1 **Chapter 3**

Environmental Systems: Chemistry, Energy, and Ecosystems

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2 **This lecture will help you understand:**

- The nature of environmental systems
- The fundamentals of environmental chemistry
- The molecular building blocks of organisms
- Energy and energy flow
- Photosynthesis and respiration
- Ecosystems and interactions
- Fundamentals of landscape ecology
- Carbon, phosphorus, nitrogen, and water cycles

3 **Central Case: The Gulf of Mexico's "Dead Zone"**

- Gulf of Mexico used to bring in 600 million kg/year shrimp, fish, and shellfish
- Gulf "dead zone": a region of water so depleted of oxygen that marine organisms are killed or driven away
- In 2000, this zone encompassed 22,000 km^2 (8,500 mi^2) — an area larger than New Jersey.
- Hypoxia: low concentrations of dissolved oxygen water
  - Caused by fertilizer, runoff, sewage
- The U.S. government proposed that farmers reduce fertilizer use.

4 **The Earth's systems**

- System: a network of relationships among components that interact with and influence one another
  - Exchange of energy, matter, or information
  - Receives inputs of energy, matter, or information, processes these inputs, and produces outputs
- Feedback loop: a system's output serves as input to that same system
  - A circular process

5 **Negative feedback loop**

- Negative feedback loop: output resulting from a system moving in one direction acts as an input that moves the system in the other direction
  - Input and output neutralize one another
  - Stabilizes the system
  - Example: body temperature
  - Most systems in nature

6 **Positive feedback loop**

- Positive feedback loop: instead of stabilizing a system, it drives it further toward an extreme
- Examples: erosion
- Rare in nature
  - But are common in natural systems altered by humans

7 **Environmental systems interact**

- Natural systems are divided into categories
  - Lithosphere: rock and sediment
  - Atmosphere: the air surrounding the planet
  - Hydrosphere: all water on earth
  - Biosphere: the planet's living organisms
- Categorizing systems allows humans to understand earth's complexity.
  - Most systems overlap

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8 **The Gulf of Mexico: a systems perspective**

Very high levels of nutrients such as nitrogen and phosphorus from a variety of sources cause the abnormally low levels of oxygen in the Gulf of Mexico.

9 **Eutrophication in the Gulf of Mexico**

- Nutrients (nitrogen and phosphorus) from various Midwestern sources enter the Mississippi River, which causes....
- Phytoplankton (microscopic algae and bacteria) to grow, then...
- Bacteria eat dead phytoplankton and wastes and deplete oxygen, causing...
- Fish and other aquatic organisms to suffocate
- Eutrophication: the process of nutrient overenrichment, blooms of algae, increased production of organic matter, and ecosystem degradation

10 **Eutrophication**

11 **Chemistry is crucial for understanding...**

- Any environmental issue:
  - How gases contribute to global climate change
  - How pollutants cause acid rain
  - The effects of chemicals on the health of wildlife and people
  - Water pollution
  - Wastewater treatment
  - Hazardous waste
  - Atmospheric ozone depletion
  - Energy issues

12 **Energy fundamentals**

- Energy: an intangible phenomenon that can change the position, physical composition, or temperature of matter
  - Potential energy: energy of position
  - Kinetic energy: energy of motion
  - Chemical energy: potential energy held in the bonds between atoms
- Potential energy is changed into kinetic energy to produce motion, action, and heat.

13 **Energy is conserved...but changes in quality**

- First law of thermodynamics: energy can change forms, but cannot be created or destroyed
- Second law of thermodynamics: the nature of energy changes from a more-ordered to a less-ordered state if no force counteracts this tendency
  - Entropy: an increasing state of disorder
  - For example, burning a log of firewood transforms the log from a highly organized product into light and heat energy, gases, smoke, and carbon ash.

14 **The sun's energy powers life**

- The energy that powers Earth's ecological systems originates mainly from the sun.
- The sun releases radiation from the electromagnetic spectrum.
  - Some is visible light

15 **Photosynthesis**

- Autotrophs (producers): produce their own food from the sun's energy
  - Green plants, algae, and cyanobacteria
- Photosynthesis: the process of turning light energy from the sun into chemical energy
  - Carbon dioxide + water + sun's energy is converted into sugars and high-quality energy.
  - Low-quality energy is turned into high-quality energy.

