26.1 Ecology: The Interconnecting Web of Life

- **Microbial ecology** – microbes in their natural habitats
- **Applied microbiology** – study of practical uses of microbes in food processing, industrial production, and biotechnology
- **Biotic** – any living or dead organisms that occupy an organism’s habitat
- **Abiotic** – nonliving components
- **Ecosystem** – collection of organisms and the surrounding physical and chemical factors
Organization of Ecosystems

Biosphere – thin envelope of life that surrounds the earth’s surface

Made up of:
- Hydrosphere (water)
- Lithosphere (soil)
- Atmosphere (air)

Maintains and creates the conditions of temperature, light, gases, moisture, and minerals required for life processes

• Biomes – particular climatic regions
• **Communities** – the association of organisms that live together and that exhibit well-defined nutritional or behavioral interrelationships

• **Population** – a group of organisms of the same kind

• **Habitat** – the physical location in the environment to which an organism has adapted

• **Niche** – overall role that a species, or population, serves in a community; nutritional intake, position in the community, and rate of population growth
Figure 26.1
Levels of organization
Energy and Nutritional Flow in Ecosystems

• Food chain or energy pyramid summarizes the feeding levels:
  – Producers
  – Consumers
    • Autotrophs
  – Decomposers
    • Mineralization
    • Bioremediation
      – Consortium
<table>
<thead>
<tr>
<th>Role</th>
<th>Description of Activity</th>
<th>Examples of Microorganisms Involved</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary producers</td>
<td>Photosynthesis</td>
<td>Algae, bacteria, sulfur bacteria</td>
</tr>
<tr>
<td></td>
<td>Chemosynthesis</td>
<td>Chemolithotrophic bacteria in thermal vents</td>
</tr>
<tr>
<td>Consumers</td>
<td>Predation</td>
<td>Free-living protozoa that feed on algae and bacteria; some fungi that prey upon nematodes</td>
</tr>
<tr>
<td>Decomposers</td>
<td>Degrading dead organisms and wastes</td>
<td>Soil saprobes (primarily bacteria and fungi) that degrade cellulose, lignin, and other complex macromolecules</td>
</tr>
<tr>
<td></td>
<td>Mineralization of organic compounds</td>
<td>Soil bacteria that reduce organic compounds to inorganic compounds such as CO$_2$ and minerals</td>
</tr>
<tr>
<td>Cycling agents for</td>
<td>Recycling compounds containing</td>
<td>Specialized bacteria that transform elements and keep them cycling from the biotic to the abiotic and back to the biotic phases of the biosphere</td>
</tr>
<tr>
<td>biogeochemical cycles</td>
<td>carbon, nitrogen, phosphorus, sulfur</td>
<td></td>
</tr>
<tr>
<td>Parasites</td>
<td>Living and feeding on hosts</td>
<td>Viruses, bacteria, protozoa, fungi, and worms that play a role in population control</td>
</tr>
</tbody>
</table>
Microorganisms are the only living beings at all three levels
Figure 26.3 Food chain

Food Chain

Minnow → Top carnivore

Insect larva → Tertiary consumer

Cyclops (crustacean) → Secondary consumer

Didinium (protozoan) → Primary consumer

Diatoms → Producer
• **Food Web**: feeding relationships in communities

• Energy does not cycle

• As energy is transferred to the next level, a large proportion of the energy will be lost that cannot be utilized in the system

• Feeding relationships are represented by a food web which represents the actual nutritional structure of a community
Figure 26.4 Food web
Ecological Interactions Between Organisms in a Community

• Dynamic interrelationships based on nutrition and shared habitat

• **Mutualism** – beneficial to both members

• **Commensalism** – one member benefits while the other does not benefit nor is it harmed
  – **Syntrophism** – metabolic products of one are useful nutrients for another

• **Synergism** – two usually independent organisms cooperate to break down a nutrient neither one could have metabolized alone
• Parasitism – one derives its nutrients and habitat from a host that is usually harmed in the process

• Competition – one member gives off antagonistic substances that inhibit or kill susceptible species sharing its habitat

• Predator – consumer that actively seeks out and ingests live prey

• Scavengers – feed on a variety of food sources
26.2 The Natural Recycling of Bioelements

- Processes by which bioelements and essential building blocks of protoplasm are recycled between biotic and abiotic environments
- Essential elements are cycled through biological, geologic, and chemical mechanisms – biogeochemical cycles
- Microorganisms remove elements from their inorganic reservoirs and convey them into the food web
- **Gaia theory**: the biosphere contains a diversity of habitats and niches favorable to life because living things made it that way
Atmospheric Cycles

