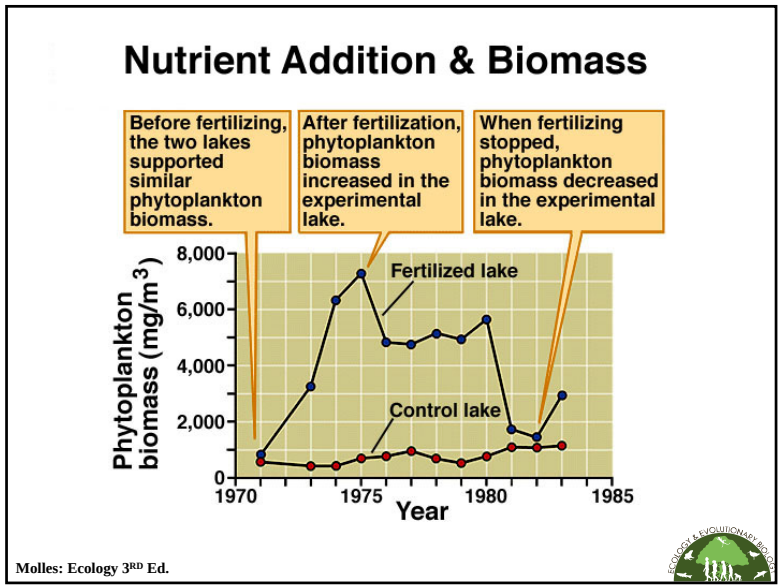
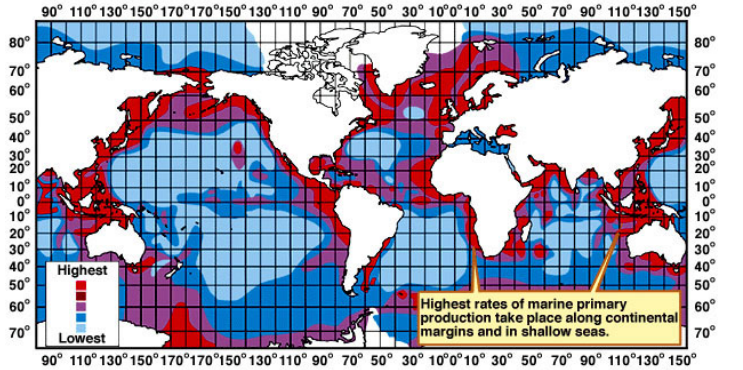


Geographic Variation



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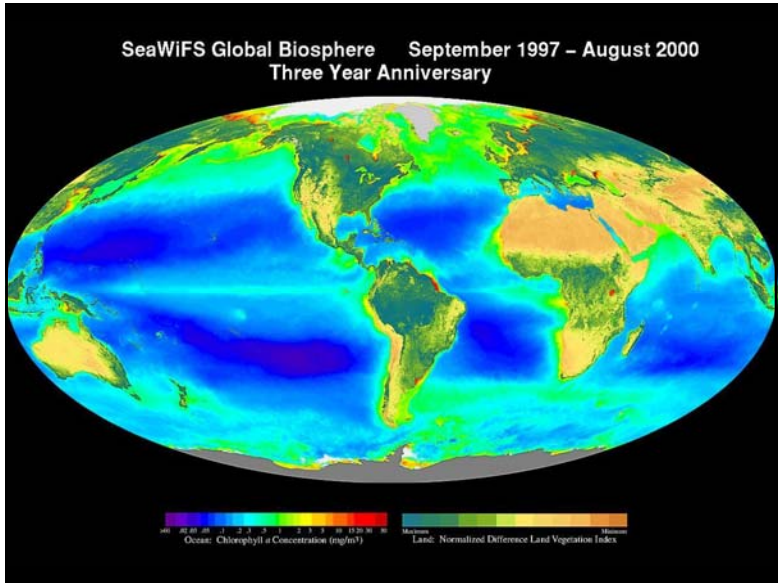
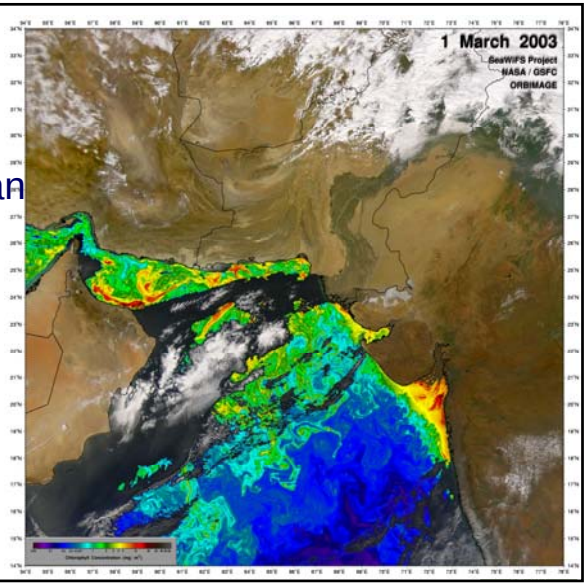


