Chapter 3
Ecosystems:
What Are They and How Do They Work

"It's A Small World After All"

Outline

The Nature of Ecology

A. Ecology is the study of connections in the natural world. Ecologists try to understand interactions among organisms, populations, communities, ecosystems and the biosphere.
   1. An organism is any form of life. The cell is the basic unit of life in organisms.
   2. Organisms are classified as either eukaryotic or prokaryotic based on the presence or absence of a membrane-bound nucleus.
   3. Organisms are classified into species, which groups organisms similar to each other together.
   4. Sexually reproducing organisms are classified as a species if, under natural conditions, they can potentially breed with one another and produce live, fertile offspring
   5. The tiny microbes rule the world; they are unseen by the naked eye but keep the natural world operating.
   6. About 1.4 million species have been identified, but estimates of number of species range from 3.6 million to 100 million.

B. A population consists of a group of interacting individuals of the same species occupying a specific area. Genetic diversity explains why these individuals may not behave nor look exactly alike. The habitat is the place where a population or an individual usually lives. Its distribution or range is the area over which a species may be found.

C. A community represents populations of different species living and interacting in a specific area. A biological community consists of all the populations of different species interacting and living in a specific area; this is a network of plants, animals, and microorganisms.

D. An ecosystem is a community of different species interacting with each other and with their nonliving environment of matter and energy. All of the earth's diverse ecosystems comprise the biosphere.

The Earth's Life-support Systems

A. Various interconnected spherical layers make up the earth's life-support system.

B. The atmosphere is the thin membrane of air around the planet.

C. The troposphere is the air layer about 11 miles above sea level.

D. The stratosphere lies above the troposphere between 11-30 miles; it filters out the sun's harmful radiation.

E. The hydrosphere consists of earth's water, found in liquid water, ice, and water vapor.

F. The lithosphere is the crust and upper mantle of the earth's soil. It contains nonrenewable fossil fuels, minerals, and soil, and renewable soil chemicals needed for plant life.

G. The biosphere includes most of the hydrosphere, parts of the lower atmosphere and upper lithosphere. All parts of the biosphere are interconnected.

H. Ecology's goal is to understand the interactions in the earth's global skin of air, water, soil, and organisms.

I. Sun, cycles of matter and gravity sustain life on earth.
   1. The one-way flow of high-quality solar energy through materials and living things (as they eat) produces low-quality energy. Energy can't be recycled.
   2. Matter cycles through parts of the biosphere.
   3. Gravity causes the downward movement of chemicals as matter cycles through the earth.

J. Solar energy just passes through the earth as electromagnetic waves; they warm the atmosphere, evaporate and recycle water, generate wind, and support plant growth.

K. As solar radiation interacts with the earth, infrared radiation is produced. Greenhouse gases trap the heat and warm the troposphere. This natural greenhouse effect makes the planet warm enough to support life. Energy from the sun supports photosynthesis.

L. The Earth's temperatures, distance from the sun and size all produce a livable planet. Its liquid water, orbit from the sun, and its gravitational mass all contribute to sustaining life in this natural greenhouse.

