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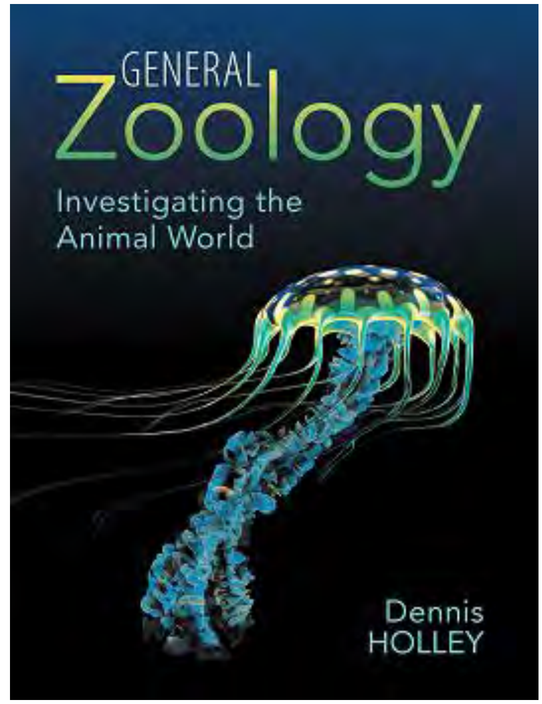
GENERAL ZOOLOGY: Investigating the Animal World 2e

Dennis Holley



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- ***Research-based.*** This book is based on current educational research and best educational practices, not tradition.
- ***Understandable.*** This textbook is content (ideas) driven and not consumed with terms and terminology (definitions). Terms and scientific names are used when and where appropriate to illustrate and explain the concepts and ideas inherent in a particular chapter.
- ***Readable.*** Presented in a single column format, this book is written more similar to a magazine article than a dry, stilted entry in an encyclopedia. This allows for easier student reading which in turn increases reading comprehension.
- ***Appropriate level.*** Many, if not most, of the students that take introductory biology courses come with only a fair to poor biology background. This problem is compounded by college biology textbooks that are written at a higher technical level than they should be. Our textbook, however, takes such student deficiencies into account as is written at an appropriate level to address those deficiencies.
- ***Connected.*** Often students do not appreciate how they connect with animals directly or indirectly on a daily basis. In order to convey the importance of animals, each specific phylum chapter concludes with a detailed look at how the animals in that chapter connect to humans economically, ecologically, medically and even culturally.

Table of Contents and Sample Chapter

BRIEF TABLE OF CONTENTS

PREFACE

Greetings zoology student and welcome to the always astonishing, sometimes strange, and occasionally even bizarre world of animals.

> *We patronize them for their incompleteness, for their tragic fate of having taken form so far below ourselves, And therein do we err. For the animal shall not be measured by man. In a world older and more complete than ours, they moved finished and complete, gifted with the extension of senses we have lost or never attained, living by voices we shall never hear. They are not our brethren. They are not our underlings. They are other nations, caught with ourselves in the net of life and time, fellow prisoners of the splendor and travail of the earth.*
>
> —Henry Beston

Zoology or any scientific endeavor should be thought of as consisting of two phases: the first being the *Investigation* and *Exploration* phase while the final is the *Accumulation* phase. Zoologists attempt to answer questions about the animal world by actively investigating animals through experimentation and by discovering new animal species through exploration. Investigation and exploration in turn lead to the accumulation of facts and information. These accumulated facts and information lead to even more questions that in turn lead to more investigation resulting in even more facts and information being accumulated. And the cycle continues.

In this course, you will confront the facts and concepts of zoology in your textbook (*Accumulation*). However, you will also be challenged to think, act, and work like a zoologist (*Investigation*) at certain points in your textbook, and especially in the laboratory segment of this course. As you investigate, you will use the same information, develop the same scientific skills, and employ the same scientific processes as do professional zoologists.

Science Process Skills

Organizing Information

- Classify
- Sequence

- Describe
- Summarize
- Explain
- Definition and proper use of terminology
- Accessing and using reference materials
- Reading comprehension

Critical Thinking

- Critical and creative thinking
- Observe
- Infer
- Compare and contrast
- Recognize cause and effect
- Formulate and use models

Experimentation

- Experimental design
- Formulate hypothesis/prediction
- Establish variables and controls
- Collect and organize data
- Accurate measurement
- Analyze data
- Draw reasonable conclusions

Graphics and Numbers

- Make and interpret graphs
- Construct and interpret tables
- Interpret scientific illustrations
- Calculate and compute

Communication

- Brainstorming
- Collaboration
- Communicating

Developing and using these skills effectively is very important if you are biology major, but even if you are not majoring in a scientific field, mastering these skills will help you function as a clear-thinking and scientifically literate citizen of a society that grows ever more science-based and technologically oriented.

Approach and Organization

Approach

Biology textbooks and related curricular materials at all levels have come under harsh but justified criticism by various scientific and educational groups in the past decade. From the inception of this text, it has been the goal to write a zoology program that acts on the criticisms and recommendations of those authorities and is based on current educational research. This textbook has been designed and written to be:

- **Readable and Interesting**. My goal has been to write a textbook in which the chapters read more like an interesting magazine or newspaper article and less like a dry and detailed technical entry from an encyclopedia. Increasing reader interest increases readability and to aid in that goal, I include out-of-the-ordinary things in each chapter that would not normally be found in zoology texts. I have also taken a different approach than other zoology books in that while I firmly believe that evolution is driving force and cornerstone of all things biological, I did not make the theoretical and often speculative aspects of origins and patterns of evolution the focal point of each chapter. Instead, I opted for a more concrete "here-and-now" approach in which our focus is mainly on animal systematics, phyla and class characteristics, and ecology. Hopefully, less emphasis on the theoretical translates into a work that is more relevant to you the student.
- **Understandable.** As I wrote this textbook I tried to avoid the "Huh? Factor" as much as possible. That is; students should not be obliged to reread a passage several times all the while armed with a biological dictionary to understand what they just read. The chapters of this textbook are centered on concepts and ideas. Specific facts, terms and terminology, and scientific names are used only when necessary and appropriate to illustrate and explain the concepts and ideas inherent in a particular chapter. This textbook is concept (idea) driven, not terminology (definitions) driven.
- **Connected.** Animals are all around us, on us and possibly in us, and they affect our daily lives directly and indirectly in ways we are continuing to uncover. In an attempt to connect you the reader directly to each animal group, each chapter concludes with a discussion on how the animals encountered in that chapter connect to humans economically, environmentally, medically, and even culturally.
- **Personable** Many textbooks are written by teams of writers, some of which are anonymous. As a result, the reader (student) lacks a personal connection with the author(s). Again, this text is different. First, this text was written in entirety only by the name you see stamped on the front of this book—Dennis Holley. Secondly, I have attempted to write each chapter in the tone of enthusiastic and passionate, but caring and concerned teacher speaking directly to you the student. Hopefully, I have succeeded. Lastly, personal notes will appear at the end of each chapter. In