- Carbon cycle
- Nitrogen cycle
The Carbon Cycle

• Intimately associated with the energy transfers and trophic patterns of the biosphere

• Carbon is recycled through ecosystems via photosynthesis, respiration, and fermentation of organic molecules, limestone decomposition, and methane production
The Carbon Cycle

- Principle users of atmospheric CO$_2$ are photosynthetic autotrophs
- Carbon is returned to the atmosphere as CO$_2$ by respiration, fermentation, decomposition of marine deposits, and burning fossil fuels
- Methanogens reduce CO$_2$ and give off methane (CH$_4$)
The Nitrogen Cycle

• N₂ gas is the most abundant gas in the atmosphere, 79% of air volume

• Involves several types of microbes

• 4 types of reactions:
  – **Nitrogen fixation** – atmospheric N₂ gas is converted to NH₄ salts; nitrogen-fixing bacteria live free or in symbiotic relationships with plants
    • **Root nodules**: symbiosis between rhizobia and legumes
  – **Ammonification** – bacteria decompose nitrogen-containing organic compounds to ammonia
  – **Nitrification** – convert NH₄⁺ to NO₂⁻ and NO₃⁻
  – **Denitrification** – microbial conversion of NO₃⁻ back to atmospheric N₂
Figure 26.7
Nitrogen Cycle
Figure 26.8 Nitrogen fixation through symbiosis
Figure 26.9 Inoculating legume seeds with *Rhizobium* bacteria
Sedimentary Cycles

- Sulfur cycle
- Phosphorous cycle
The Sulfur Cycle

• Sulfur originates from rocks, oceans, and lakes
• Sulfur exists in the elemental form and as hydrogen sulfide gas, sulfate, and thiosulfate
• Plants and many microbes can assimilate only \( \text{SO}_4 \) and animals require an organic source – amino acids: cystine, cysteine, and methionine
• Bacteria convert environmental sulfurous compounds into useful substrates (sulfates)
The Phosphorous Cycle

- Chief inorganic reservoir of phosphate ($\text{PO}_4$) is phosphate rock
- $\text{PO}_4$ must be converted into a useable form ($\text{PO}_4^{-3}$) by the action of acid; sulfuric acid is naturally released by some bacteria
- Organic phosphate is returned to soluble phosphate by decomposers
Figure 26.10 The phosphorous cycle
Other Forms of Cycling

• Introduction of toxic substances escalates cycling of elements
  – Some are converted to less harmful ones
  – Some persist and flow in biosphere

• **Bioaccumulation:** when a pollutant is accumulated by living things through the natural trophic flow of the ecosystem
  – Mercury compounds
26.3 Microbes on Land and in Water
Soil Microbiology: The Composition of the Lithosphere

• Soil is a dynamic ecosystem that supports interactions between geologic, chemical, and biological factors

• **Humus** – rich moist layer of soil containing plant and animal debris being decomposed by microbes

• **Rhizosphere** – zone of soil around plant roots contains associated bacteria, fungi, and protozoa

• **Mycorrhizae** – symbiotic relationship formed between fungi and certain plant roots
Figure 26.11 The soil habitat
Figure 26.12 Mycorrhizae, symbiotic associations between fungi and plant roots
Aquatic Microbiology

- Water is the dominant compound on the earth; it occupies $\frac{3}{4}$ of the earth’s surface.
- Water is continuously cycled between hydrosphere, atmosphere, and lithosphere – hydrologic cycle.
  - Water evaporates, accumulates in the atmosphere, and returns to the earth through condensation and precipitation.
- Surface water collects in subterranean pockets forming groundwater source, called an aquifer – resurfaces through springs, geysers, and hot vents, also tapped as primary supply for $\frac{1}{4}$ of water for human consumption.
Figure 26.13 Hydrologic cycle
<table>
<thead>
<tr>
<th>Water Source</th>
<th>Water Volume, in Cubic Miles</th>
<th>Percentage of Total Water</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oceans</td>
<td>317,000,000</td>
<td>97.24</td>
</tr>
<tr>
<td>Icecaps, glaciers</td>
<td>7,000,000</td>
<td>2.14</td>
</tr>
<tr>
<td>Groundwater</td>
<td>2,000,000</td>
<td>0.61</td>
</tr>
<tr>
<td>Freshwater lakes</td>
<td>30,000</td>
<td>0.009</td>
</tr>
<tr>
<td>Inland seas</td>
<td>25,000</td>
<td>0.008</td>
</tr>
<tr>
<td>Soil moisture</td>
<td>16,000</td>
<td>0.005</td>
</tr>
<tr>
<td>Atmosphere</td>
<td>3,100</td>
<td>0.001</td>
</tr>
<tr>
<td>Rivers</td>
<td>300</td>
<td>0.000001</td>
</tr>
</tbody>
</table>