Spring Bloom in the Arabian Sea



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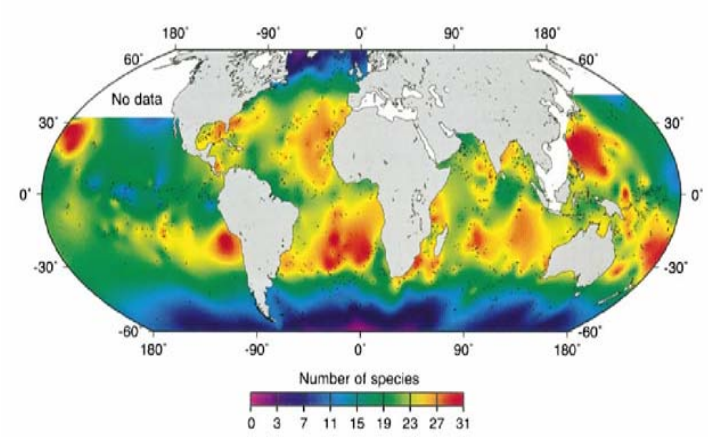

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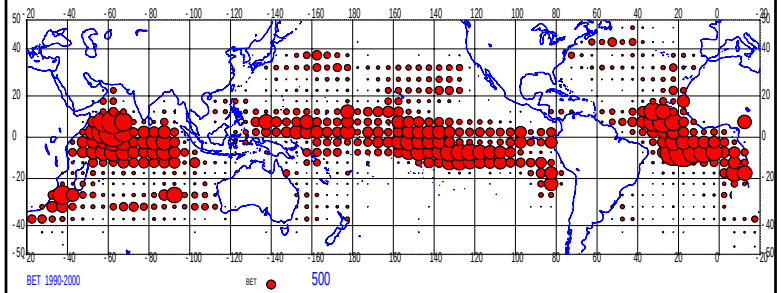

The Bigeye Tuna

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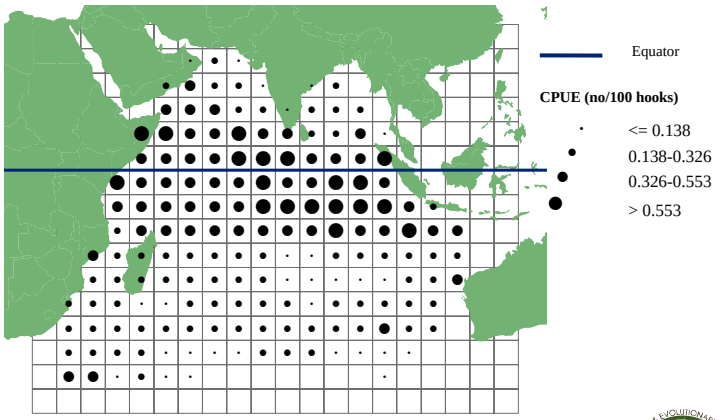
Bigeye Tuna: Catch Per Unit Effort



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Global Patterns of Marine Primary Production

- Highest rates of primary production by marine phytoplankton are generally concentrated in areas with higher levels of nutrient availability
- Highest rates found along continental margins
  - ❖Nutrient run-off from land
  - ❖Sediment disturbance
- Open ocean tends to be nutrient poor
  - ❖Vertical mixing main nutrient source

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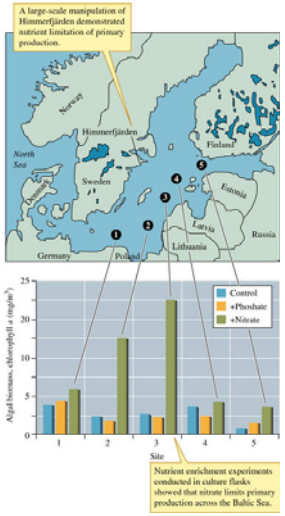
Global Patterns of Marine Primary Production