these short conversations and dialogues, I may share an anecdote, look behind the headlines, or pose intriguing questions. You will encounter the first of these conversations and dialogues in this preface. Hopefully, you will find them interesting, thought-provoking and even amusing.

Organization

A quick glance at the table of contents reveals that what zoology is and how it works is detailed in Chapter 1. With this foundation in place, Unit One examines the place of animals in the bigger picture of the web of life. Unit Two delves into animal structure and behavior then investigates the possible origins of animals (phylogeny) as well as the system of organization (taxonomy) developed to bring scientific order to biologic chaos. In the remaining three units, we will voyage through the animal realm from the simplest life form—sponges to the most complex—humans. The progression of units is based on increasing morphological and anatomical complexity.

At the end of each chapter you will find both a set of *Review and Reflect* questions that will test your critical thinking skills while reviewing the main concepts of that particular chapter and a set of *Create and Connect* challenges that will help you develop and use important science process skills. Some or all of these questions and challenges may be assigned by the instructor as part of the assessment package for this course. In these assignments, you will be asked to write everything from formal scientific reports to essays to position papers to short stories. The exact format and details will be given with each assignment. Consult Appendix A—Scientific Writing for guidelines and suggestions for correct scientific writing.

I believe this textbook represents a major paradigm shift in the way college biology textbooks are written and presented because it was written by a teacher (not a research scientist) for students. I have labored to make this textbook accurate, understandable, and interesting so that you can and will read it. And if you do indeed bother to read it, I guarantee that you will gather not only a wealth of information, but also a never-ending respect for those amazing creatures we call animals.

A Personal Note from the Author

I am a biologist to the core, always have been, and always will be. My interest in all things living is broad and generic. If it's a living creature—plant, animal, or microbe—I find it fascinating. How did I get this way? Understanding parents and a nurturing habitat are to blame. My mother was constantly contending with tadpoles in jars, aquariums of fish, mice in cages, and occasionally rewashing the clothes she had just hung out to dry because my flock of pigeons flew too low overhead. She pretended to make a fuss but encouraged my every adventure. My father helped me build cages and traps and was quite adept at capturing and helping me rear the many kinds of small animals that constantly caught my attention and interest.

I was blessed with growing up in a very small rural village where my family's acreage was only several blocks from a meandering stream aptly known by the locals as "Muddy Creek." This brook was shaded by many huge overhanging trees and was full of snails, fish, frogs, turtles, and even beavers and muskrats. Many inquisitive hours were spent around and in that stream.

Two events sealed my fate and set me on my course. In my early high school years, my parents finally gave in to my pestering and bought me a small, simple microscope (which they couldn't afford even though it cost only around $30). This amazing black beauty came complete with a wooden box of slides and a few dissecting instruments. Once I dove into the microscopic world, I was hooked on all things biological. Later, I stumbled on Paul de Kruif's 1926 book, *Microbe Hunters* and was inspired to get the education that would allow me to become a professional biologist. At that point, I didn't know exactly what I wanted to do professionally, but I did know my future would have something to do with biology.

I eagerly devoured every biology course I could take in college, and while I flirted for a time with the idea of becoming a marine biologist, I eventually became an educator. For nearly forty years, high schools and universities have actually paid me for merely doing what I love—teaching biology and teaching others how to teach biology and science. I am a very inquiry-oriented, hands-on type of teacher whose philosophy as an educator is best and most simply articulated in the words of Louis Agassiz:

Study nature, not books.

My love of all things biological continues unabated to this day. As such, I would consider the day poorly spent were I not to stumble upon at least several biological "WOW! Moments" (*WoMos*) during the course of that day. Such moments are not hard to find for they are everywhere. You just have to be receptive to them. Stop, look, and appreciate the natural world around you.

It was my intent and it is my hope that through this zoology program, you will come to know and respect those amazing creatures we call animals and that you too will have many personal zoological *WoMos* as this course unfolds.

I would like to dedicate this book to my parents for their nurturing and understanding, my wife and family for their patience and support, and to my students—past and present—who have taught me more than they will ever know.

Dennis Holley

CHAPTER

3

THE ECOLOGY OF ANIMALS: ECOSYSTEMS AND BIOMES

I have killed the deer.
I have crushed the grasshopper
And the plants he feeds upon.
I have cut through the heart
Of trees growing old and straight.
I have taken fish from the water
And birds from the sky.
In my life, I have needed death
So that my life might be.
When I die, I must give life
To what has nourished me.
The earth receives my body
And gives it to the caterpillars
To the birds and to the coyotes
Each in its own turn so that
The circle of life is never broken.

—Native American tribe of Puebloan people

Introduction

The other planets of our solar system and, for the most part, those we have discovered orbiting distant stars, are hellish places where life as we know it could not possibly exist. By a series of fortuitous happenings that we struggle to unravel and fathom, our small world is perfectly equipped with a dynamic physical structure that supports and nourishes the flora, fauna, and microbe passengers that have come to populate it. Not only is our cosmic real estate perfectly constructed and landscaped, it is also perfectly located. Our planet is nestled just close enough to an immense ball of nuclear energy to benefit from that energy without being destroyed by it, aided, of course, by our planet-generated "sunscreen"—the earth's magnetic field. When viewed and understood from the proper perspective, our world is seen for what it truly is—a unique and irreplaceable gem that is to be cherished and protected at all costs.

