Chapter 24

• Microbiology: A Systems Approach
  Cowan & Talaro
  1st Edition
Chapter 24

Topics

- Ecology
- Applied Microbiology and Biotechnology
Ecology

- Ecosystem organization
- Energy and nutrient flow
- Recycling of bioelements
- Atmospheric cycles
- Sedimentary cycles
- Soil microbiology
- Aquatic microbiology
Ecology organization

• Microbial ecology – the study of microbes in their natural habitats
• Levels of ecology
Levels of ecology

• Biosphere
  – Terrestrial – biomes
  – Aquatic

• Ecosystem
  – Hydrosphere
  – Lithosphere
  – Atmosphere

• Communities
• Populations
• Habitats
• Niche
The different levels of organization in an ecosystem, which ranges from the biosphere to the individual organism.

Fig. 24.2 Levels of organization in an ecosystem
Energy and nutrient flow

- Food chain
- Producers
- Consumers
- Decomposers
- Limitation
- Ecological interactions
Food chain

• Energy pyramid
  – Begins with a large amount of usable energy and ends with a smaller amount of usable energy

• Trophic (feeding) levels
  – The number of organisms that are producers, consumers and decomposers
An example of the trophic and energy pyramid.

Fig. 24.3 A trophic and energy pyramid.
The roles, description of their activities, and types of microorganisms involved in the ecosystem.

### Table 24.1 The Major Roles of Microorganisms in Ecosystems

<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, cyanobacteria, 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>Degradation of plant and animal matter 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 nutrients</td>
<td>Soil bacteria that reduce organic compounds to inorganic compounds such as CO₂ and minerals</td>
</tr>
<tr>
<td>Cycling agents for biogeochemical cycles</td>
<td>Recycling compounds containing carbon, nitrogen, phosphorus, sulfur</td>
<td>Specialized bacteria that transform elements into different chemical compounds to keep them cycling from the biotic to the abiotic and back to the biotic phases of the biosphere</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>
Producer

- Fundamental energy source
- Drives the trophic pyramid
- Autotrophs - produce organic carbon compounds by fixing inorganic carbon
- Photosynthetic organisms
  - Plants
  - Cyanobacteria
- Lithotrophs
Consumers

- Feed on other living organisms
- Obtain energy from organic substrate bonds (break bonds = release energy)
- Ex. Animals, protozoa, some bacteria and fungi
- Several levels
  - Primary, secondary, tertiary and quaternary consumers
A simple example of the different levels of a consumer.

Fig. 24.4 Food chain
Decomposer

- Saprobics - inhabit all levels of the food pyramid
- Primarily bacteria
- Reduce organic matter into inorganic minerals and gases
- Mineralization - cycled decomposed material back into the ecosystem
Trophic patterns can be complex, as many producers and composers are involved.

Fig. 24.5 Food web
Limitation

• Energy is not cycled
• As energy is transferred from producer to consumer, large amounts of energy are lost in the form of heat
• Amount of energy available decreases at each successive trophic level
• Fewer individuals can be supported by remaining available energy
Ecological interactions

- Commensalism
- Co-metabolism
- Synergism
- Parasitism
- Competition
- Predator
- Scavengers
Recycling of bioelements

- Bioelements – carbon, nitrogen, sulfur, phosphorus, oxygen, iron, and essential building blocks
- Biogeochemical cycles – recycling of essential elements and essential building blocks through biotic and abiotic environments
Atmospheric cycles

- Carbon cycles
- Photosynthesis
- Nitrogen cycle
Soil Microbiology

- Dynamic ecosystem
- Lithosphere - interactions between geologic, chemical, and biological factors
- Humus
- Rhizosphere - synergism (plant and biofilm)
- Mycorrhizae – synergism (plant and fungi)
- Top soil – supports nematodes, termites, earthworms as well as aerobic and anaerobic bacteria
A microhabitat can contain soil particles, bacteria, fungi, protozoa, nematodes, gas, and water.

Fig. 24.12 The structure of the rhizosphere and the microhabitats that develop in response to soil particles
Mycorrhizae is a symbiotic association between fungi and plant roots, which helps the plant absorb water and minerals more efficiently.

Fig. 24.13 Mycorrhizae, symbiotic association between Fungi and plant roots
Aquatic microbiology

- Hydrolic cycle
- Marine environments
- Communities
- Water management
Two important mechanisms of the hydrologic cycle involve plants releasing water through transpiration, and heterotrophs releasing water through respiration.

Fig. 24.14 The hydrologic cycle
The distribution of water on the earth’s surface.

