Ecosystems: What Are They and How Do They Work?

Chapter 3
Core Case Study: Tropical Rain Forests Are Disappearing

- Cover about 2% of the earth’s land surface

- Contain about 50% of the world’s known plant and animal species

- Disruption will have three major harmful effects
  - Reduce biodiversity
  - Accelerate global warming
  - Change regional weather patterns
Natural Capital Degradation: Satellite Image of the Loss of Tropical Rain Forest
Concept 3-1  Ecology is the study of how organisms interact with one another and with their physical environment of matter and energy.
Species Make Up the Encyclopedia of Life

- Species
  - 1.75 Million species identified
  - Insects make up most of the known species
  - Perhaps 10–14 million species not yet identified
Ecologists Study Connections in Nature

- Ecology

- Levels of organization
  - Population
    - Genetic diversity
  - Community
  - Ecosystem
  - Biosphere
Some Levels of Organization of Matter in Nature

- **Biosphere**: Parts of the earth's air, water, and soil where life is found.
- **Ecosystem**: A community of different species interacting with one another and with their nonliving environment of matter and energy.
- **Community**: Populations of different species living in a particular place and potentially interacting with each other.
- **Population**: A group of individuals of the same species living in a particular place.
- **Organism**: An individual living being.
- **Cell**: The fundamental structural and functional unit of life.
- **Molecule**: Chemical combination of two or more atoms of the same or different elements.
- **Atom**: Smallest unit of a chemical element that exhibits its chemical properties.
Biosphere: Parts of the earth's air, water, and soil where life is found

Ecosystem: A community of different species interacting with one another and with their nonliving environment of matter and energy

Community: Populations of different species living in a particular place, and potentially interacting with each other

Population: A group of individuals of the same species living in a particular place

Organism: An individual living being

Cell: The fundamental structural and functional unit of life

Molecule: Chemical combination of two or more atoms of the same or different elements

Atom: Smallest unit of a chemical element that exhibits its chemical properties
Population of Glassfish in the Red Sea
Science Focus: Have You Thanked the Insects Today?

- Pollinators
- Eat other insects
- Loosen and renew soil
- Reproduce rapidly
- Very resistant to extinction
Importance of Insects
3-2 What Keeps Us and Other Organisms Alive?

- **Concept 3-2** Life is sustained by the flow of energy from the sun through the biosphere, the cycling of nutrients within the biosphere, and gravity.
The Earth’s Life-Support System Has Four Major Components

- **Atmosphere**
  - Troposphere
  - Stratosphere

- **Hydrosphere**

- **Geosphere**

- **Biosphere**
Natural Capital: General Structure of the Earth
Life Exists on Land and in Water

- **Biomes**

- **Aquatic life zones**
  - Freshwater life zones
    - Lakes and streams
  - Marine life zones
    - Coral reefs
    - Estuaries
    - Deep ocean
Major Biomes along the 39th Parallel in the U.S.
Average annual precipitation:
- 100–125 cm (40–50 in.)
- 75–100 cm (30–40 in.)
- 50–75 cm (20–30 in.)
- 25–50 cm (10–20 in.)
- Below 25 cm (0–10 in.)

Coastal mountain ranges
Sierra Nevada
Great American Desert
Rocky Mountains
Great Plains
Mississippi River Valley
Appalachian Mountains

Coastal chaparral and scrub
Coniferous forest
Desert
Coniferous forest
Prairie grassland
Deciduous forest
Three Factors Sustain Life on Earth

- One-way flow of high-quality energy beginning with the sun
- Cycling of matter or nutrients
- Gravity
What Happens to Solar Energy Reaching the Earth?

- UV, visible, and IR energy

- Radiation
  - Absorbed by ozone
  - Absorbed by the earth
  - Reflected by the earth
  - Radiated by the atmosphere as heat

- Natural greenhouse effect
Flow of Energy to and from the Earth
Solar radiation

UV radiation

Most absorbed by ozone

Visible light

Lower Stratosphere (ozone layer)

Troposphere

Heat

Reflected by atmosphere

Absorbed by the earth

Radiated by atmosphere as heat

Greenhouse effect

Heat radiated by the earth
3-3 What Are the Major Components of an Ecosystem?

- **Concept 3-3A** Ecosystems contain living (biotic) and nonliving (abiotic) components.