Whereas the ecology of populations and communities deals with interactions between species and individuals, the study of ecosystems and biomes delves into the connectedness between living things and the physical properties of this tiny ball of rock, air, and water we call home.

> *We travel together, passengers on a little spaceship, totally dependent on its vulnerable resources of air, water, and soil, being preserved from annihilation only by the care, work, and love we give our fragile craft.*
>
> —Adlali Stevenson

Ecology of Ecosystems

At the community level of organization, ecologists are most concerned with the connections and interactions between living things. However, at the larger ecosystem level, the focus tends to be more on the interactions between biotic (living things) and the abiotic (physical) environment in an attempt to understand how **biogeochemicals** and energy circulate and move through the system.

Any ecosystem is composed of two entities: the living biota and the abiotic medium the life exists in. In the largest sense, *ecosystem* refers to continental ecosystems, such as forests, prairies, and deserts, freshwater ecosystems, such as lakes, ponds, streams, and rivers, and oceanic ecosystems, or what are called **macroecosystems**. However, the concept of an ecosystem can apply to areas of smaller size as well. A **microecosystem** might be only a large stone and all the life under it whereas a **mesoecosystem** could be a meadow in a small clearing within a forest.

Biogeochemical Cycles

The body of any animal, including you, is formed from the chemical elements found in the air, water, and soil of this planet. And when an animal dies, these chemical elements must be returned to the planet. Must be returned? Why? The Earth is sealed by the cold and airlessness of space and thus the supply of these elements is fixed and unchanging. That is, the earth is a **closed system.** The Earth has only the types and amounts of elements that were present when the planet first formed (Discounting the tons of space dust that rain down on the planet yearly). Because these chemicals operate on a closed system basis, they must be recycled throughout all of Earth's processes that use those chemicals or elements. These cycles include both the living (bio-), and the nonliving atmosphere, hydrosphere, and lithosphere (geo-).

Molecules of these chemical elements are sometimes held for long periods of time in one place or **reservoir**. Coal deposits are huge reservoirs that have been storing carbon for very long periods of time. Other times chemicals may be held for short periods of time in what are known as **exchange pools**. Generally, reservoirs are abiotic situations whereas the term "exchange pool" applies to living things. Examples of exchange pools include plants and animals, which temporarily hold and use carbon in their bodies for a relatively short time and then release the carbon back into the physical environment on their death. The amount of time an element or chemical remains in a reservoir or exchange pool is called its **residence time**.

Chemicals flow back and forth from the biotic to the abiotic and back in often complicated processes known as **biogeochemical cycles**.

Box 3.1
Worlds Within Worlds

On this planet there exist smaller worlds so alien to each other that should the inhabitants of one of those worlds chose to visit the other, they would have to wear spacesuits (humans in SCUBA equipment) or possess special evolutionary modifications (Mud skippers are able to spend time out on tidal flats because they possess the ability to breathe through their skin and lining of their mouth and they can move around out of water though somewhat clumsily because of their pectoral fins are modified into leg-like appendages). Consider TerraWorld and AquaWorld, places so totally different that they might be considered separate planets in their own right. TerraWorld is a sovereignty primarily of dry land and air and AquaWorld is the dominion of water.

Water and air are both considered to be fluids, but it is the different physical properties of the two fluids that make aquatic and terrestrial places quite different from each other. Compared to air, water has high density, high viscosity, low oxygen concentration, and high heat capacity and conductivity. Such differences in physical characteristics are reflected in the structure, physiology, and behavior of terrestrial and aquatic animals.

Density A liter (0.3 gallon) of water weighs 1 kg (2.2 pounds), whereas a liter of air weighs about 1.25 gram (0.044 ounce). Thus, water is more than 800 times denser than air. The high density of water is very supportive of an animal's bulk dramatically lessening the effect of gravity on that creature. This manifests itself in aquatic vertebrates that can grow to gigantic proportions (whales) or those—sharks, skates, and rays—that get by with softer cartilaginous skeleton rather than weight-bearing bone skeletons because they are close to neutral buoyancy in water and are thus supported by the water.

Viscosity Viscosity is a measure of how readily a fluid flows—the higher the viscosity, the slower the fluid flows. (Think of how fast cold water [low viscosity] flows in comparison to how fast cold syrup [high viscosity] flows.). Water is 18 times more viscous than air.

The combined effects of high density and viscosity are reflected in the hydrodynamic (streamlined) shape of aquatic animals versus terrestrial ones. Moving through water is much more physically and metabolically demanding than is moving through air.

Oxygen Concentration Water has a low oxygen content whereas air has a high oxygen content. There are 209 ml (0.4 pint) of oxygen in a liter (0.23 gallon)of air everywhere constantly resulting in oxygen composing 21 percent of the total volume of air. However, the oxygen content of water varies, but is never more than 50 ml (1.70 ounce) per liter of water and can be as low as 10 ml (0.34 ounce) or less.

The differences between water and air in regards to density, viscosity, and oxygen content have led to terrestrial and aquatic animals evolving different strategies for moving fluids in and out of their bodies and extracting oxygen from those fluids—lungs in terrestrial animals and gills in aquatic animals.

Heat Capacity and Heat Conductivity The specific heat of water (the energy required to increase the temperature of1 gram of fluid by 1 degree) is nearly 3400 times that of air, and water conducts heat almost 24 times faster than air. As a result, water heats more slowly than air during the day but cools more slowly than air during the night. Thus, aquatic animals live in a more stable thermal realm than do animals on shore. However, because the heat conductivity of water is so high, the temperature at any given depth scarcely varies from one place to another, terrestrial animals have a wider variety of temperatures to choose from.

When viewed in this manner, one cannot help but come to the amazing realization that the entity we know as Earth is in actuality a set of smaller worlds within that larger entity.

Biogeochemical cycles of particular interest to ecologists include the water cycle, the carbon cycle, the nitrogen cycle, the oxygen cycle, and the phosphorous cycle.