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Ecosystem Components

A. Terrestrial parts of the biosphere are classified as biomes, areas such as deserts, forests, and grasslands. Aquatic life zones describe the many different areas found win a water environment such as freshwater, or marine life zones (coral reefs, coastal estuaries, deep ocean).
B. The major components of ecosystems are abiotic (nonliving) water, air, nutrients, solar energy, and biotic (living) plants, animals, and microbes.
C. Ecosystem characteristics include a range of tolerance to physical and chemical environments by the ecosystem's populations.
   1. Law of tolerance: The distribution of a species in an ecosystem is determined by the levels of one or more physical or chemical factors' being within the range tolerated by that species.
      a. The limiting factor principle states that too much or too little of any abiotic factor can limit or prevent growth of a population, even if all other factors are at or near the optimum range of tolerance. An abiotic factor such as lack of water or poor soil can be understood here.
      b. Aquatic life zones can be limited by the dissolved oxygen (DO) content in the water or by the salinity.
D. The major biological components of ecosystems are the producers/autotrophs that are self-feeders and the consumers/heterotrophs.
   1. Autotrophs make their own food from compounds in the environment (organisms such as green plants and algae). A few specialized producers can convert simple compounds to more complex compounds without sunlight, a process called chemosynthesis.
   2. Consumers, or heterotrophs feed on other organisms or their remains.
      a. Decomposers break down organic detritus (bacteria/fungi) into simpler inorganic compounds.
      b. Omnivores feed on both plants and animals.
      c. Carnivores feed on animals.
      d. Detritivores feed on dead organic matter and break it down into smaller molecules
      e. Herbivores feed on plants.
      f. Natural ecosystems produce little waste or no waste. In nature, waste becomes food.
   3. Glucose and other organic compounds are broken down and energy released by the process of aerobic respiration, the use of oxygen to convert organic matter back to carbon dioxide and water. This process is a net chemical change to that of photosynthesis.
   4. Some decomposers are able to break down organic compounds without using oxygen. This process is called anaerobic respiration, or fermentation. The end products are compounds such as methane gas, ethyl alcohol, acetic acid, and hydrogen sulfide.
   5. Matter is recycled; there is a one-way flow of energy.

Biodiversity

A. Biodiversity is the amazing variety of earth's genes, species, ecosystems, and ecosystem processes.
   1. The kinds of biodiversity are: genetic diversity, species diversity, ecological diversity and functional diversity.
   2. Human cultural diversity is included as part of earth's biodiversity by some people.
   3. Biodiversity keeps us alive and supports our economies.
   4. Biodiversity is a renewable resource as long as humans live off the income, not destroy the capital.

Energy Flow in Ecosystems.

A. Food chains and food webs help us understand how eaters, the eaten, and the decomposed are interconnected in an ecosystem.
B. The sequence of organisms as they are eaten is a food chain.
   1. Trophic levels are feeding levels for organisms within an ecosystem.
      a. Producers belong to the first tropic level.
      b. Primary consumers belong to the second tropic level.
      c. Secondary consumers belong to the third tropic level.

d. Detritivores and decomposers process detritus from all trophic levels.
2. Food webs are complex networks of interconnected food chains. They are maps of life's interdependence.

C. Energy flow in a food web/chain decreases at each succeeding organism in a chain or web.
D. The dry weight of all organic matter within the organisms of a food chain/web is called biomass. Ecological efficiency is the term that describes the percentage of usable energy transferred as biomass from one trophic level to another and ranges from 2%-40% with 10% being typical.
E. The greater number of trophic levels in a food chain, the greater loss of usable energy.
F. The pyramid of energy flow visualizes the loss of usable energy through a food chain. The lower levels of the trophic pyramid support more organisms. If people eat at a lower trophic level (fruits, vegetables, grains directly consumed) earth can support more people. There is a large loss of energy between successive trophic levels.
G. Production of biomass takes place at different rates among different ecosystems.
   1. The rate of an ecosystem's producers converting energy as biomass is the gross primary productivity (GPP).
   2. Some of the biomass must be used for the producers' own respiration. Net primary productivity (NPP) is the rate which producers use photosynthesis to store biomass minus the rate which they use energy for aerobic respiration. NPP measures how fast producers can provide biomass needed by consumers in an ecosystem.
   3. Ecosystems and life zones differ in their NPP. The three most productive systems are swamps and marshes, tropical rain forest, and estuaries. The three least productive are tundra, desert scrub and extreme desert.
H. The planet's NPP limits the numbers of consumers who can survive on earth.
   1. The highly productive tropical rain forest cannot support agriculture as practiced in developed countries.
   2. Marshes and swamps do not produce food that can be eaten directly by humans; they feed other aquatic species that humans consume (fish, shrimp, clams).
I. Humans are using, wasting, and destroying biomass faster than producers can make it.