16 **Photosynthesis produces food**

- Chloroplasts: organelles where photosynthesis occurs
  - Contain chlorophyll: a light-absorbing pigment
  - Light reaction: solar energy is used to split water to form oxygen and a small, high-energy molecule that fuels the....

- Calvin cycle: links carbon atoms from carbon dioxide into sugar (glucose)

$6CO_2 + 6H_20$ + the sun's energy $C_6H_{12}O_6 + 6O_2$

17 **Cellular respiration releases chemical energy**

- Organisms can use chemical energy created by photosynthesis through cellular respiration.
  - Oxygen is used to convert glucose into water + carbon dioxide + energy.
  - Only 2/3 of the original energy input per glucose molecule is gained in respiration.
  - Occurs in autotrophs and organisms that feed on others
- Heterotrophs (consumers): organisms that gain energy by feeding on others
  - Animals, fungi, microbes

18 **Energy and matter in ecosystems**

- Ecosystem: all organisms and non-living entities occurring and interacting in a particular area
  - Animals, plants, water, soil, nutrients, etc.
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19 **Energy is converted to biomass**

- Primary production: conversion of solar energy to chemical energy by autotrophs
  - Gross primary production: assimilation of energy by autotrophs
  - Net primary production (NPP): energy remaining after respiration, used to generate biomass
  - Available for heterotrophs
- Productivity: rate at which autotrophs convert energy to biomass

20 **Net primary productivity of ecosystems**

21 **A global map of NPP**

22 **Nutrients can limit productivity**

- Nutrients: elements and compounds that organisms consume and require for survival
  - Stimulate plant production
  - Lack of nutrients can limit production.
  - Nitrogen and phosphorus are important for plant and algal growth.
- Oceanic primary productivity is highest in water near shore.
  - Over 200 dead zones now exist due to nutrient pollution.
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23 **Nutrient runoff devastates aquatic systems**

- Aquatic dead zones result from nutrient pollution from farms, cities, and industry.
  - Most dead zones are located near Europe and the eastern U.S.
- Scientists are investigating innovative and economical ways to reduce nutrient runoff.

24 **Ecosystems come in different sizes**

- Ecosystems vary greatly in size.
- The term "ecosystem" is most often applied to self-contained systems of moderate geographic extent.
  - Adjacent ecosystems may interact extensively.
  - Ecotones: transitional zones between two ecosystems in which elements of each ecosystem mix

25 **Landscape ecology**

- Landscape ecology: the study of how landscape structure affects the abundance, distribution, and interaction of organisms
  - Helpful for sustainable regional development
  - Useful for studying migrating birds, fish, mammals
- Patches: ecosystems, communities, or habitat form the landscape and are distributed in complex patterns (a mosaic)

26 **Conservation biology**

- If a habitat is distributed in patches, organisms face danger in traveling from one patch to another.

- Patches spaced too far apart prevent travel
- Conservation biologists: study the loss, protection, and restoration of biodiversity
  - Humans are dividing habitat into small, isolated patches.
  - Corridors of habitat can link patches.
- Geographic information systems (GIS): computer software that layers multiple types of satellite data to create a complete picture of a landscape
  - Geology, vegetation, animal species, and human development

27 **Nutrients circulate through ecosystems**

- Physical matter is circulated continually in an ecosystem.
- Nutrient (biogeochemical) cycle: the movement of nutrients through ecosystems
  - Pools (reservoirs): where nutrients remain for varying amounts of time
  - Flux: movement of nutrients among pools
    - Can change over time

28 **The carbon cycle**

- Carbon cycle: describes the routes that carbon atoms take through the environment
- Through photosynthesis, producers move carbon from the air and water to organisms.
- Respiration returns carbon to the air and oceans.
- Decomposition returns carbon to the sediment, the largest reservoir of carbon.
  - Ultimately, it may be converted into fossil fuels.
- The world's oceans are the second largest reservoir.
  - Obtain carbon from the air and organisms

29 **The carbon cycle**

30 **Humans affect the carbon cycle**

- Burning fossil fuels moves carbon from the ground to the air.
- Cutting forests and burning fields moves carbon from organisms to the air.
- Today's atmospheric carbon dioxide reservoir is the largest in the past 800,000 years.
  - The driving force behind climate change

31 **The phosphorus cycle**

- Phosphorus cycle: describes the routes that phosphorus atoms take through the environment
  - No significant atmospheric component
  - Most phosphorus is within rocks and is released by weathering.
- With naturally low environmental concentrations, phosphorus is a limiting factor for plant growth.
- Phosphorus is a key component of cell membranes, DNA, RNA, and other biochemical compounds.