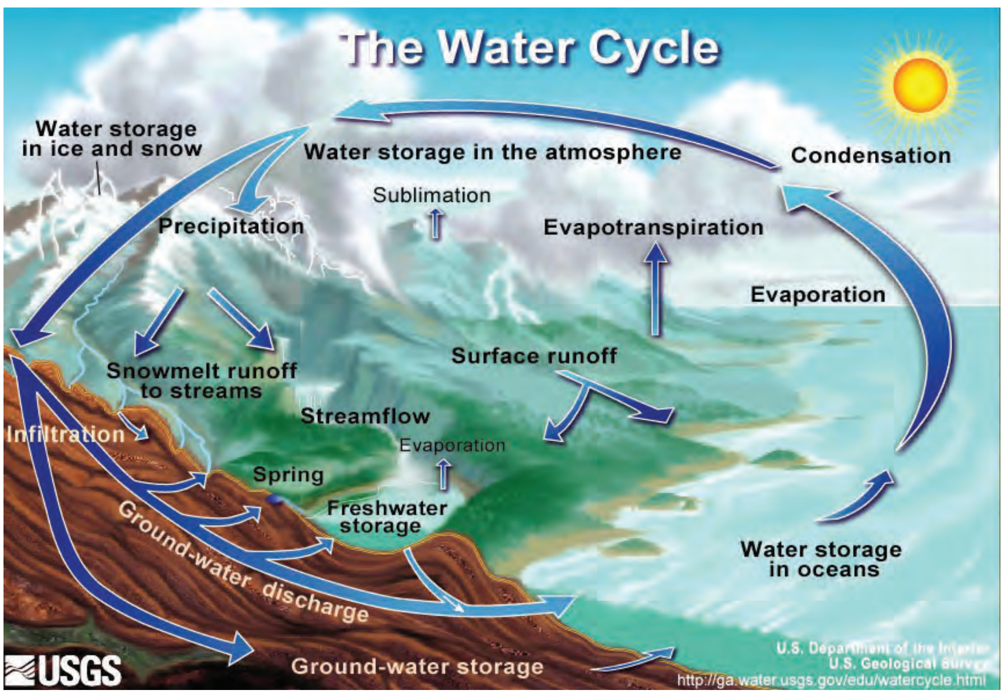

Figure 3.1 The Water (Hydrologic) Cycle. Water changes form as it circulates between air and land.

Hydrologic (Water) Cycle. Water is the most critical chemical on the planet as it is indispensable to the life and function of any organism. Not only do the bodies of living things consist mainly of this substance, but the chemical reactions that nourish and drive each cell of an organism must occur in water (**Figure 3.1**).

Driven by solar radiation, the water cycle is the continuous movement of water over, above, and beneath the Earth's surface. Only about 2% of all the water on earth is held in a reservoir of some sort—chemically bound into the bodies of organisms, frozen as ice, or residing in the soil. The remainder is free water circulating between the atmosphere, the ocean, and the land.

Movement of water through the cycle takes place by a variety of physical and biophysical processes. The main two transport processes responsible for moving the greatest quantities of water are precipitation and evaporation, thought to transport 505,000 km^3 (121,156 $miles^3$) of water each year.

As water moves around the hydrosphere, it changes state between liquid, vapor, and ice. The time taken for water to move from one place to another varies from seconds to thousands of years and the amount of water stored in different parts of the hydrosphere is estimated at up to 1.37 billion km^3 (329 million $miles^3$). Despite continual movement within the hydrosphere, the total amount of water at any one time remains essentially constant (discounting any that may be added from outer space on board comets or meteorites).

Carbon Cycle. The molecules that compose the physical structure (cells) of any organism have the carbon atom at their core. So important is this element to living things that it exists in living matter (bio) in amounts almost 100 times greater than its concentration in the earth (geo)—18% in living bodies vs 0.19% in the earth and 0.03% in the atmosphere.

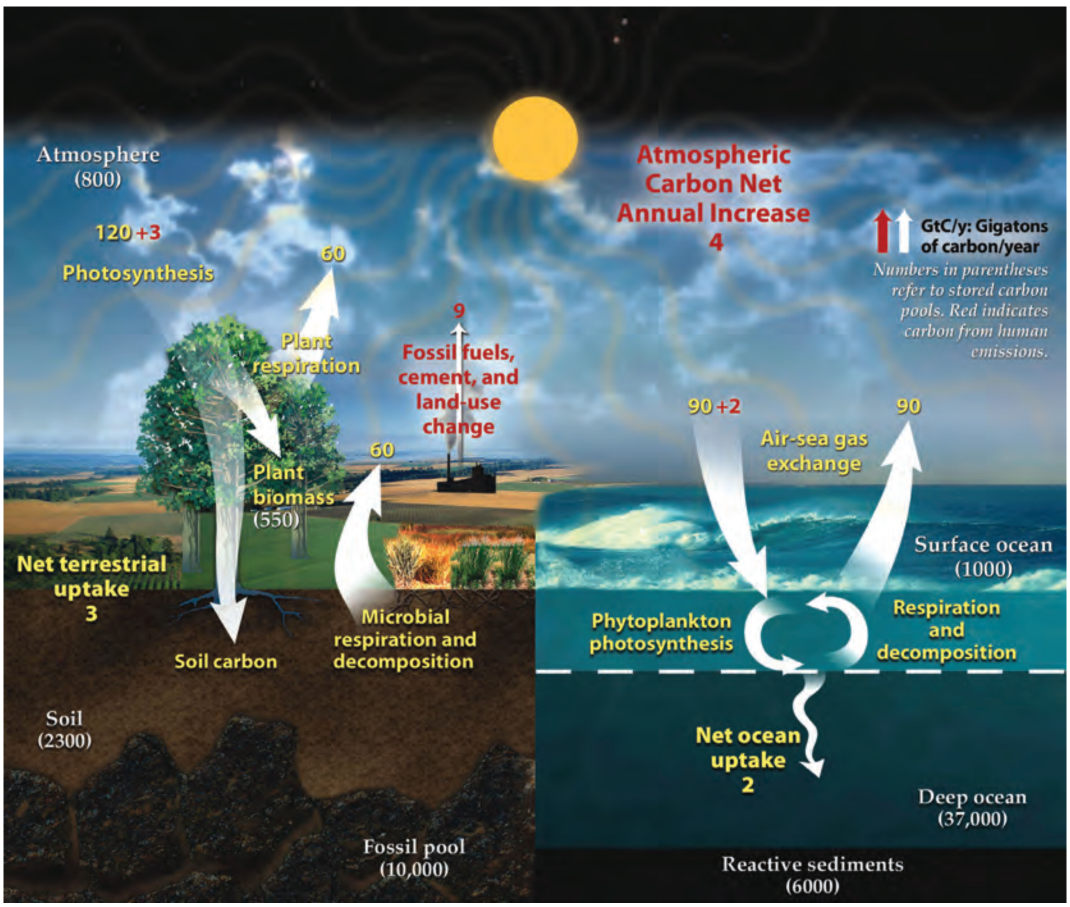

Figure 3.2 The Carbon Cycle.