- **Concept 3-3B** Some organisms produce the nutrients they need, others get their nutrients by consuming other organisms, and some recycle nutrients back to producers by decomposing the wastes and remains of organisms.
Ecosystems Have Living and Nonliving Components

- **Abiotic**
  - Water
  - Air
  - Nutrients
  - Rocks
  - Heat
  - Solar energy

- **Biotic**
  - Living and once living
Major Biotic and Abiotic Components of an Ecosystem

- Producer
- Primary consumer (rabbit)
- Secondary consumer (fox)
- Oxygen (O₂)
- Carbon dioxide (CO₂)
- Precipitation
- Water
- Soluble mineral nutrients
- Decomposers
Decomposers

Precipitation

Oxygen ($O_2$)

Carbon dioxide ($CO_2$)

Producer

Primary consumer (rabbit)

Secondary consumer (fox)

Producers

Water

Soluble mineral nutrients

Producers

Water

Soluble mineral nutrients
Range of Tolerance for a Population of Organisms

- Lower limit of tolerance
  - No organisms
  - Few organisms

- Abundance of organisms

- Higher limit of tolerance
  - Few organisms
  - No organisms

- Zone of intolerance
- Zone of physiological stress
- Optimum range
- Zone of physiological stress
- Zone of intolerance

Temperature

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Few organisms

No organisms

Lower limit of tolerance

Few organisms

Abundance of organisms

Higher limit of tolerance

No organisms

Zone of intolerance

Zone of physiological stress

Optimum range

Zone of physiological stress

Zone of intolerance

Population size

Temperature

Low

High

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Fig. 3-10, p. 58
Several Abiotic Factors Can Limit Population Growth

- **Limiting factor principle**
  - 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 optimal range of tolerance
Producers and Consumers Are the Living Components of Ecosystems (1)

- **Producers, autotrophs**
  - Photosynthesis
  - Chemosynthesis

- **Consumers, heterotrophs**
  - Primary
  - Secondary
  - Third and higher level

- **Decomposers**
Producers and Consumers Are the Living Components of Ecosystems (2)

- Detritivores
- Aerobic respiration
- Anaerobic respiration, fermentation
Detritivores and Decomposers on a Log

- Detritus feeders:
  - Long-horned beetle holes
  - Bark beetle engraving
  - Carpenter ant galleries
  - Termite and carpenter ant work

- Decomposers:
  - Dry rot fungus
  - Wood reduced to powder
  - Mushroom

Time progression: Powder broken down by decomposers into plant nutrients in soil.
Mushroom
Detritus feeders
Decomposers

Long-horned beetle holes
Bark beetle engraving
Carpenter ant galleries
Termite and carpenter ant work
Dry rot fungus

Powder broken down by decomposers into plant nutrients in soil
Time progression
Energy Flow and Nutrient Cycling Sustain Ecosystems and the Biosphere

- One-way energy flow
- Nutrient cycling of key materials
The Main Structural Components of an Ecosystem

Abiotic chemicals (carbon dioxide, oxygen, nitrogen, minerals)

Solar energy

Heat

Producers (plants)

Decomposers (bacteria, fungi)

Consumers (herbivores, carnivores)
Heat Decomposers (bacteria, fungi)

Abiotic chemicals (carbon dioxide, oxygen, nitrogen, minerals)

Solar energy

Heat

Producers (plants)

Consumers (herbivores, carnivores)

Heat

Heat
Science Focus: Many of the World’s Most Important Species Are Invisible to Us

- Microorganisms
  - Bacteria
  - Protozoa
  - Fungi
3-4 What Happens to Energy in an Ecosystem?

- **Concept 3-4A** Energy flows through ecosystems in food chains and webs.

- **Concept 3-4B** As energy flows through ecosystems in food chains and webs, the amount of chemical energy available to organisms at each succeeding feeding level decreases.
Energy Flows Through Ecosystems in Food Chains and Food Webs

- Food chain
- Food web
A Food Chain

First Trophic Level
- Producers (plants)
- Heat

Second Trophic Level
- Primary consumers (herbivores)
- Heat

Third Trophic Level
- Secondary consumers (carnivores)
- Heat

Fourth Trophic Level
- Tertiary consumers (top carnivores)
- Heat

Decomposers and detritus feeders

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Solar energy flows through a series of trophic levels, with each level representing different types of organisms:

- **First Trophic Level:** Producers (plants)
- **Second Trophic Level:** Primary consumers (herbivores)
- **Third Trophic Level:** Secondary consumers (carnivores)
- **Fourth Trophic Level:** Tertiary consumers (top carnivores)