Soils: A Renewable Resource

A. Soil provides nutrients needed for plant growth; it helps purify water. It is a thin covering that is made of eroded rock, minerals, decaying organic matter, water, air, and billions of living organisms.
B. Layers of soil, called soil horizons, vary in number, composition, and thickness.
C. Soil provides nutrients for plant growth, is the earth's primary filter for cleansing water and for decomposing and recycling biodegradable wastes.
D. The major layers of soil are as follows.
   1. Mature soils have developed over a long time, are arranged in soil horizons (series of horizontal layers), have distinct textures and compositions in these layers that vary among different types of soils.
   2. Cross-sectional views of these layers are soil profiles.
   3. The layers/horizons of mature soils have at least three parts.
      a. The top part/layer is the surface litter layer or O horizon. This layer is brown/black and composed of leaves, twigs, crop wastes, animal waste, fungi and other organic material.
      b. The topsoil layer or A horizon is composed of decomposed organic matter called humus, as well as some inorganic mineral particles. Thick topsoil layers help hold water and nutrients. These two top layers teem with bacteria, fungi, earthworms, and small insects.
         1) Dark-brown/black topsoil is rich in nitrogen and organic matter.
         2) Gray, yellow or red topsoils need nitrogen enrichment.
      c. The B horizon (subsoil) and the C-horizon (parent material) have most of the soil's inorganic matter—sand, silt, clay, and gravel. The C-horizon rests on bedrock.
      d. Air and water fill spaces between soil particles. Plant roots need oxygen for aerobic respiration.
   4. Downward movement of water through the spaces in the soil is infiltration. Water moving downward dissolves minerals and organic matter and carries them to lower levels; this process

is leaching.

E. Soil differences in texture are affected by the size of particles and the space between particles.
F. To determine soil's texture, do the following:
   1. Take a small amount of topsoil, moisten, and rub between fingers and thumb:
      a. A gritty feel equals the soil has a lot of sand; this soil is easy to work.
      b. A sticky feel means the soil has a lot of clay; these retain a lot of water.
      c. A smooth feel means the soil is silt-laden.
      d. A crumbly, spongy feel means the soil is heavily loam; they hold water.
   2. Soil porosity is affected by soil texture. The average size of spaces or pores in soil determines soil permeability.

Matter Cycling in Ecosystems.

A. Nutrient cycles/biogeochemical cycles are global recycling systems that interconnect all organisms.
   1. Nutrient atoms, ions, and molecules continuously cycle between air, water, rock, soil, and living organisms.
   2. These cycles include the carbon, oxygen, nitrogen, phosphorus, and water cycles. They are connected to chemical cycles of the past and the future.
B. The water/hydrologic cycle collects, purifies, and distributes the earth's water in a vast global cycle.
   1. Solar energy evaporates water, the water returns as rain/snow, goes through organisms, goes into bodies of water, and evaporates again.
   2. Some water becomes surface runoff, returning to streams/rivers, causing soil erosion, and also being purified, itself.
   3. The water cycle is powered by energy from the sun. Winds and air masses transport water over the earth's surface.
   4. Water is the primary sculptor of earth's landscape.
   5. Water is the major form of transporting nutrients within and between ecosystems.
C. The water cycle is altered by man's activities:
   1. We withdraw large quantities of fresh water.
   2. We clear vegetation and increase runoff, reduce filtering, and increase flooding.
   3. We add nutrients like fertilizers and modify the quality of the water.
   4. The earth's water cycle may be speeding up due to a warmer climate. This could change global precipitation patterns and may intensify global warming (water vapor increases in the troposphere).
D. The carbon cycle circulates through the biosphere. Carbon moves through water and land systems, using processes that change carbon from one form to another.
   1. CO_2 gas is an important temperature regulator on earth.
   2. Photosynthesis in producers and aerobic respiration in consumers, producers, and decomposers circulates carbon in the biosphere.
   3. Fossil fuels contain carbon; in a few hundred years we have almost depleted such fuels that have taken millions of years to form.
   4. Carbon recycles through the oceans. Oceans act as a carbon sink, but when warming occurs they release carbon dioxide.
E. Excess carbon dioxide's addition to the atmosphere through our use of fossil fuels and our destruction of the world's photosynthesizing vegetation has contributed to global warming. The natural greenhouse effect is being strengthened by increasing temperatures.
F. Nitrogen is recycled through the earth's systems by different types of bacteria.
   1. The nitrogen cycle converts nitrogen (N_2) into compounds that are useful nutrients for plants and animals.
   2. The nitrogen cycle includes these steps:
      a. Specialized bacteria convert gaseous nitrogen to ammonia in nitrogen fixation.
      b. Special bacteria convert ammonia in the soil to nitrite ions and nitrate ions; the latter is used by plants as a nutrient. This process is nitrification.
      c. Decomposer bacteria convert detritus into ammonia and water-soluble salts in