32 **The phosphorus cycle**

33 **Humans affect the phosphorus cycle**

- Mining rocks for fertilizer moves phosphorus from the soil to water systems.
- Wastewater discharge also releases phosphorus, which boosts algal growth and causes eutrophication.
- May be present in detergents
  - Consumers should purchase phosphate-free detergents.
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34 **The nitrogen cycle**

- Nitrogen comprises 78% of our atmosphere and is contained in proteins, DNA, and RNA.
- Nitrogen cycle: describes the routes that nitrogen atoms take through the environment
  - Nitrogen gas is inert and cannot be used by organisms.
  - Needs lightning, bacteria, or human intervention
- Nitrogen fixation: Nitrogen gas is combined (fixed) with hydrogen by nitrogen-fixing bacteria or lightning to become ammonium
  - Can be used by plants

- Nitrogen-fixing bacteria live in legumes (i.e., soybeans)
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35 **Nitrification and denitrification**
- Nitrification: bacteria that convert ammonium ions first into nitrite ions then into nitrate ions
  - Plants can take up these ions
- Animals obtain nitrogen by eating plants or other animals.
- Denitrifying bacteria: convert nitrates in soil or water to gaseous nitrogen, releasing it back into the atmosphere
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36 **The nitrogen cycle**

37 **Humans affect the nitrogen cycle**
- Excess nitrogen leads to hypoxia in coastal areas.
- Synthetic fertilizers doubled the rate of Earth's nitrogen fixation.
- Burning forests and fossil fuels leads to acid precipitation.
- Wetland destruction and increased planting of legumes has increased nitrogen-rich compounds on land and in water.
- Increased emissions of nitrogen-containing greenhouse gases
- Calcium and potassium in soil are washed out by fertilizers.
- Reduced biodiversity of plants adapted to low-nitrogen soils.
- Changed estuaries and coastal ecosystems and fisheries

38 **Human inputs of nitrogen into the environment**

39 **A law addressing hypoxia in the Gulf**
- The Harmful Algal Bloom and Hypoxia Research and Control Act (1998) called for an assessment of hypoxia in the Gulf and to:
  - Reduce nitrogen fertilizer use in Midwestern farms
  - Change timing of fertilizer applications to minimize runoff
  - Use alternative crops
  - Manage livestock manure
  - Restore wetlands and create artificial ones
  - Improve sewage-treatment technologies
  - Evaluate these approaches
- This Act has worked, and was reauthorized in 2003.

40 **The hydrologic cycle**
- Water is essential for biochemical reactions and is involved in nearly every environmental system.
- Hydrologic cycle: summarizes how liquid, gaseous, and solid water flows through the environment
  - Oceans are the main reservoir.
  - Less than 1% is available as fresh water.
- Evaporation: water moves from aquatic and land systems to air
- Transpiration: release of water vapor by plants
- Precipitation: condensation of water vapor as rain or snow returns water from the air to Earth's surface

41 **Groundwater**
  - Aquifers: underground reservoirs of spongelike regions of rock and soil that hold …
  - Groundwater: water found underground beneath layers of soil
  - Water table: the upper limit of groundwater held in an aquifer
  - Water may be ancient (thousands of years old).

42 **The hydrologic cycle**

43 **Human impacts on hydrologic cycle**
- Damming rivers increases evaporation and infiltration into aquifers.

- Altering the surface and vegetation increases runoff and erosion.
- Spreading water on agricultural fields depletes rivers, lakes, and streams and increases evaporation.
- Overdrawing groundwater for drinking, irrigation, and industrial uses depletes groundwater resources.
- Removing forests and vegetation reduces transpiration and lowers water tables.
- Emitting pollutants changes the nature of precipitation.

44 **Conclusion**

- Life interacts with its abiotic environment in ecosystems through which energy flows and materials are recycled.
- Understanding biogeochemical cycles is crucial.
  - Humans are causing significant changes in the ways those cycles function.
- Understanding energy, energy flow, and chemistry increases our understanding of organisms, their environment, and how environmental systems function.
- Thinking in terms of systems can teach us how to avoid disrupting Earth's processes and how to mitigate any disruptions we cause.