Dynamics of Ecosystems

Chapter 57

Outline

- The Water Cycle
- Nutrient Cycles
- Trophic Levels
- Primary Productivity
- The Energy in Food Chains
- Ecological Pyramids
- Interactions Among Trophic Levels
- Species Richness
- Island Biogeography

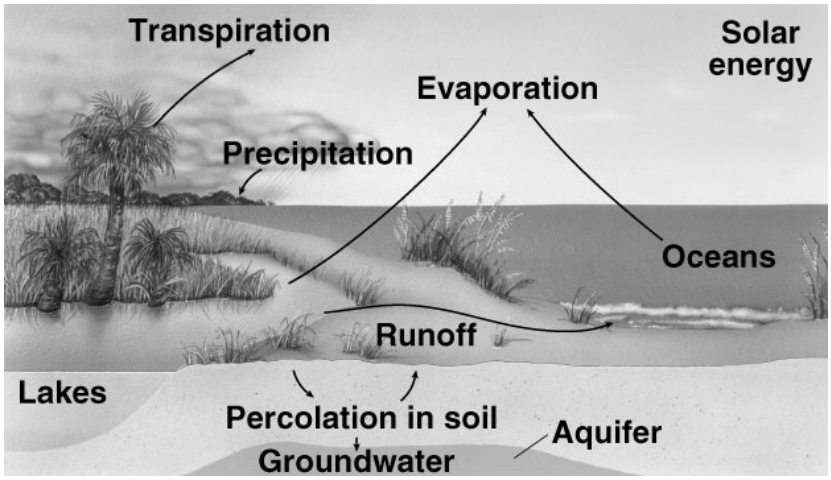
Chemical Cycling

- An ecosystem includes all the organisms living in a particular place, and the abiotic environment in which they interact.
  - two main processes:
    - energy entering ecosystems
    - biogeochemical cycles

The Water Cycle

- From the oceans, water evaporates into the atmosphere.
- From land, 90% of water reaching the atmosphere transpires from plants.
  - Only about 2% of all water on earth is captured in any form.
    - rest is free water circulating between the atmosphere and the oceans

Water Cycle



The Water Cycle

- Groundwater
  - Groundwater amounts to more than 96% of all fresh water in the US.
    - Upper, unconfined portion (water table) is partially accessible to plants, while lower layers are generally out of reach.
      - Water table recharged via percolation from rainfall.
        - slow process

The Water Cycle

- Groundwater provides about 25% of all water used in the US, and supplies 50% of the US population with drinking water.
  - Many underground aquifers have much higher withdraw rates than recharge rates.
    - water mining
    - increasing chemical pollution

The Water Cycle

- Breaking the cycle
  - In dense forest ecosystems, more than 90% of moisture is taken up by plants and transpired back into the atmosphere.
    - When forests are cut down, the organismic water cycle is broken.
      - Water drains from the area instead of evaporating and forming clouds.

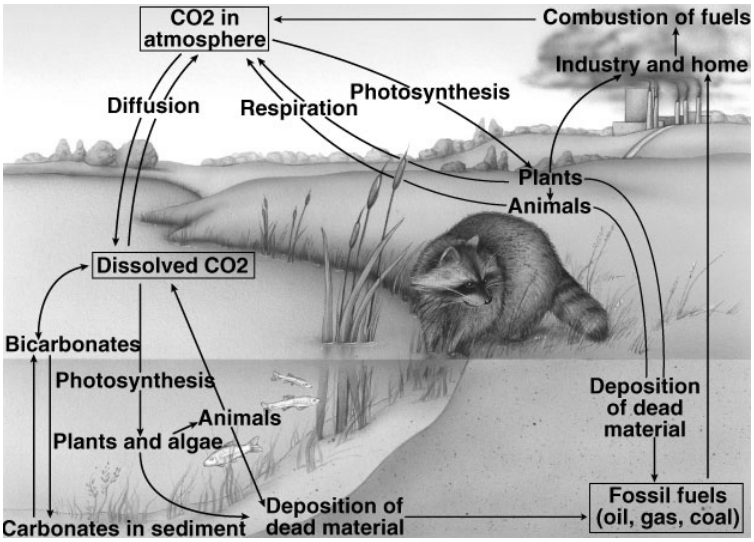
The Carbon Cycle

- Carbon cycle is based on carbon dioxide which makes up only about 0.03% of the atmosphere.
  - All terrestrial heterotrophic organisms obtain carbon indirectly from photosynthetic organisms.
    - Most organic compounds formed as a result of carbon dioxide fixation are ultimately broken down and released back into the atmosphere.

