3

Earth Systems and Ecosystems

Chapter Objectives

This chapter will help students

Describe the fundamental properties of systems, and the importance of linkages and flows of matter and energy among environmental systems

Outline the characteristics of Earth's major subsystems

Discuss how living and nonliving entities interact and how energy and matter move around in ecosystems

Recognize the importance and complexity of the differing spatial and temporal scales of Earth processes

Summarize the main global biogeochemical cycles and their human impacts, especially the global water, carbon, nitrogen, and phosphorus cycles

Chapter Outline

Section	PPT #
Central Case: The Plight of the St. Lawrence Belugas	3-3 to 3-4

Environmental Systems Systems are networks of relationships Feedbacks are common in environmental systems Homeostasis is a state of balance A whole may be more than the sum of its parts Complex systems have multiple subsystems	3-5 to 3-13
Earth's Major Subsystems The geosphere is the ground beneath our feet The atmosphere is our planet's gaseous envelope Surface and near-surface waters compose the hydrosphere The biosphere is the living sphere The anthrosphere is the human realm	3-14 to 3-20
Ecosystems Ecosystems are systems of interacting biotic and abiotic components Energy is converted to biomass through primary productivity Nutrient availability limits primary productivity Ecosystems provide vital services	3-21 to 3-31
Environmental Systems in Space and Time Temporal and spatial scales of natural processes differ dramatically Models help scientists understand complex systems Ecosystems are studied on a variety of spatial scales Landscape ecologists study broad geographical patterns Remote sensing and GIS are important tools	3-32 to 3-40

Key Terms

abiotic
air
anthrosphere
atmosphere
bioaccumulate
biochemical cycles
biomass
biosphere
biotic
carbon (C)
carbon cycle
closed systems
cryosphere
cumulative effects
cycles
dentrification
dynamic equilibrium
ecology
ecosystem
ecosystem ecology
ecotones
emergent properties
eutrophication
evaporation
feedback loop
flux
Geographic information systems (GIS)
geosphere
Gross primary production (GPP)
ground water
Haber-Bosch process
homeostasis
hydrologic cycle
hydrosphere
hypoxia
landscape ecology
limiting factor
model
negative feedback loop
Net primary production (NPP)
nitrogen (N)
nitrogen cycle
nitrogen fixation
nitrification
nutrient cycles
nutrients
open systems
phosphorus (P)
phosphorus cycle
positive feedback loop

precipitation
productivity
remote sensing
reservoir
residence time
resilience
resistance
runoff
secondary production
sinks
sources
steady state
system
transpiration
turnover time

Teaching Tips

1. Illustrate the relative size of the lithosphere and the atmosphere by making a comparison with an apple. The skin of the apple represents the atmosphere, while the flesh and core of the apple represent the lithosphere.

2. Ask students to conduct internet research on the Gulf of Mexico “dead zone.” What is the current status of the dead zone? Has it increased or decreased in size since 2002? What is being done to address the problem?

3. Describe human activities that are affecting the flux rates in each of the major biogeochemical cycles. Divide students into small groups and have each group take one of the cycles, either on land, in freshwater, or in the oceans, and research the human effects. Depending on the size of the class, you may need to divide them further; you might do so by industrialized countries, emerging economies, and non-industrialized countries, or by continent. Groups could present their findings as written reports, posters, web pages, or oral presentations.

4. Have students make a table to compare and contrast the major biogeochemical cycles, their reservoirs, which is the sink and which is the source, time frames for flux, and other pertinent information. This could be done in groups or individually and during a lab period or for homework.

5. Consider having students make a miniature biosphere as a lab project. They have to consider producers, consumers, detritivores, nutrient cycling, water cycles, energy input, and waste heat. Small aquariums covered with glass or plastic sheeting can be used if you have space for such a long-term project. Otherwise, see the ideas listed at www.bottlebiology.org, a website maintained by the University of Wisconsin-Madison through an National Science Foundation grant. Some of the site’s ideas are simplistic, but students can create a fairly sophisticated biosphere using the given techniques. These biospheres have the advantages of being inexpensive and taking up little space in a classroom or lab.

Discussion Questions

1. Discuss the importance of understanding the complexities associated within the Earth’s ecosystems?

   Systems seldom have well-defined boundaries. No matter how we attempt to isolate or define a system, we soon wee that it has many connections to systems larger and smaller than itself. Systems may exchange energy, matter, and information with other systems, and they may contain or be contained within other systems – so where we draw boundaries may depend on the spatial or temporal scale we wish to consider. In order to be in informed citizen it is important that you understand these interrelationships and the impacts each has on each subsystem.

2. How do the various cycles (e.g. Carbon) impact you on a day-to-day basis?

   Answers will vary. Students should discuss how their lives (example transport, work, consumption) are all impacted by the various subsystems. After reading the first three chapters, students should have an introductory understanding of the interrelationships.