The carbon cycle (**Figure 3.2**) can be thought of as six major reservoirs of carbon interconnected by pathways of exchange:

- *In the atmosphere* as carbon dioxide. At an estimated 700 billion metric tons, atmospheric carbon dioxide comprises only about 0.04% of the total atmosphere, although this number is rising possibly due to human-caused releases. Ice core studies indicate that the concentration of CO_2 in the atmosphere varies over geologic time and that the level of CO_2 in the past has been higher at times than present increasing readings.

- *In the ocean* as weak carbonic acid (H_2CO_3) and bicarbonate (HCO_3^-). Of the approximately 1 trillion metric tons dissolved in the ocean, more than half is found in the upper layers where photosynthesis occurs. Increases in atmospheric CO_2 translate into increasing acidity in the ocean, which has a negative impact on the formation and maintenance of the calcium carbonate shells of some marine invertebrates.
- *In the biosphere* where between 600 million and 1 trillion metric tons are locked up in the bodies of living things at any one time. Carbon enters the biotic world through the actions of photoautotrophs such as green plants and algae.
- *In carbonate rocks* such as limestone and coral ($CaCO_3$).
- *In fossil fuels* such as coal, oil, and natural gas.
- *In the soil* as organic matter (humus).

Nitrogen Cycle. Nitrogen is vital to living things as an essential component of organic compounds such as chlorophyll, nucleic acids, proteins, and amino acids. Weighing in at 4.11×10^{18} kg (9.05×10^{18} pounds) and comprising 78% of the total air, atmospheric nitrogen is the largest reservoir of that element. This reservoir is about one million times larger than the total nitrogen contained in the bodies of living organisms. Other stores of nitrogen include the organic matter in the soil and the ocean.

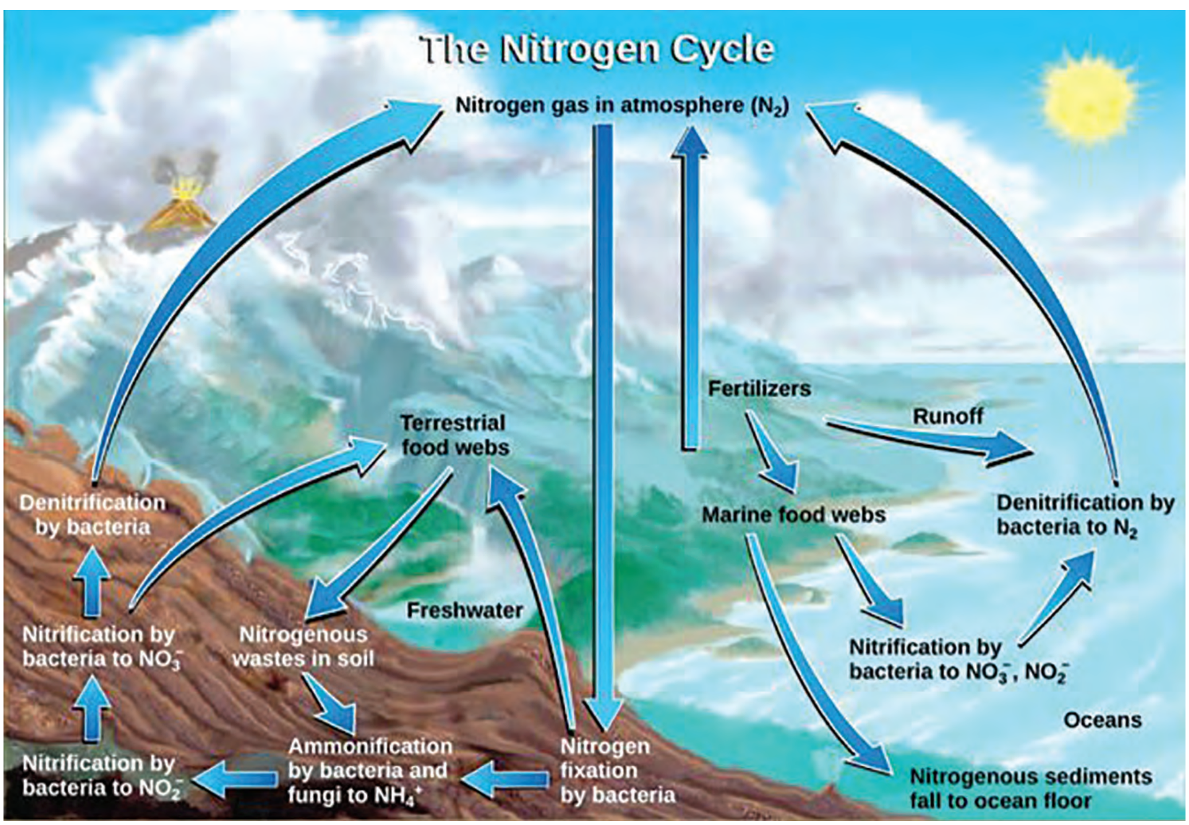

Figure 3.3 The Nitrogen Cycle. The first critical step is the conversion of atmospheric nitrogen by bacteria and fungi in the soil.

Atmospheric nitrogen exists as a very stable diatomic molecule in which two atoms of nitrogen are triple bonded together (N_2). However, most living things are not able to directly convert this abundant atmospheric nitrogen in the nitrogenous compounds they need. Although significant amounts enter the soil in rainfall or through the effects of lightning, the vast majority are **biochemically fixed** within the soil by specialized microorganisms such as some bacteria and fungi. Biologists estimate that biological fixation globally adds approximately 140 metric tons of nitrogen to ecosystems every year (**Figure 3.3**).