ammonification.

d. In denitrification, nitrogen leaves the soil. Anaerobic bacteria in soggy soil and bottom sediments of water areas convert NH_3 and NH_4^+ back into nitrite and nitrate ions, then nitrogen gas and nitrous oxide gas are released into the atmosphere.

3. Human activities affect the nitrogen cycle.
   a. In burning fuel, we add nitric oxide into the atmosphere; it can be converted to NO_2 gas and nitric acid and it can return to the earth's surface as acid rain.
   b. Nitrous oxide that comes from livestock, wastes and inorganic fertilizers we use on the soil can warm the atmosphere and deplete the ozone layer.
   c. We destroy forest, grasslands and wetland and, thus, release large amounts of nitrogen into the atmosphere.
   d. We pollute aquatic ecosystems with agricultural runoff and human sewage.
   e. We remove nitrogen from topsoil with our harvesting, irrigating and land-clearing practices.
   f. Increased input of nitrogen into air, soil and water is affecting the biodiversity toward species that can thrive on increased supplies of nitrogen nutrients.

G. We need to use phosphorus-based fertilizers because the phosphorus cycle is much slower in moving through the earth's water, soil, and organisms and is often the limiting factor for plant growth.
   1. Phosphorous washes from the land, ending up in the ocean where it may stay for millions of years. Phosphorus is used as a fertilizer to encourage plant growth.
   2. Phosphorus also limits growth of producers in freshwater streams and lakes due to low solubility in water.

H. Man interferes with the phosphorous cycle in harmful ways.
   1. We mine phosphate rock to produce fertilizers and detergents.
   2. We cut down tropical forests and, thereby, reduce the phosphorus in tropical soils.
   3. We compromise aquatic systems with animal waste runoff and human sewage.

I. Sulfur cycles through the earth's air, water, soil, and living organisms. Much is sorted in rocks and minerals, buried deep under ocean sediments.
   1. Natural sources of sulfur are hydrogen sulfide, released from volcanoes, swamps, bogs, and tidal flats where anaerobic decomposition occurs.
   2. Some marine algae produce dimethyl sulfide (DMS). DMS acts as nuclei for condensation of water found in clouds. This can affect the cloud cover and climate.
   3. Sulfur compounds can be converted to sulfuric acid that falls as acid deposition.
   4. Burning coal and oil, refining oil and the production of some metals from ores all add sulfur to the environment.

How Ecologists Learn About Ecosystems

A. Ecologists do field research, observing, measuring the ecosystem structure and function.
B. New technologies such as remote sensing, geographic information systems (GISs) gather data that is fed into computers for analysis and manipulation of data. Computerized maps may be made of an area to examine forest cover, water resources, air pollution emissions, coastal changes, and changes in global sea temperatures.
C. Ecologist use tanks, greenhouses, and controlled indoor and outdoor chambers to study ecosystems (laboratory research). This allows control of light, temperature, CO_2, humidity and other variables.
D. Field and laboratory studies must be coupled together for a more complete picture of an ecosystem.
E. Systems analysis develops mathematical and other models that simulate ecosystems that are large and very complex and can't be adequately studied with field and laboratory research. This allows the analysis of the effectiveness of various alternate solutions to environmental problems and can help anticipate environmental surprises.
F. We need baseline data about components, physical and chemical conditions in order to determine how well the ecosystem is functioning in order to anticipate and determine how best to prevent harmful environmental changes.