The Carbon Cycle

- Roughly 700 billion metric tons of carbon dioxide are located in the atmosphere, and approximately 1 trillion metric tons are dissolved in the oceans.
  - Fossil fuels contain another 5 trillion metric tons.
    - Increasing fuel consumption is liberating carbon at an increasing rate.

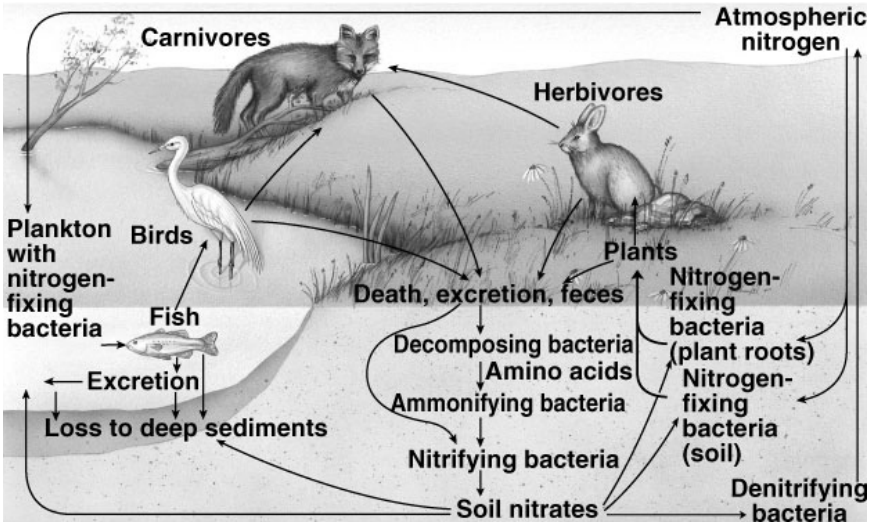
Carbon Cycle



The Nitrogen Cycle

- Relatively few types of organisms can fix nitrogen into forms that can be used for biological processes.
- Nitrogen fixation: $N_2 + 3H_2 \rightarrow 2NH_3$
  - Only symbiotic bacteria fix enough nitrogen to be of major significance in nitrogen production.
  - ammonification
  - denitrification

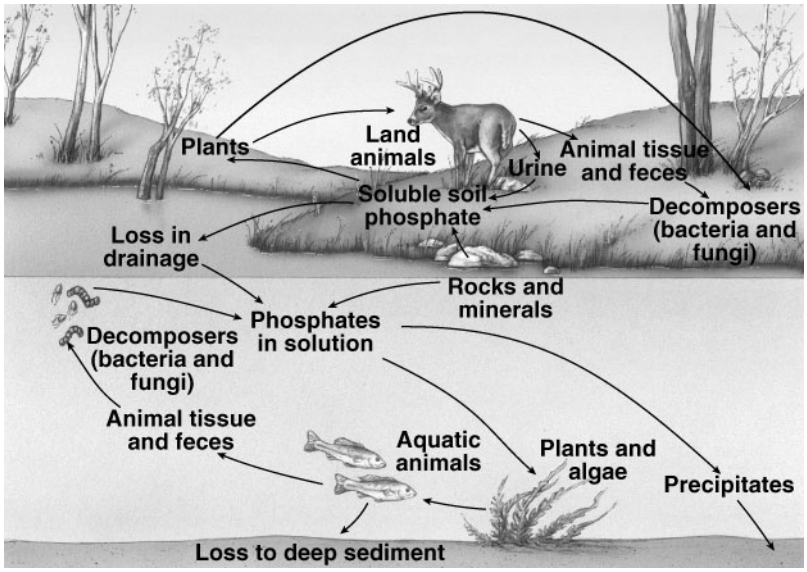
Nitrogen Cycle



The Phosphorus Cycle

- Phosphates weather from soils into water, enter plants and animals, and are re-deposited in the soil when plants and animals decompose.
  - Millions of tons are added to agricultural land annually to increase crop production.
    - superphosphate

Phosphorus Cycle



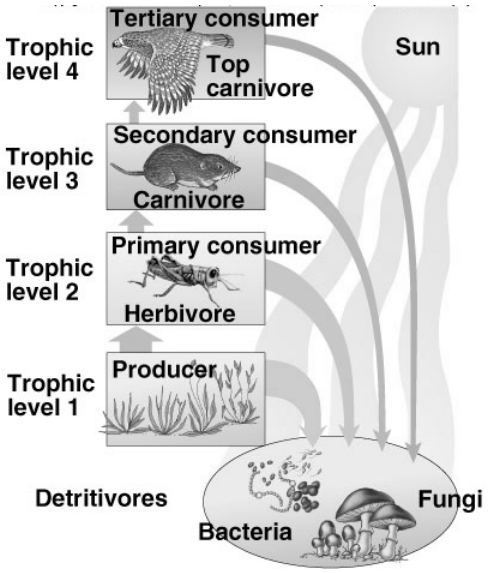
Trophic Levels

- Autotrophs - capture light energy and manufacture own chemical energy
  - primary producers
- Heterotrophs - must obtain organic molecules that have been synthesized by autotrophs
  - consumers