3. Why are humans only "part" of the Earth's ecosystem?

   Ecological processes form the soil that nourishes our crops, purify the water we drink and the air that we breathe, store and stabilize supplies of water that we use, pollinate the food plants we eat, and receive and break down the waste we dump and the pollution we emit (Figure 3.11).

Essay Questions

1. Explain the concept of systems – including open and closed systems – as they relate to the environment.

   A system is a network of relationships among parts, elements, or components that interact with and influence one another through the exchange of energy, matter, or information. Systems receive inputs of energy, matter, or information, process these inputs, and produce outputs. Systems that receive inputs of both energy and matter and produce outputs of both are called open systems. Systems that receive inputs and produce outputs of energy, but not matter, are called closed systems. In a closed system, matter cycles among the various parts of the system but doe3s not leave or enter the system.

2. Explain the concepts of ecosystems.

   Ecosystem ecology refers to the study of energy and nutrient flows among living and nonliving components of a system. Ecosystems are systems that receive inputs of energy, process and transform that energy while cycling matter internally, and produce a variety of outputs. Energy and matter are passed among organisms through feeding relationship. Energy flows through ecosystems, in one direction' most arrives as radiation from the Sun, powers the system, and exits in the form of heat.

3. Explain the Nitrogen cycle and how humans have influence this vital cycle.

   Nitrogen makes up 78% of our atmosphere by mass. It is an essential ingredient in the proteins that build our bodies, and an essential nutrient for plant growth.

The nitrogen cycle is of vital importance to all organisms. The impacts of excess nitrogen from agricultural fertilizers in the Great Lakes and St. Lawrence have had a negative impact on both water quality and the health of marine organisms. Fertilizer-laden runoff increases the nitrogen available to aquatic plants and algae, boosting their growth.

Additional Resources

Websites

1. National Centers for Coastal Ocean Science Gulf of Mexico Hypoxia Assessment, NOAA's National Ocean Service (www.nos.noaa.gov).
   This website provides an integrated assessment of hypoxia in the Gulf of Mexico.
2. Rock Images (http://geology.about.com).
   This website provides an introduction to geology and descriptions of the rock types.
   This Dynamic Earth: The Story of Plate Tectonics, USGS (http://pubs.usgs.gov).
   This online publication describes plate tectonics with images and maps.

Audiovisual Materials

1. Strange Days on Planet Earth, National Geographic (http://shop.nationalgeographic.com).
   This two-DVD set follows scientists as they try to solve a series of mysteries.
2. World's Last Great Places, National Geographic (http://shop.nationalgeographic.com).
   This 11-part series examines specific locations to illustrate biome characteristics.
3. US Geological Survey video library (http://gallery.usgs.gov).
   These videos cover a wide range of topics.

Answers to End-of-Chapter Questions

Testing Your Comprehension

1. Which type of feedback loop is most common in nature, and which more commonly results from human action? How might the emergence of a positive feedback loop affect a system in homeostasis?

Negative feedback loops are most common in nature, whereas positive loops more commonly result from human actions. Positive feedback loops tend to move systems away from their homeostatic condition.

2. Name and briefly describe Earth's major subsystems.

Earth's major subsystems are:

- the geosphere (the rock and sediment of the solid planet Earth);
- the atmosphere (the envelope of gas, or air, that surrounds our planet);
- the hydrosphere (all of the water—salt or fresh, liquid, ice, or vapour—held in surface water bodies, including the ocean, lakes, rivers, wetlands, soil moisture, and ground water);
- the cryosphere (a subsystem of the hydrosphere, which includes all of Earth's frozen water, including glaciers, snow cover, and sea ice);
- the biosphere (the planet's living organisms, and recently deceased and decaying organic matter); and
- the anthroposphere (the parts of the Earth system that are modified by humans or constructed for human use, including the built environment in which we live, work, and study).

3. What is an ecosystem?

An ecosystem is a system that includes a biotic community and its abiotic environment, existing in a particular area at the same time, including the interactions of the organisms and abiotic components.

4. Describe the typical movement of energy through an ecosystem. Describe the typical movement of matter through an ecosystem.

Typically, energy moves through an ecosystem from its source (primarily, the Sun) to plants or other photosynthetic primary producers. The producers are then consumed by a variety of organisms, which in turn are consumed by others. At each step, some energy is passed along to the consumer and some is lost to the surrounding environment as waste heat. Therefore, we generally say that "energy passes through an ecosystem."

Matter is also transferred through the food chain as organisms eat organisms on lower trophic levels. However, matter from waste and from dead organisms is consumed and broken down by detritivores and decomposers, returning the matter to the soil so that it can be recycled through the food web in the ecosystem. Therefore, we generally say that "matter is recycled in ecosystems."

5. What is the difference between net primary productivity and gross primary productivity?

The conversion of solar energy to the energy of chemical bonds in biomass by autotrophs is called gross primary production (GPP) (or gross primary productivity, referring to the process). Net primary production (NPP) (or net primary productivity, referring to the process) is what is left of GPP after autotrophs use some of their acquired energy for their own metabolism (respiration). Thus, net primary production equals gross primary production minus respiration (or NPP = GPP – respiration by autotrophs).