Large amounts of nitrogen are added by human activity to the environment in the form of agricultural fertilizers, the burning of fossil fuels, and other sources. For better or worse, humans now play a major role in the global nitrogen cycle

Oxygen Cycle. The fact that diatomic oxygen (O_2) makes up about 21% of the total atmosphere might lead one to conclude that oxygen's largest reservoir is the air as is the case with nitrogen. The silicate and oxide minerals in rocks of the crust (lithosphere), however, contain by far the largest reservoir of the Earth's total oxygen supply (99.5%). Only a small percent (0.01%) exists in the biosphere and only nominally more in the atmosphere (0.49%). Residence times for oxygen vary from the tightly locked oxygen in lithospheric rocks at around 50,000,000 years to diatomic atmospheric oxygen at around 4,500 years to biospheric oxygen which comparatively flies in and out of life cycles at roughly 50 year pulses.

Oxygen is removed from the atmosphere and water by the respiratory activities of animals, decay of organic matter, chemical weathering of rock, and shell building in some marine organisms. Chemical weathering, such as the formation of iron oxides (rust), consumes lithospheric oxygen. Oxygen is replaced into the atmosphere primarily by the action of green plants, algae, and cyanobacteria through the biochemical process of photosynthesis. Because of the vast amounts of oxygen in the atmosphere, however, even if all photosynthesis ceased this instant forever, it would still take about 2.5 million years to strip out all the oxygen from the air.

Phosphorous Cycle. The main reservoirs of phosphorous are as mineral salts in rocks bearing the element or in ocean sediments. Phosphorous is biologically important as a component of nucleic acids, phospholipids, and the energy storage molecule ATP. Furthermore, phosphorous compounds (phosphates) are very important to the nutrition of plants and algae.

As with nitrogen, millions of tons of phosphates are added to agricultural lands yearly in amounts often double or triple what is required and utilized by crops. The excess enters the groundwater or runs off into streams, lakes, and ponds. An excess load of phosphates in aquatic habitats can cause rapid growth of water plants and algae. The result is **eutrophication** in which rapid depletion of dissolved oxygen by the explosive growth of algae results in the suffocation of fish and other aquatic fauna.

Flow of Energy

Unlike the chemical elements that recycle through a closed system, the energy to power life and ecosystems occurs in an **open system**. The sun bombards the Earth with energy which in turn flows through the trophic levels of food chains and food webs. All the energy that comes into the system is eventually lost and is continually being replaced, not recycled.

Trophic levels (Gr., *trophos* = feeder) refer to how far removed from the original source of energy an organism is within a trophic structure whereas **trophic structures** are the feeding relationships within communities and therefore within ecosystems, a list of who's eating whom in other words. Organisms from each level, feeding on each other in turn, make up a sequence known as a **food chain**. Food chains illustrate specifically who does eat whom in a short sequence but sometimes it is beneficial to consider the bigger picture and investigate who could eat whom. By overlapping and interlocking the possible food chains in an ecosystem, we end up with a **food web** (**Figure 3.4**). A food web consists of all the food chains in an ecosystem.

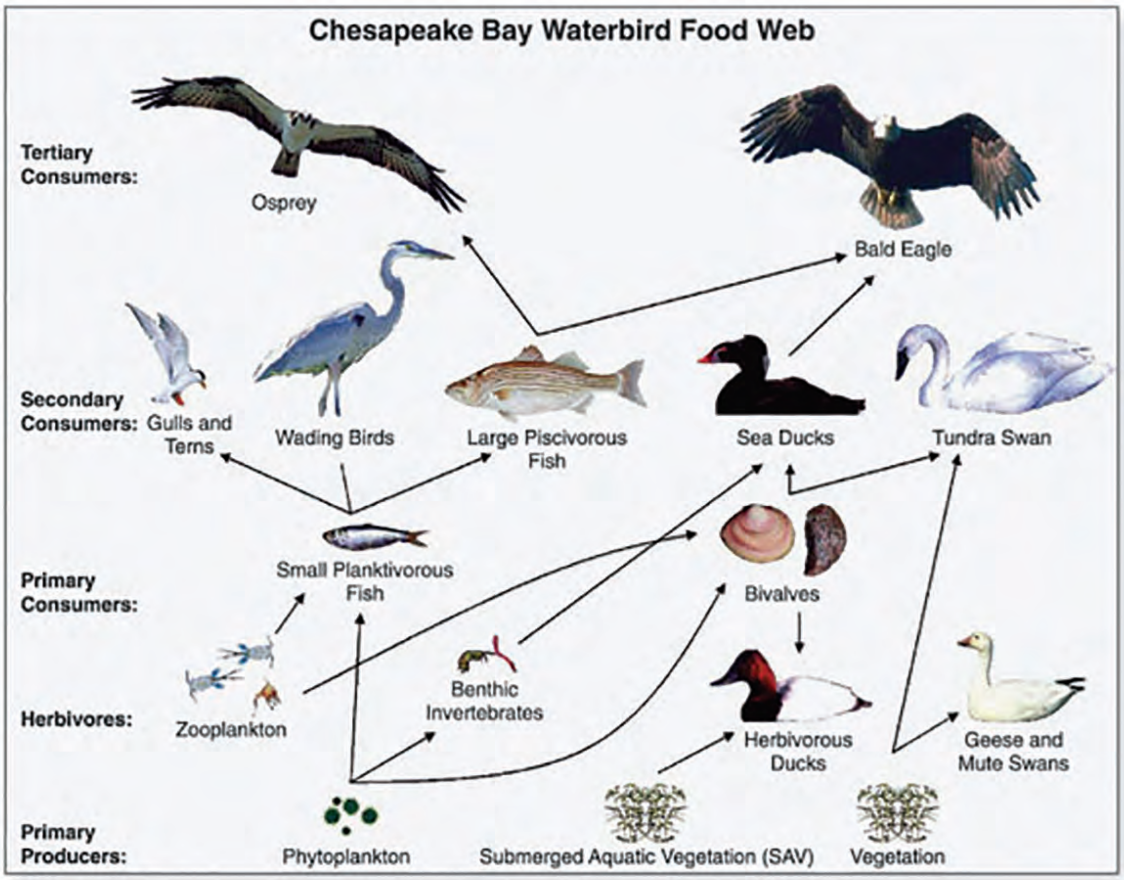

Figure 3.4 A food web found in and around Chesapeake Bay. The arrows indicate the direction of energy flow.