### TABLE 24.2 Distribution of Water on Earth’s Surface

<table>
<thead>
<tr>
<th>Water Source</th>
<th>Water Volume, in Cubic Miles</th>
<th>Percent 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>0.0001</td>
</tr>
</tbody>
</table>

**Source:** U.S. Geological Survey.

Table 24.2 Distribution of water on earth’s surface.
Marine environments

• Variable
  – Estuary (salinity, nutrients)
  – Mixing (tidal and wave action)
  – Temperature
  – Abyssal zone (hydrostatic pressure, lack sunlight, low temperature, oxygen poor, depth)
Communities

• Freshwater
• Plankton – provides nutrients for zooplankton
• Temperature strata
  – Epilimnion
  – Thermocline
  – Hypolimnion
• Upwelling – red tides
• Oligotrophic – low nutrient water
• Viruses present
• Eutrophication - bloom
The three strata in a lake vary in temperature and nutrient content, and mixing (upwelling) of the strata occurs seasonally.

Fig. 24.15 Profiles of a lake.
Upwelling in the ocean can result in increased microbial activity of toxin-producing dinoflagellates, which causes red tides.

Fig. 24.16 Red tides.
Excess nutrients and warm pond water can result in eutrophication or blooms, which is the heavy growth of algae resulting in oxygen depletion below the surface.

Fig. 24.17 Heavy surface growth of algae and cyanobacteria in a eutrophic pond.
Water management

• Indicator bacteria – coli forms
  – Standard plate count
  – Membrane filtration
  – Most probable number

• Water and sewage treatment
An example of the filter method, where visible colonies are observed as well as the presence of specific enzymes.

Fig. 24.18 Rapid methods of water analysis for coliform contamination.
Water and sewage treatment

• Water treatment
  – Rivers
  – Reservoirs
  – Wells (less stringent)

• Sewage treatment
  – Homes
  – Industry
  – Three stages
    • Second stage – anaerobic digester – methane gas
The steps involved in water treatment.

Fig. 24.19 The major steps in water purification as carried out by a modern municipal treatment plant.
To remove all potential health hazards, sewage treatment requires three stages.

Fig. 24.20 The primary, secondary, and tertiary stages in Sewage treatment.
Large digester tanks are used in the primary and secondary stages.

Fig. 24.21 Treatment of sewage and wastewater.
Applied microbiology and biotechnology

- Food microbiology
- Industrial microbiology
Food microbiology

• Food fermentation
• Dairy products
• Microbes as food
• Food-borne diseases
Food fermentation

- Bread
- Beer
- Wine and liquors
- Others
Bread

• Baker’s yeast
• Fermentation
  – Release carbon dioxide and water
  – Leavening
• Microbes breakdown flour proteins (gluten)
• Generates volatile organic acids and alcohols – imparts flavor and aroma
Beer

- Ethyl alcohol is produced from wort sugar
- Malting - nutrients from barley are made available to yeasts
- Mash – malt grain, which is supplemented with sugar and starch
- Wort – clear liquid rich in dissolved carbohydrates, obtained after mash mixing and heating
- Hops – dried scales of the female flower *Humulus lupulus*
Hops is boiled with wort in order to remove bitter acids and resins, as well as to provide the final flavor and aroma.

Fig. 24.22 Hops
Wine and liquors

• Wine
  – Must – juice of crushed fruit
  – Bloom – yeast on the surface of grapes
  – Alcohol content limits fermentation

• Liquors
  – Distill fermentation product to obtain higher alcohol content

• Other fermented plant products
  – Pickles, sauerkraut, vinegar
Dairy products

• Milk
  – Curd
  – Whey

• Cheese - curd
  – Soft
  – Ripening – infusion of microbes for further fermentation
    • semisoft and hard cheeses

• Yogurt
Different stages of milk fermentation, and the number and type microbes involved.

Fig. 24.24 Microbes at work in milk products.
An example of the curd cutting process in the making of cheese.

Fig. 24.25 Cheese making.
Microbes in food

- Microbes can supply protein, fat, and vitamins
- Yeast, bacteria and some algae are made into food
  - pellets
- Use the product of microbes
  - Single cell protein
Food-borne diseases

- Incidence
- Prevention
The Centers for Disease Control’s (CDC) estimate of the incidence of food-borne illness in the United States.

<table>
<thead>
<tr>
<th></th>
<th>Estimated Incidence of Food-Borne Illness in the United States</th>
</tr>
</thead>
<tbody>
<tr>
<td>Illnesses</td>
<td>76,000,000 cases</td>
</tr>
<tr>
<td>Hospitalizations</td>
<td>325,000 cases</td>
</tr>
<tr>
<td>Deaths</td>
<td>5,200 cases</td>
</tr>
</tbody>
</table>

Table 24.3 Estimated incidence of food-borne illness
Prevention

- Measures to prevent food poisoning and spoilage
  - Prevent incorporation
  - Prevent survival
- Temperature
- Radiation – UV, gamma rays
- Preservation – chemical, osmotic pressure, desiccation
Example of different temperatures and their effects on microbes.