- *Graneli* gathered results suggesting rate or primary production in Baltic Sea is nutrient limited
  - ❖Increased nutrients led to increased chlorophyll concentrations
    - N appears to be limiting nutrient



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Global Patterns of Marine Primary Production

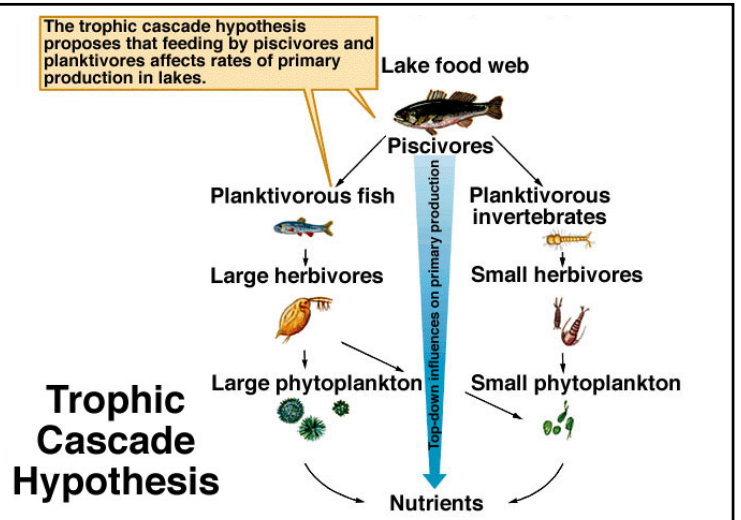
- *Residual Variation* – proportion of variation not explained by the independent variable
  - *Dillon and Rigler* suggested environmental factors besides nutrient availability significantly influence phytoplankton biomass
    - Intensity of predation on zooplankton

Consumer Influences

- Bottom-Up Controls
  - Influences of physical and chemical factors of an ecosystem
- Top-Down Controls
  - Influences of consumers

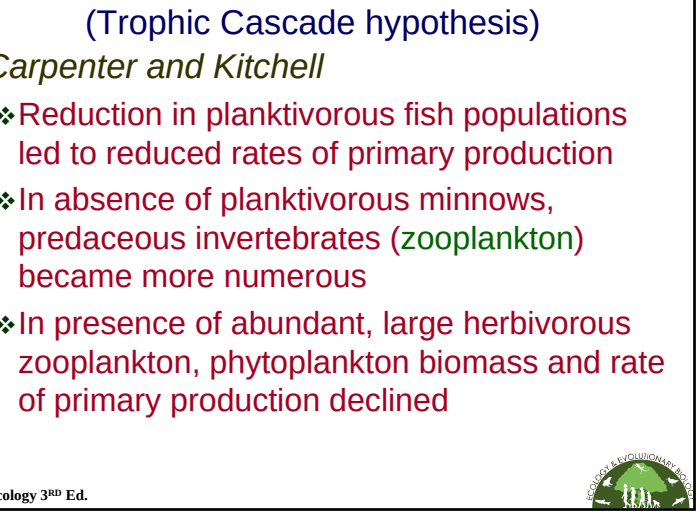
Lake Primary Production

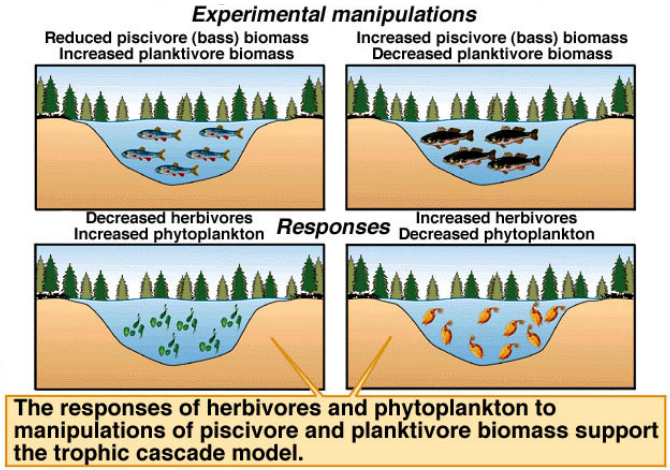
- *Carpenter* proposed piscivores, planktivorous fish can cause significant deviations in primary productivity
- *Carpenter and Kitchell* proposed the influence of consumers on lake primary productivity propagate through food webs
  - Trophic Cascade Hypothesis



Lake Primary Production (Trophic Cascade hypothesis)