Energy enters food chains through the action of **primary producers** (or **autotrophs**) such as green plants, algae and some prokaryotes (bacteria). Once solar energy enters an ecosystem, almost exclusively as the result of photosynthesis, it is converted and passed from one trophic level to the next in the form of chemical energy.

The producers are fed upon in turn by the **consumers** (or **heterotrophs**). Several different levels of consumers exist. **Primary consumers** (or **herbivores**) feed directly on green plants, s**econdary consumers** (or **carnivores**) in turn eat the herbivores, and **tertiary consumers** eat secondary consumers. **Omnivores** such as some fish, pigs, bears, rats, humans, raccoons, foxes, gulls, and crows can eat both plant material and flesh.

Close examination of the trophic levels of any ecosystem illustrate that it really is a “dog-eat-dog” world, but in the end, the Big Dogs eat everybody. Who or what are the Big Dogs? The answer lies with the **saprotrophs**. Saprotrophs include the **scavengers** (or **detritivores**) such as vultures, crabs, hyenas, burying beetles, and flies, that feed on the wastes given off by living organisms or the remains of dead organisms and the **decomposers**, such as bacteria and fungi, that complete the chemical breakdown of decaying organic matter. The eventual fate of any living creature is to be rendered back into air, water, and soil by the Big Dog saprotrophs.

Biological Productivity

Biological systems are not very energy efficient. Green plants, the primary producers of terrestrial ecosystems, capture only about 1% of the solar energy falling on their leaves converting it to food molecules. Phytoplankton, however, are substantially more energy efficient. Accountings for less than 1% of Earth’s photosynthetic biomass, marine phytoplankton are responsible for more than 45% of our planet’s annual net productivity.

The small amount of solar energy that is actually captured is further lost as it moves through the various trophic levels. First, most plants are not consumed by herbivores but die and become fodder for the saprotrophs. Second, much of the energy that an herbivore takes in is not assimilated into the herbivore’s body but is utilized in growth and cellular respiration and lost through the feces. Finally, a great deal of the chemical bond energy is lost as heat produced by work at each trophic level, especially in the upper levels which are populated by endothermic (warm-blooded) animals.

When examining the productivity (efficiency) of ecosystems, ecologists speak of **biomass** (the total living matter in a given place), primary productivity, secondary productivity, and even tertiary productivity. **Primary productivity** is the productivity of the photosynthetic biomass in the form of terrestrial plants and photosynthetic phytoplankton. **Gross primary productivity** is the total amount of energy that is fixed by plants, whereas **net primary productivity** is smaller because it is adjusted for energy losses required to support plant respiration. If the net primary productivity of green plants and phytoplankton in an ecosystem is positive, then the photosynthetic biomass is increasing over time.

Gross and net **secondary productivities** refer to herbivorous animals whereas **tertiary productivities** refer to carnivores. Plants typically account for more than 90% of the total productivity of the food web, herbivores most of the rest, and carnivores less than 1%.

Because of differences in the availability of solar radiation, water, and nutrients, the world’s ecosystems differ greatly in the amount of productivity that they sustain. Deserts, tundra, and the deep ocean are the least productive ecosystems, typically having an energy fixation of less than 0.5×10^3 kilocalories per square meter per year (kcal/m^2/yr). Grasslands, montane (moist, cool upland slopes below the timberline), and boreal forests, waters of the continental shelf, and rough agriculture typically have productivities of $0.5\text{-}3.0 \times 10^3$ kcal/m^2/yr. Moist forests, moist prairies, shallow lakes, and typical agricultural systems have productivities of $3\text{-}10 \times 10^3$ kcal/m^2/yr. The most productive ecosystems are fertile estuaries and marshes, coral reefs, terrestrial vegetation on moist alluvial deposits, and intensive agriculture, which can have productivities of $10\text{-}25 \times 10^3$ kcal/m^2/yr (**Table 3.1**).

Table 3.1
Ecosystem Productivity

	Area	**Net Primary Productivity per Unit Area per Year (g/m² or t/km² per Year)***		**World Net Primary Production**
Ecosystem Type	**(106 km²)***	**Normal Range**	**Mean**	**(10⁹ t per year)***
Tropical rain forest	17.0	1,000-3,500	2200	37.4
Tropical seasonal forest	7.5	1,000 -2,500	1600	12.0
Temperate evergreen forest	5.0	600-2500	1300	6.5
Temperate deciduous forest	7.0	600-2500	1200	8.4
Boreal northern forest	12.0	400-2000	800	9.6
Woodland and shrubland	8.5	250-1,200	700	6.0
Savanna	15.0	200-2,000	900	13.5
Temperate grassland	9.0	200-1,500	600	5.4
Tundra and alpine	8.0	10-400	140	1.1
Desert and semidesert shrub	18.0	10-250	90	1.6
Extreme desert, rock, sand, and ice	24.0	0-10	3	0.07
Cultivated land	14.0	100-3500	650	9.1
Swamp and marsh	2.0	800-3,500	2000	4.0
Lake and stream	2.0	100-1,500	250	0.5
Total continental	149	773	115	
Open ocean	332.0	2-400	125	41.5
Upwelling zones	0.4	400-1,000	500	0.2
Continental shelf	26.6	200-600	360	9.6
Reefs	0.6	500-4,000	2500	1.6
Estuaries	1.4	200-3,500	1500	2.1
Total marine	361		152	55.0
Full total	510		333	170

*$t/km^2 = g/m^2$ = metric tons/km² = approximately 2.85 tons per square mile.

ᵗ10^9 t = 1 billion metric tons = approximately 1.102 billion tons.

ᵗ106 km² = approximately 386,000 square miles.

Source: Begon M. Harper J, Townsend C. *Ecology*, 2d ed. Cambridge, MA: Blackwell, 1990. Reprinted by permission of Blackwell Science, Inc.