Fig. 24.28 Temperature favoring and inhibiting the growth of microbes in food.
High temperature short-time pasteurization (HTST) is a method used to preserve milk.

Fig. 24.27 A modern flash pasteurizer
Examples of methods used to prevent food poisoning and food spoilage.

Fig. 24.26 The primary methods to prevent food poisoning and food spoilage.
Industrial microbiology

- Use of microbes to manufacture consumable materials
- Use of microbes to generate organic compounds
- Metabolites
- Controlled environment
- Primarily a fermentation process
Examples of industrial products produced by microbes.

<table>
<thead>
<tr>
<th>Chemical</th>
<th>Microbial Source</th>
<th>Substrate</th>
<th>Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pharmaceuticals</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bacitracin</td>
<td><em>Bacillus subtilis</em></td>
<td>Glucose</td>
<td>Antibiotic effective against gram-positive bacteria</td>
</tr>
<tr>
<td>Cephalosporins</td>
<td><em>Cephalosporium</em></td>
<td>Glucose</td>
<td>Antibacterial antibiotic, broad spectrum</td>
</tr>
<tr>
<td>Pencillins</td>
<td><em>Penicillium chrysogenum</em></td>
<td>Lactose</td>
<td>Antibacterial antibiotic, broad and narrow spectrum</td>
</tr>
<tr>
<td>Erythromycin</td>
<td><em>Streptomyces</em></td>
<td>Glucose</td>
<td>Antibacterial antibiotic, broad spectrum</td>
</tr>
<tr>
<td>Tetracycline</td>
<td><em>Streptomyces</em></td>
<td>Glucose</td>
<td>Antibacterial antibiotic, broad spectrum</td>
</tr>
<tr>
<td>Amphotericin B</td>
<td><em>Streptomyces</em></td>
<td>Glucose</td>
<td>Antifungal antibiotic</td>
</tr>
<tr>
<td>Vitamin B₁₂</td>
<td><em>Pseudomonas</em></td>
<td>Molasses</td>
<td>Dietary supplement</td>
</tr>
<tr>
<td>Riboflavin</td>
<td><em>Asba</em></td>
<td>Glucose, corn oil</td>
<td>Animal feed supplement</td>
</tr>
<tr>
<td>Steroids</td>
<td><em>Rhizopus, Cunninghamella</em> (hydrocortisone)</td>
<td>Deoxycholic acid, stigmasterol</td>
<td>Treatment of inflammation, allergy; hormone replacement therapy</td>
</tr>
<tr>
<td><strong>Food Additives and Amino Acids</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Citric acid</td>
<td><em>Aspergillus, Candida</em></td>
<td>Molasses</td>
<td>Acidifier in soft drinks; used to set jam; candy additive; fish preservative; retards discoloration of crabmeat; delays browning of sliced peaches</td>
</tr>
<tr>
<td>Lactic acid</td>
<td><em>Lactobacillus, Bacillus</em></td>
<td>Whey, corn cobs, cottonseed; from maltose, glucose, sucrose</td>
<td>Acidifier of jams, jellies, candies, soft drinks, pickling brine, baking powders</td>
</tr>
<tr>
<td>Xanthan</td>
<td><em>Xanthomonas</em></td>
<td>Glucose medium</td>
<td>Food stabilizer; not digested by humans</td>
</tr>
<tr>
<td>Acetic acid</td>
<td><em>Acetobacter</em></td>
<td>Any ethylene source, ethanol</td>
<td>Food acidifier; used in industrial processes</td>
</tr>
<tr>
<td>Glutamic acid</td>
<td><em>Corynebacterium, Arthrobacter, Brevibacterium</em></td>
<td>Molasses, starch source</td>
<td>Flavor enhancer monosodium glutamate (MSG)</td>
</tr>
<tr>
<td>Lysine</td>
<td><em>Corynebacterium</em></td>
<td>Casein</td>
<td>Dietary supplement for cereals</td>
</tr>
<tr>
<td><strong>Miscellaneous</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ethanol</td>
<td><em>Saccharomyces</em></td>
<td>Beet, cane, grains, wood, wastes</td>
<td>Additive to gasoline (gasohol)</td>
</tr>
<tr>
<td>Acetone</td>
<td><em>Clostridium</em></td>
<td>Molasses, starch</td>
<td>Solvent for lacquers, resins, rubber, fat, oil</td>
</tr>
<tr>
<td>Butanol</td>
<td><em>Clostridium</em></td>
<td>Molasses, starch</td>
<td>Added to lacquers, rayon, detergent, brake fluid</td>
</tr>
<tr>
<td>Gluconic acid</td>
<td><em>Aspergillus, Gluconobacter</em></td>
<td>Corn steep, any glucose source</td>
<td>Baking powder, glass-bottle washing agent, rust remover, cement mix, pharmaceuticals</td>
</tr>
<tr>
<td>Glycerol</td>
<td>Yeast</td>
<td>By-product of alcohol fermentation</td>
<td>Explosive (nitroglycerine)</td>
</tr>
<tr>
<td>Dextran</td>
<td><em>Klebsiella, Acetobacter, Leuconostoc</em></td>
<td>Glucose, molasses, sucrose</td>
<td>Polymer of glucose used as adsorbents, blood expanders, and in burn treatment; a plasma extender; used to stabilize ice cream, sugary syrup, candies</td>
</tr>
<tr>
<td>Thirucide insecticide</td>
<td><em>Bacillus thuringiensis</em></td>
<td>Molasses, starch</td>
<td>Used in biocontrol of caterpillars, moths, loopers, and hornworm plant pests</td>
</tr>
</tbody>
</table>
Examples of industrial enzymes produced by microbes.