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G. Natural ecosystems achieve long-term sustainability by use of renewable solar energy and by recycling the chemical nutrients.

These guidelines from nature need to be adopted by humans in order to live more sustainably on earth.

Summary

1. Ecology is the study of connections in nature.

2. Life on earth is sustained by the one-way flow of high-quality energy from the sun, by the cycling of matter, and by gravity.

3. Matter, energy, and life are the major components of an ecosystem.

4. Energy in an ecosystem decreases in amount to each succeeding organism in a food chair or web.

5. Soil is a complex mixture of eroded rock, mineral nutrients, water, air, decaying organic matter, and billions of living organisms. It covers most of the earth and provides nutrients for plant growth. Soils are formed by a break down of rock, decomposing surface litter and organic matter. Bacteria and other decomposer microorganisms break down some of soil's organic compounds into simpler inorganic compounds.
6. Matter is recycled through the earth's ecosystem of air, land, water, and living organisms. This vast global recycling system is composed of nutrient cycles.

7. Scientists study ecosystems through the use of aquarium tanks, greenhouses, and controlled indoor and outdoor chambers. Specific variables are carefully controlled, like temperature, light, carbon dioxide and humidity.

8. Two principles of sustainability found from learning how nature works are the law of conservation of matter and the two laws of thermodynamics.

Objectives

1. Define ecology. List and distinguish among five levels of organization of matter that are the focus of the realm of ecology.

2. List the characteristics of life.

3. Distinguish among *lithosphere, hydrosphere, atmosphere, and ecosphere.* Briefly describe how the sun, gravity, and nutrient cycles sustain life on Earth. Compare the flow of matter and the flow of energy through the biosphere.

4. Define soil horizon. Briefly describe six soil layers. Using Figure 4-25 on p. 73 in the text, compare soil profiles of five important soil types.

5. Describe a fertile soil. In doing so, be sure to refer to soil texture, porosity, loam, and acidity.

6. Distinguish between an open system and a closed system. Name and describe three types of biogeochemical cycles.

7. Define *abiotic component of an ecosystem*. List three important physical factors and three important chemical factors that have large effects on ecosystems.

8. Summarize the law of tolerance. Compare limiting factors in terrestrial and aquatic ecosystems.

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9. Define *biotic component of an ecosystem*. Distinguish between producers and consumers. List and distinguish four types of consumers. Distinguish among scavengers, detritus feeders and decomposers. Distinguish between photosynthesizers and chemosynthesizers; aerobic respiration and anaerobic respiration.

10. Distinguish between food chains and food webs; grazing food web and detrital food web. Apply the second law of energy to food chains and pyramids of energy, which describe energy flow in ecosystems. Explain how there may be exceptions to pyramids of numbers and biomass, but not energy.

11. Evaluate which ecosystems show the highest average net primary productivity and which contribute most to global net primary productivity.

12. Briefly describe the historical development and distinguishing features of three approaches ecologists use to learn about ecosystems: field research, laboratory research, and systems analysis.

13. Define ecosystem service. List five examples of ecosystem services. Distinguish among three types of biodiversity. Briefly state two principles to sustain ecosystems.