At each level, some energy is lost as heat, and decomposers and detritus feeders recycle nutrients.
Simplified Food Web in the Antarctic
Usable Energy Decreases with Each Link in a Food Chain or Web

- Biomass
- Ecological efficiency
- Pyramid of energy flow
Pyramid of Energy Flow

Usable energy available at each trophic level (in kilocalories)

- Tertiary consumers (human) 10
- Secondary consumers (perch) 100
- Primary consumers (zooplankton) 1,000
- Producers (phytoplankton) 10,000

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Usable energy available at each trophic level (in kilocalories)

- **Producers (phytoplankton)**: 10,000
- **Primary consumers (zooplankton)**: 1,000
- **Secondary consumers (perch)**: 100
- **Tertiary consumers (human)**: 10

Energy loss as heat is indicated by red arrows.

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Fig. 3-15, p. 63
Usable energy available at each trophic level (in kilocalories)

Tertiary consumers (human) 10
Secondary consumers (perch) 100
Primary consumers (zooplankton) 1,000
Producers (phytoplankton) 10,000

Decomposers

Steped Art

Fig. 3-15, p. 63
Some Ecosystems Produce Plant Matter Faster Than Others Do

- Gross primary productivity (GPP)

- Net primary productivity (NPP)
  - Ecosystems and life zones differ in their NPP
Estimated Annual Average NPP in Major Life Zones and Ecosystems

**Terrestrial Ecosystems**
- Swamps and marshes
- Tropical rain forest
- Temperate forest
- Northern coniferous forest (taiga)
- Savanna
- Agricultural land
- Woodland and shrubland
- Temperate grassland
- Tundra (arctic and alpine)
- Desert scrub
- Extreme desert

**Aquatic Ecosystems**
- Estuaries
- Lakes and streams
- Continental shelf
- Open ocean

*Average net primary productivity (kcal/m²/yr)*
3-5 What Happens to Matter in an Ecosystem?

- **Concept 3-5** Matter, in the form of nutrients, cycles within and among ecosystems and the biosphere, and human activities are altering these chemical cycles.
Nutrients Cycle in the Biosphere

- Biogeochemical cycles, nutrient cycles
  - Hydrologic
  - Carbon
  - Nitrogen
  - Phosphorus
  - Sulfur

- Connect past, present, and future forms of life
Water Cycles through the Biosphere

- Natural renewal of water quality: three major processes
  - Evaporation
  - Precipitation
  - Transpiration

- Alteration of the hydrologic cycle by humans
  - Withdrawal of large amounts of freshwater at rates faster than nature can replace it
  - Clearing vegetation
  - Increased flooding when wetlands are drained
Hydrologic Cycle Including Harmful Impacts of Human Activities
Transpiration from plants
Evaporation from land
Precipitation to land
Precipitation to ocean
Evaporation from ocean
Condensation
Infiltration and percolation into aquifer
Surface runoff
Groundwater movement (slow)
Lakes and reservoirs
Runoff
Global warming
Ice and snow
Reduced recharge of aquifers and flooding from covering land with crops and buildings
Point source pollution
Aquifer depletion from overpumping
Increased flooding from wetland destruction
Surface runoff
Surface runoff
Condensation
Precipitation to ocean
Ocean

Processes
Processes affected by humans
Reservoir
Pathway affected by humans
Natural pathway

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Fig. 3-17, p. 66
Science Focus: Water’s Unique Properties

- Properties of water due to **hydrogen bonds** between water molecules:
  - Exists as a liquid over a large range of temperature
  - Changes temperature slowly
  - High boiling point: 100°C
  - Adhesion and cohesion
  - Expands as it freezes
  - Solvent
  - Filters out harmful UV
Carbon Cycle Depends on Photosynthesis and Respiration

- Link between photosynthesis in producers and respiration in producers, consumers, and decomposers

- Additional $\text{CO}_2$ added to the atmosphere
  - Tree clearing
  - Burning of fossil fuels
Natural Capital: Carbon Cycle with Major Harmful Impacts of Human Activities
Pathway affected by humans

Diffusion
Transportation
Deforestation
Respiration
Decomposition
Forest fires
Compaction
Burning fossil fuels
Photosynthesis
Animals (consumers)
Plants (producers)
Carbon in plants (producers)
Carbon in animals (consumers)
Carbon in fossil fuels
Decomposition
Compaction
Carbon dioxide in atmosphere
Respiration
Carbon dioxide dissolved in ocean
Marine food webs
Producers, consumers, decomposers
Carbon in limestone or dolomite sediments
Carbon in plants (producers)
Carbon in animals (consumers)
Carbon in fossil fuels