Trophic Levels

- Primary consumers - herbivores
- Secondary consumers - organisms that feed on herbivores
- Decomposers - break down complex organic material into simpler compounds
- Detritivores - live on refuse of an ecosystem

Trophic Levels



Trophic Levels

- Trophic level refers to the feeding level of an organism.
  - Organisms from each trophic level constitute a food chain.
    - Interconnected food chains constitute a food web.
- On average, 10% of the organic matter (energy) transfers from one trophic level to the next.

Primary Productivity

- Primary productivity refers to the amount of organic matter produced from solar energy in a given area during a given period of time.
  - Gross primary productivity is the total organic matter produced.
  - Net primary productivity is the amount of organic matter produced that is available to heterotrophs.
- Secondary productivity - rate of production by heterotrophs

Ecosystem Productivity Per Year

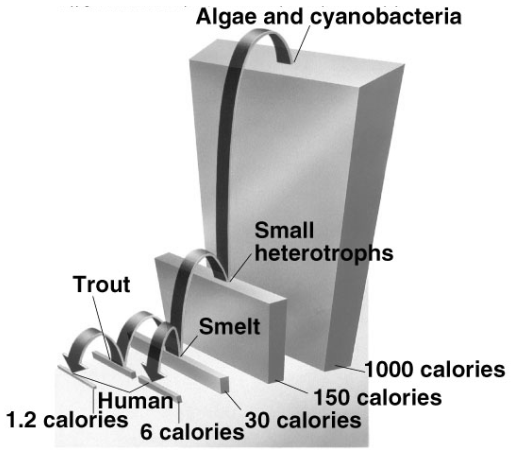
Ecosystem Type	Net Primary Productivity (NPP) NPP per Unit Area (g/m^2)	World NPP (10^{12} kg)
Algal beds and reefs	2500	1.6
Tropical rain forest	2200	37.4
Wetlands	2000	4.0
Tropical seasonal forest	1600	12.0
Estuaries	1500	2.1
Temperate evergreen forest	1300	6.5
Temperate deciduous forest	1200	8.4
Savanna	900	13.5
Boreal forest	800	9.6
Woodland and shrubland	700	6.0
Cultivated land	650	9.1
Temperate grassland	600	5.4
Continental shelf	360	9.6
Lake and stream	250	0.5
Tundra and alpine	140	1.1
Open ocean	125	41.5
Desert and semidesert shrub	90	1.6
Extreme desert, rock, sand, and ice	3	0.07

The Energy in Food Chains

- Due to the Second Law of Thermodynamics, food chains are generally limited to three or four steps (trophic levels).
  - A community's productivity is ultimately determined by the amount of sunlight it receives.
  - In northern climates, net primary productivity often increases as the growing season lengthens.

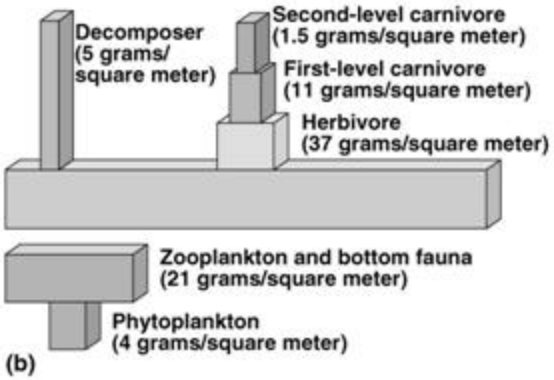
Ecological Pyramids

- Moving up a food chain, you generally find fewer individuals at each successive trophic level.



Ecological Pyramids

- Some aquatic ecosystems have inverted biomass pyramids due to high turnover rates.