Key Terms **(Terms are listed in the same font style as they appear in the text.)**

abiotic (p. 56)	*acid rain* (p. 75)
acid deposition (p. 75)	**aerobic respiration** (p. 60)
aerobic respiration (p. 73)	**hydrosphere** (p. 54)
ammonification (p. 74)	*hydrothermal vents* (p. 60)
anaerobic respiration (p. 60)	**infiltration** (p. 69)
aquatic life zones (p. 56)	*laboratory research* (p. 79)
aquifers (p. 70)	**leaching** (p. 69)
atmosphere (p. 54)	**limiting factor** (p. 57)
autotrophs (p. 58)	**limiting factor principle** (p. 57)
baseline data (p. 80)	*liquid water* (p. 54)
bedrock (p. 69)	**lithosphere** (p. 54)
Biological community (p. 50)	*mantle* (p. 54)
biological community (p. 53)	*matter recycling* (p. 60)
biological diversity (**biodiversity**) (p. 61)	*mature soils* (p. 68)
biomass (p. 63)	*microbes* (p. 52)
biomes (p. 56)	**natural greenhouse effect** (p. 56)
biosphere (p. 53)	*natural greenhouse effect* (p. 74)
biotic (p. 56)	**net primary productivity** (**NPP**) (p. 66)
carbon cycle (p. 73)	*nitrate ions* (p. 74)
carnivores (p. 60)	*nitrification* (p. 74)
chemosynthesis (p. 60)	*nitrite ions* (p. 74)
clay (p. 70)	**nitrogen cycle** (p. 74)
community (p. 53)	*nitrogen fixation* (p. 74)
consumers (p. 56)	*nitrogen-fixing bacteria* (p. 74)
consumers (p. 60)	**nutrient (biogeochemical) cycles** (p. 70)
core (p. 54)	**nutrients** (p. 70)
crust (p. 54)	*ocean* (*marine*) *life zones* (p. 56)
cycling of matter (54)	**omnivores** (p. 60)
decomposers (p. 57)	*one-way energy flow* (p. 60)
decomposers (p. 60)	*one-way flow of matter and energy* (p. 60)
denitrification (p. 74)	*optimum level* (*range*) (p. 57)
detritivores (p. 60)	**organism** (p. 52)

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dissolved oxygen (DO) content (p. 58)	*parent material (C horizon)* (p. 69)
distribution (p. 53)	*permafrost* (p. 54)
ecological efficiency (p. 64)	*Pests* (p. 50)
ecology (p. 51)	phosphorous cycle (p. 76)
ecosystem (p. 53)	*photosynthesis* (p. 54)
fermentation (p. 60)	**photosynthesis** (p. 58)
field research (p. 79)	*photosynthesis* (p. 73)
flow of high-quality energy (p. 54)	*phytoplankton* (p. 58)
food chain (p. 63)	**population** (p. 53)
food web (p. 63)	**primary consumers** (p. 60)
fossil fuels (p. 73)	*producers* (p. 56)
freshwater life zones (p. 56)	**producers** (p. 58)
Gaia hypothesis (p. 78)	**pyramid of energy flow** (p. 64)
genetic diversity (p. 53)	**range** (p. 53)
geographic information systems (*GIS*) (p. 79)	**range of tolerance** (p. 57)
glaciers (p. 70)	*remote sensing* (p. 79)
global warming (p. 74)	*salinity* (p. 58)
gravity (p. 54)	*sand* (p. 70)
greenhouse gases (p. 55)	**secondary consumers** (p. 60)
gross primary productivity (**GPP**) (p. 66)	*silt* (p. 70)
habitat (p. 53)	**soil** (p. 67)
herbivores (p. 60)	**soil horizons** (p. 68)
humus (p. 68)	**soil profile** (p. 68)
hydrologic (water) cycles (p. 70)	**soil texture** (p. 70)
species (p. 52)	**third and higher level consumers** (p. 60)
stratosphere (p. 54)	*topsoil layer (A horizon)* (p. 68)
subsoil (B horizon) (p. 69)	**trophic level** (p. 63)
sulfur cycle (p. 77)	**troposphere** (p. 54)
surface litter layer (O horizon) (p. 68)	*water vapor* (p. 54)
surface runoff (p. 70)	**weathering** (p. 67)
systems analysis (p. 80)	