100

*Source: U.S. Geological Survey.*
The Structure of Aquatic Ecosystems

- Surface waters differ considerably in size, geographic location, and physical and chemical character.
- Sunlight, temperature, aeration, and dissolved nutrient content are factors that contribute to the development of zones.
- Lake is stratified vertically into 3 zones or strata:
  - **Photic zone** – surface to lowest limit of sunlight penetration
  - **Profundal zone** – edge of the photic zone to lake sediment
  - **Benthic zone** – organic debris and mud forming the basin
- Stratified horizontally into 2 zones:
  - **Littoral zone** – shoreline, relatively shallow water
  - **Limnetic zone** – open, deeper water
Figure 26.14 Stratification in a freshwater lake
Marine Environments

- Resembles profile of lake but has variations in salinity, depth, temperature, hydrostatic pressure, and mixing
- Contains a zone, called an **estuary**, where river meets the sea; fluctuates in salinity, is very high in nutrients
- Tidal wave action subjects the coastal habitat to alternate period of submersion and exposure
- **Abyssal zone** – extends to a depth of 10,000 m; supports communities with extreme adaptations including:
  - Halophilic, psychrophilic, barophilic, and anaerobic
Aquatic Communities

• Microbial distribution is associated with sunlight, temperature, oxygen levels, and available nutrients

• Photic zone is most productive – contains plankton
  – Phytoplankton – variety of photosynthetic algae and cyanobacteria
  – Zooplankton – microscopic consumers; filter feed, prey, or scavenge

• Benthic zone supports variety of organisms including aerobic and anaerobic bacterial decomposers
• Large bodies of standing water develop thermal stratification
• **Epilimnion** – upper region, warmest
• **Hypolimnion** – deeper, cooler
• **Thermocline** – buffer zone between warmest and coolest layers; ordinarily prevents the mixing of the two
• Currents, brought on by temperature change, cause upwelling of nutrient-rich benthic sediments and outbreaks of abundant microbial growth – red tides
Figure 26.15 Profiles of a lake
Figure 26.16 Red Tides
• Nutrient range is variable

• **Oligotrophic** – nutrient-deficient aquatic ecosystem; supports few microorganisms; many bacteriophage

• **Eutrophication** – addition of excess quantities of nutrients; naturally or by effluents from sewage, agriculture, or industry; encourages heavy surface growth of algae (bloom) which cuts off the $O_2$ supply; disturbs the ecological balance

• Only anaerobic and facultative anaerobes will survive
Figure 26.17 Heavy surface growth of algae and cyanobacteria in a eutrophic pond
Microbiology of Drinking Water Supplies

• **Potable** (drinkable) water – free of pathogens, toxins, turbidity, odor, color, and taste

• Most prominent water-borne pathogens – *Giardia*, *Cryptosporidium*, *Campylobacter*, *Salmonella*, *Shigella*, *Vibrio*, *Mycobacterium*, HAV, and Norwalk viruses

• Most assays of water purity focus on detecting fecal contamination – indicator bacteria *E. coli*, *Enterobacter*, *Citrobacter*
Water Quality Assays

- **Standard plate count** – number of colonies that develop provide estimate of the total population
- **Membrane filter method** – after filtration, filter is placed on selective and differential media, incubated, colonies are presumptively identified and counted
- **Most probable number** (MPN) – presumptive, confirmatory and completed tests
- No acceptable level for fecal coliforms, enterococci, viruses, or pathogenic protozoans in drinking water
Figure 26.18

(a) Membrane filter technique. The water sample is filtered through a sterile membrane filter assembly and collected in a flask.

(b) The filter is removed and placed in a small Petri dish containing a differential selective medium such as M-FD endo agar and incubated.

(c) On M-FD endo medium, colonies of *Escherichia coli* often yield a noticeable metallic sheen. The medium permits easy differentiation of various genera of coliforms, and the grid pattern can be used as a guide for rapidly counting the colonies.

(d) Some tests for water-borne coliforms are based on formation of specialized enzymes to metabolize lactose. The MI tests shown here utilize synthetic substrates that release a colored substance when the appropriate enzymes are present. The total coliform count is indicated by the plate on the left; fecal coliforms (*E. coli*) are seen in the plate on the right. This test is especially accurate with surface or groundwater samples.