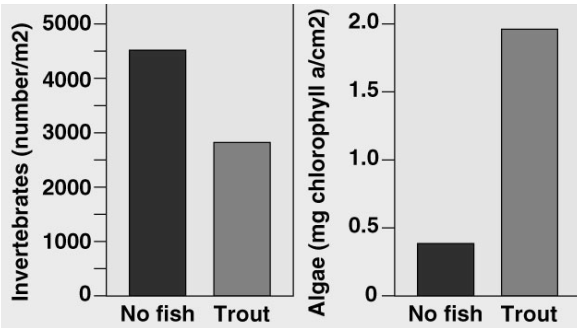


Ecological Pyramids

- Top carnivores
  - Top-level predators tend to be relatively large, thus the small residual biomass available at the top of the pyramid is concentrated in a relatively small number of individuals.

Interactions Among Trophic Levels

- Trophic cascading refers to the idea that the effect of one trophic level flows down to lower levels. (top-down effects)

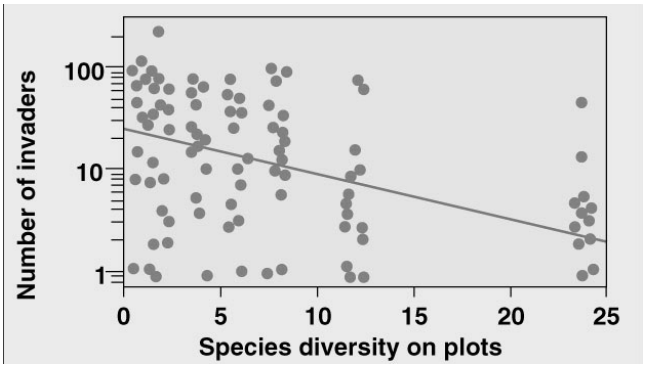


Interactions Among Trophic Levels

- Bottom-up effects
  - When productivity of an ecosystem is low, herbivore populations will be too small to support any predators.
    - Increases in productivity will increase herbivore populations.
      - Further increases in productivity will not increase herbivore populations, but will increase predator populations.

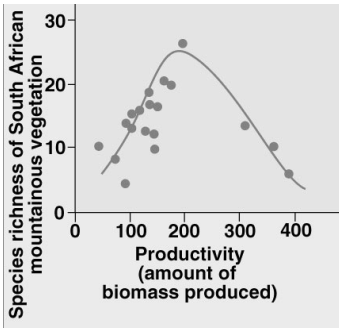
Effects of Species Richness

- One theory suggests species-rich communities tend to be more stable.
  - resist disturbance better



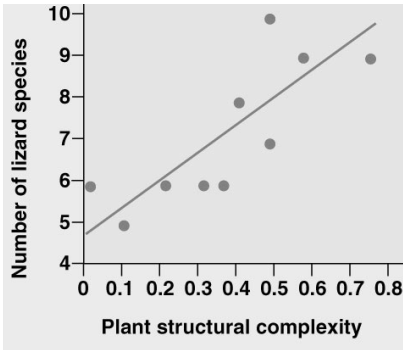
Causes of Species Richness

- Factors promoting species richness
  - ecosystem productivity
    - Ecosystems with intermediate levels of productivity tend to have the most species.



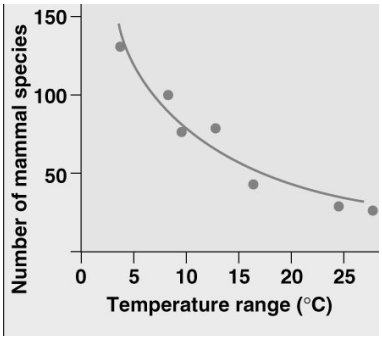
Causes of Species Richness

- Spatial heterogeneity
  - Heterogeneous ecosystems provide a greater variety of microhabitats and microclimates.



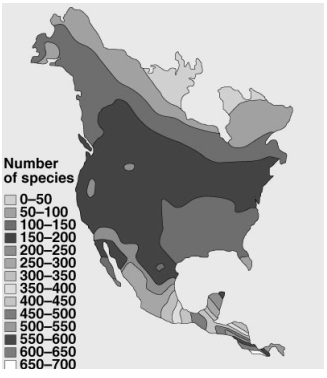
Causes of Species Richness

- Climate
  - Difficult to assess. In western N. America, species richness is inversely correlated with mean temperature range.



Biogeographic Patterns of Species Diversity

- Many species exhibit a steady increase in species richness from the arctic to the tropics.
  - species diversity cline
- Diversity in the tropics
  - evolutionary age
  - higher productivity
  - predictability
  - predation
  - spatial heterogeneity



Island Biogeography

- MacArthur and Wilson proposed larger islands contain more species than smaller islands due to the effect of area and isolation on the likelihood of species extinction and colonization.
  - species-area relationship
    - equilibrium model
      - Island species richness is a dynamic equilibrium between colonization and extinction.

Summary

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