- *Carpenter and Kitchell*
  - Reduction in planktivorous fish populations led to reduced rates of primary production
  - In absence of planktivorous minnows, predaceous invertebrates (zooplankton) became more numerous
  - In presence of abundant, large herbivorous zooplankton, phytoplankton biomass and rate of primary production declined





Experimental manipulation

- Reduced piscivore (bass) biomass, increased plankitivore biomass
- Increased piscivore biomass, decreased plankitivore biomass

Responses

- Decreased herbivores, increased phytoplankton
- Increased herbivores, Decreased phytoplankton

- The responses of herbivores and phytoplankton to manipulation of piscivore and planktivore biomass support the trophic cascade model

Primary Production (PP) in the Serengeti

- *McNaughton* estimated Serengeti grazers consume an average of 66% of annual primary production
  - Rate of primary production in the Serengeti is positively correlated with rainfall quantity

Serengeti National Park

- Endless plain
- 14,763 sq. km
- in Northern Tanzania

PP in the Serengeti

- Found grazers can increase primary production
  - Increased growth rate
    - Compensatory Growth
      - Lower respiration rate due to lower biomass
      - Reduced self-shading
      - Improved water balance due to reduced leaf area

PP in the Serengeti

- In addition, *McNaughton* found compensatory growth highest at intermediate grazing intensities
  - ❖Light grazing insufficient to produce compensatory growth
  - ❖Heavy grazing reduces plant's capacity to recover

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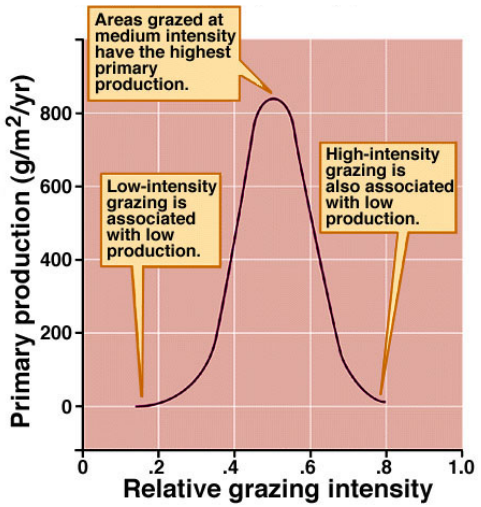
Grazing & Primary Production



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Trophic Dynamic View of Ecosystems

- *Lindeman* concluded that the ecosystem concept is fundamental to the study of energy transfer within an ecosystem
  - ❖Suggested grouping organisms within an ecosystem into trophic levels
    - ▪ Each feeds on level immediately below
      - ➢ As energy is transferred from one trophic level to another, energy is degraded
      - ➢ The 10% Law

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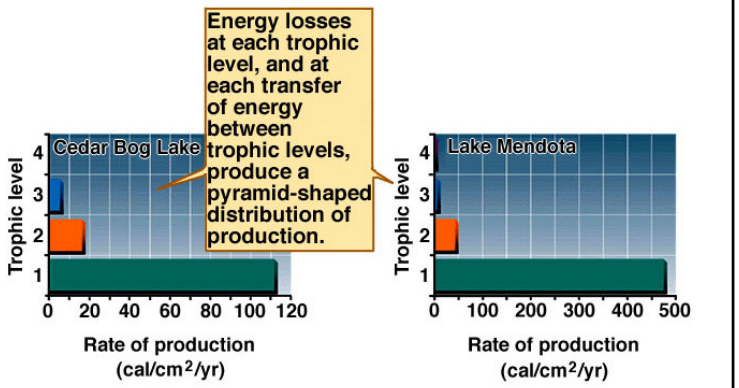
Production by Trophic Level



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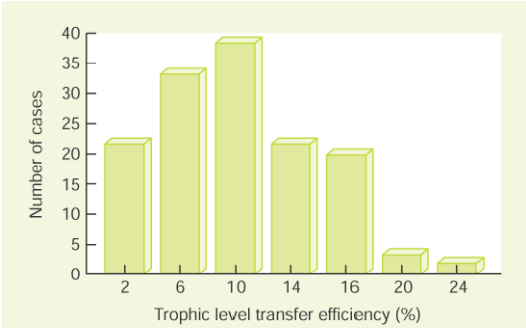

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Why SP is smaller than PP?