**Table 24.5 Industrial Enzymes and Their Uses**

<table>
<thead>
<tr>
<th>Enzyme</th>
<th>Source</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amylase</td>
<td>Aspergillus, Bacillus, Rhizopus</td>
<td>Flour supplement, desizing textiles, mash preparation, syrup manufacture, digestive aid, precooked foods, spot remover in dry cleaning</td>
</tr>
<tr>
<td>Catalase</td>
<td>Micrococcus, Aspergillus</td>
<td>To prevent oxidation of foods; used in cheese production, cake baking, irradiated foods</td>
</tr>
<tr>
<td>Cellulase</td>
<td>Aspergillus, Trichoderma</td>
<td>Denim finishing (“stone-washing”), digestive aid, increase digestibility of animal feed, degradation of wood or wood by-products</td>
</tr>
<tr>
<td>Glucose oxidase</td>
<td>Aspergillus</td>
<td>Removal of glucose or oxygen that can decolorize or alter flavor in food preparations as in dried egg products; glucose determination in clinical diagnosis</td>
</tr>
<tr>
<td>Hyaluronidase</td>
<td>Various bacteria</td>
<td>Medical use in wound cleansing, preventing surgical adhesions</td>
</tr>
<tr>
<td>Keratinase</td>
<td>Streptomyces</td>
<td>Hair removal from hides in leather preparation</td>
</tr>
<tr>
<td>Lipase</td>
<td>Rhizopus</td>
<td>Digestive aid and to develop flavors in cheese and milk products</td>
</tr>
<tr>
<td>Pectinase</td>
<td>Aspergillus, Sclerotina</td>
<td>Clarifies wine, vinegar, syrups, and fruit juices by degrading pectin, a gelatinous substance; used in concentrating coffee</td>
</tr>
<tr>
<td>Penicillinase</td>
<td>Bacillus</td>
<td>Removal of penicillin in research</td>
</tr>
<tr>
<td>Proteases</td>
<td>Aspergillus, Bacillus, Streptomyces</td>
<td>To clear and flavor rice wines, process animal feed, remove gelatin from photographic film, recover silver, tenderize meat, unravel silkworm cocoon, remove spots</td>
</tr>
<tr>
<td>Rennet</td>
<td>Mucor</td>
<td>To curdle milk in cheese making</td>
</tr>
<tr>
<td>Streptokinase</td>
<td>Streptococcus</td>
<td>Medical use in clot digestion, as a blood thinner</td>
</tr>
<tr>
<td>Streptodornase</td>
<td>Streptococcus</td>
<td>Promotes healing by removing debris from wounds and burns</td>
</tr>
</tbody>
</table>
Industrial processes harvest primary metabolites from the log phase, and secondary metabolites from the stationary phase.

Fig. 24.29 The origins of primary and secondary microbial Metabolites harvested by industrial processes.
Large cell culture vessels are used to mass-produce pharmaceutical products.

Fig. 24.30 A cell culture vessel used to mass-produce pharmaceutical products.
An example of an industrial fermentor used for mass culture of microorganisms.

Fig. 24.31 A schematic diagram of an industrial fermentor
The general steps associated with a fermentor, and the mass-production of organic substances.

Fig. 24.32 The general layout of a fermentation plant