6. Why are patches in a landscape mosaic important to scientists with an interest in conservation?

Patches can be ecosystems, communities, or habitat for specific species. Patches are spread spatially over a landscape in a mosaic. Every organism has specific habitat needs, so when its habitat is distributed in patches across a broader mosaic, individuals may need to expend energy and risk predation travelling from one to another. Scientists interested in conservation need to be aware of these habitat needs when developing restoration plans.

7. What role does each of the following play in the carbon cycle? Cars; photosynthesis; the ocean; Earth's crust.

- Cars release significant amounts of CO_2 into the atmosphere from the combustion of oil, a fossil fuel.
- Photosynthesis is the process by which plants remove CO_2 from the atmosphere and store the carbon in the form of carbohydrates.
- The ocean is a significant reservoir for carbon. It hosts a large volume of phytoplankton, which can remove CO_2 from the air by photosynthesis. CO_2 also passes from the atmosphere to the ocean by gas transfer. Carbon in the form of CO_2 also dissolves in seawater, is incorporated into carbonate minerals, and collects as organic sediment on the ocean floor. This carbon returns to the atmosphere when the crustal plates are themselves recycled in subduction zones, and some of the plate material is melted and erupts volcanically.
- Earth's crust (and the geosphere, generally) is by far the largest reservoir for carbon in the carbon cycle, held in the form of sediment and rock, primarily limestone.

8. Contrast the function performed by nitrogen-fixing bacteria with that performed by denitrifying bacteria.

Nitrogen fixation occurs through the action of nitrogen-fixing bacteria, which live in mutualistic relationships with many leguminous plants in root nodules. In nitrogen fixation, gaseou nitrogen from the air is converted by nitrogen-fixing bateria into a form that is useable by plants. Conversely, denitrifying bacteria convert nitrates from soil or water into gaseous nitrogen.

9. How has human activity altered the carbon cycle? The phosphorus cycle? The nitrogen cycle? To what environmental problems have these changes given rise?

In general, human activity has caused flows (or fluxes) among reservoirs in biogeochemical cycles to increase, upsetting some of the naturally existing balances within the cycles.

- Carbon cycle: Human activity has accelerated the release of CO_2 into the atmosphere through the combustion of fossil fuels and production of cement, as well as through deforestation and other land-use changes. High CO_2

concentrations in the atmosphere contribute to the enhanced greenhouse effect, and to global climate change.

- Phosphorus cycle: We affect the phosphorus cycle by mining rocks containing phosphorus for use as inorganic fertilizer. Excess phosphate can enter waterways, causing eutrophication.
- Nitrogen cycle: In the global nitrogen cycle, humans fix more nitrogen now by the Haber-Bosch process than is fixed by natural processes of nitrogen fixation and nitrification. This can cause eutrophication, as well as some health effects for humans and other animals consuming nitrate-contaminated drinking water. Nitrogen oxides released through the burning of fossil fuels and other industrial processes also contribute to air pollution, including the production of acid precipitation.

10. What is the difference between evaporation and transpiration? Give examples of how the hydrologic cycle interacts with the carbon, phosphorus, and nitrogen cycles.

Evaporation is the conversion of water from its liquid to gaseous form. Transpiration is the special case of evaporation and release of water vapour from the leaves of plants.

The hydrologic cycle has an impact on the other nutrient cycles because these nutrients all have water-soluble forms: CO_2 dissolves as bicarbonate ions; nitrogen in the form of ammonia, nitrates, or nitrites; and phosphorus as phosphates. This can have many environmental impacts; for example, nitrogen oxides interacting with water vapour in the atmosphere can lead to the production of acid precipitation; carbonate interacting with ground water can produce carbonic acid, which contributes to chemical weathering of rock; and phosphate dissolved in runoff can lead to eutrophication of water bodies.

Interpreting Graphs and Data

1. Are the data shown on the graph consistent with the regulatory histories of these two groups of pollutants? Why (or why not)? Are there other factors that should be considered in interpreting the graph?

Yes, the data shown on the graph are consistent with the two groups of chemicals. As the regulatory policy has become stricter in relation to the use of PCBs, the concentration has decreased. However, as the use of PBDE has increased and the policy limiting its use has not changed, the associated concentrations have increased.

2. Are there any causes of death shown on the pie chart that you think might be directly attributable to the whales' exposure to toxic pollutants? Are there any that might be indirectly related to exposure to toxins? Are there any causes of death illustrated here that definitely do not seem to be related to exposure to toxins? (Note that the term neoplasia refers to the abnormal and uncontrolled growth of cells, resulting in the formation of tumours.)

Terminal neoplasia seems to be directly caused by the whales' exposure to toxic pollutants. Indirect causes seem to be bacterial infection, parasitic infection, and trauma, because the whales' immune systems could have been weakened due to exposure to toxins, making them more susceptible to these causes. Causes of death that seem to be unrelated are birth period, unknown, and others, because there is not enough data or detail to be sure about the connections.