- Not all the plant biomass is consumed (some is decomposed)
- Not all the eaten parts is assimilated (some is lost in feces)
- Not all the energy assimilated is actually converted to biomass (some is lost as heat)

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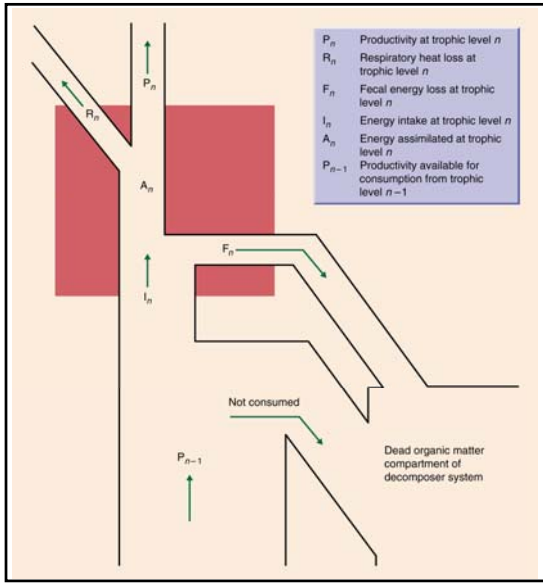

Pattern of energy flow through a trophic level

The laws of thermodynamics

- 1st = Energy is neither created nor destroyed
- 2nd = No energy conversion process is 100% efficient. Part of the energy is lost in a form of heat to the environment that is useless for further transfer

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Consumption efficiency

- Ingested energy
- Herbivores 5% in forests, 25% in grassland & 50% in aquatic ecosystem
- Carnivore (vertebrate-vertebrate 50-100%, vertebrate-invertebrate 5%, invertebrate-invertebrate 25%)

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Assimilation efficiency

- Energy taken that is assimilated
- Bacteria/fungi 100%
- Herbivore, detritivore, microbivore 20-50%
- Carnivore 80%
- Seed/fruit 60-70%
- Leaf 50%
- Wood 15%

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Production efficiency

- Assimilated energy that be included in biomass
- Invertebrate 30-40%
- Ethotherm 10%
- Endotherm 1~2%
- Microorganism high

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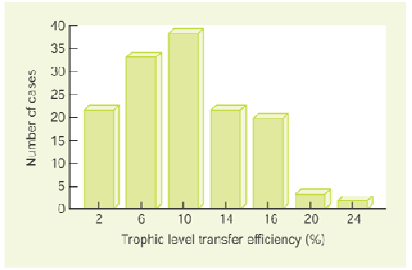
"The 10% law"

- Trophic transfer efficiency = CE*AE*PE
- Highly variable
- 2~24% in general
- Mean = 10.1%, SE = 0.49



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Trophic Dynamic View of Ecosystems

- As energy is transferred from one trophic level to another, energy is degraded:
  - Limited assimilation
  - Consumer respiration
  - Heat production
    - Energy quality decreases with each successive trophic level
      - Pyramid-shaped energy distribution

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Energy Flow - A Temperate Deciduous Forest

- *Gosz* studied solar energy flow:
  - 15% reflected
  - 41% converted to heat
  - 42% absorbed during evapotranspiration
  - 2.2% fixed by plants as gross primary production
  - 1.2% used in plant respiration
  - 1% left for primary production

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Energy Flow - A Temperate Deciduous Forest

- 99% of solar energy unavailable for use by second trophic level
- As energy losses between trophic levels accumulate, eventually there is insufficient energy left to support a viable population at a higher trophic level

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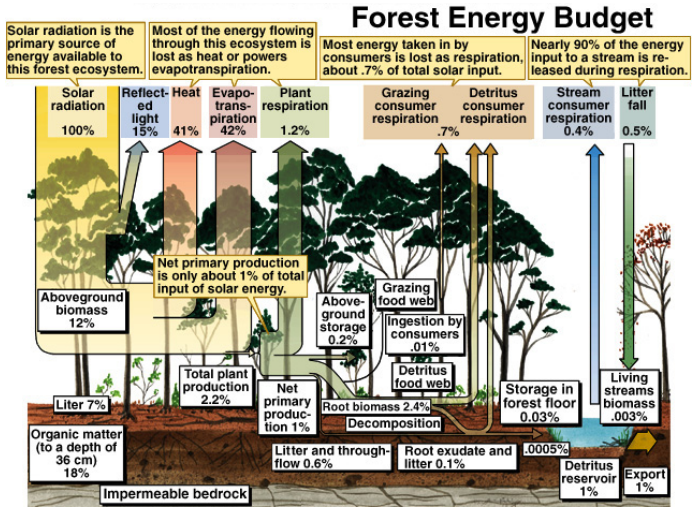

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Summary

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