Processes
Reservoir
Pathway affected by humans
Natural pathway

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Fig. 3-18, p. 68
Nitrogen Cycles through the Biosphere: Bacteria in Action (1)

- Nitrogen fixed
  - Lightning
  - Nitrogen-fixing bacteria

- Nitrification

- Denitrification
Human intervention in the nitrogen cycle
- Additional NO and N$_2$O
- Destruction of forest, grasslands, and wetlands
- Add excess nitrates to bodies of water
- Remove nitrogen from topsoil
Nitrogen Cycle in a Terrestrial Ecosystem with Major Harmful Human Impacts

- Processes
- Reservoir
- Pathway affected by humans
- Natural pathway

- Nitrogen oxides from burning fuel and using inorganic fertilizers
- Electrical storms
- Volcanic activity

- Nitrogen in animals (consumers)
- Nitrogen in plants (producers)
- Decomposition
- Uptake by plants

- Nitrate
- Nitrogen in soil

- Bacteria

- Denitrification by bacteria
- Nitrification by bacteria

- Nitrogen loss to deep ocean sediments
- Nitrogen in ocean sediments

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Decomposition 
Nitrogen loss to deep ocean sediments

Processes
Reservoir
Pathway affected by humans
Natural pathway
Annual Increase in Atmospheric N$_2$ Due to Human Activities
Projected human input

Total human input

Fertilizer and industrial use

Nitrogen fixation in agroecosystems

Fossil fuels

Nitrogen input (teragrams per year)

Year

1900 1920 1940 1960 1980 2000 2050

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Fig. 3-20, p. 70
Phosphorus Cycles through the Biosphere

- Cycles through water, the earth’s crust, and living organisms
- May be limiting factor for plant growth
- Impact of human activities
  - Clearing forests
  - Removing large amounts of phosphate from the earth to make fertilizers
Phosphorus Cycle with Major Harmful Human Impacts
Processes

Reservoir

Pathway affected by humans

Natural pathway

Phosphates in mining waste

Runoff

Phosphates in sewage

Runoff

Phosphates in fertilizer

Runoff

Phosphates in fertilizer

Phosphate in rock (fossil bones, guano)

Erosion

Phosphate dissolved in water

Phosphate in shallow ocean sediments

Bacteria

Plants (producers)

Animals (consumers)

Ocean food webs

Plate tectonics

Sea birds

Phosphate in deep ocean sediments

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Fig. 3-21, p. 71
Sulfur Cycles through the Biosphere

- Sulfur found in organisms, ocean sediments, soil, rocks, and fossil fuels
- \( \text{SO}_2 \) in the atmosphere
- \( \text{H}_2\text{SO}_4 \) and \( \text{SO}_4^- \)
- Human activities affect the sulfur cycle
  - Burn sulfur-containing coal and oil
  - Refine sulfur-containing petroleum
  - Convert sulfur-containing metallic mineral ores
Natural Capital: Sulfur Cycle with Major Harmful Impacts of Human Activities
Processes

Reservoir

Pathway affected by humans

Natural pathway

Fig. 3-22, p. 72

Dimethyl sulfide a bacteria byproduct

Sulfur in ocean sediments

Mineral and extraction

Sulfur in soil, rock and fossil fuels

Sulfuric acid and Sulfate deposited as acid rain

Sulfur in plants (producers)

Uptake by plants

Sulfur in animals (consumers)

Decay

Decay

Refining fossil fuels

Burning coal

Smelting

Sulfur dioxide in atmosphere
3-6 How Do Scientists Study Ecosystems?

- **Concept 3-6** Scientists use field research, laboratory research, and mathematical and other models to learn about ecosystems.
Some Scientists Study Nature Directly

- Field research: “muddy-boots biology”

- New technologies available
  - Remote sensors
  - Geographic information system (GIS) software
  - Digital satellite imaging

- 2005, Global Earth Observation System of Systems (GEOSS)
Some Scientists Study Ecosystems in the Laboratory

- Simplified systems carried out in
  - Culture tubes and bottles
  - Aquaria tanks
  - Greenhouses
  - Indoor and outdoor chambers

- Supported by field research
Some Scientists Use Models to Simulate Ecosystems

- Computer simulations and projections
- Field and laboratory research needed for baseline data
We Need to Learn More about the Health of the World’s Ecosystems

- Determine condition of the world’s ecosystems
- More baseline data needed