Ecologists often employ a number of different **ecological pyramids** to diagrammatically represent the relationship between energy and the trophic levels of a given ecosystem. These pyramids include: a **pyramid of biomass** that shows the relationship between energy and trophic level by quantifying the amount of biomass (as dry mass) present at each trophic level, a **pyramid of numbers** that depicts the relative numbers of organisms at each trophic level, and what is probably the most useful of the various types of pyramids, and a **pyramid of energy** which measures the number of calories per trophic level.

In a famous study that would greatly influence the development of ecosystem ecology, H. T. Odum analyzed the flow of energy through a river and stream ecosystem in Silver Springs, Florida for four years

(**Figure 3.5**). Odum's objective was to develop a system for quantifying the energy flow between the trophic levels and to study the efficiency of the ecosystem's constant productivity output. Odum discovered that at each trophic level:

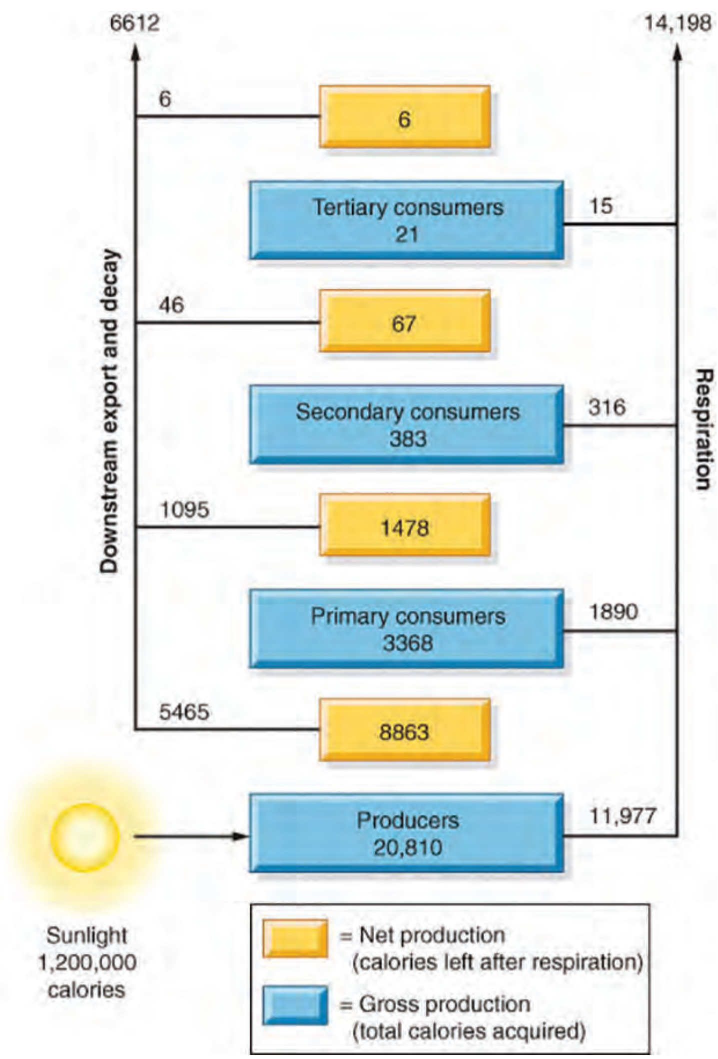

Figure 3.5 Energy flow through the different trophic levels of the Silver Springs ecosystem.

- Net production was only a fraction of gross production. Note that the difference between gross and net production is greater for consumers than for producers reflecting their greater activity.
- Much of the energy stored in net production was lost to the system by being carried downstream and through the process of decay.
- There were substantial losses in net production as energy passes from one trophic level to the next. The **conversion efficiency** (ratio of net production from one level to the next highest level) varied from 17% from producers to primary consumers to 4.5% from primary to secondary consumers. From similar studies in other ecosystems, ecologist now utilize 10% as the average conversion efficiency from producers to primary consumers.

- In this ecosystem, all the gross production of the producers ultimately disappeared in respiration and downstream export and decay. There was no storage of energy from one year to the next. We now know this is typical of mature ecosystems.

Odum's Silver Springs numbers may be used to construct visually revealing ecological pyramids of energy (**Figure 3.6**) and biomass (**Figure 3.7**). A pyramid of numbers for one acre of prairie is depicted in **Figure 3.8**.

Figure 3.6 Silver Springs Energy Pyramid. All numbers are given in kilograms per square meter per year (Kcal/m2/yr).

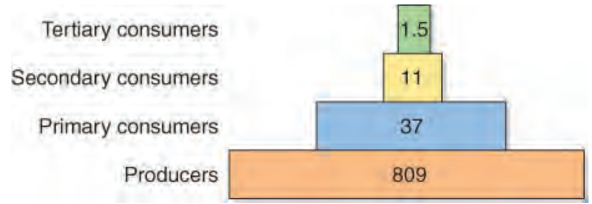

Figure 3.7 Silver Springs Biomass Pyramid. All numbers are an estimate of the dry weight of organic matter per square meter at the time of sampling.

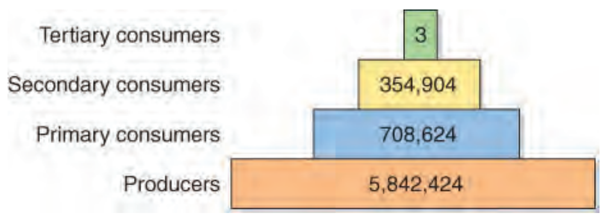

Figure 3.8 A Grassland Numbers Pyramid. All numbers are estimates of the population size of each trophic level on an acre of grassland.

Many ecosystems world-wide have been altered by humans through agriculture, mining, logging, and the construction of buildings and roads. In these disturbed ecosystems, the plants and animals of the original natural ecosystem may be found only in isolated pockets and patches. In their place humans have imposed economic and agricultural ecosystems.

> *A thing is right when it when it tends to preserve the integrity, stability and beauty of the natural community. It is wrong when it tends otherwise.*
>
> —Aldo Leopold

Ecology of Biomes

Biomes, the largest unit of the ecological hierarchy, are huge areas containing distinctive plant and animal groups which are adapted to the particular environmental conditions of a given area. Although terrestrial biomes are the most familiar and easily identified, ecologists also recognize aquatic biomes. Each biome consists of many ecosystems whose communities have adapted to the small differences in climate and other physical conditions within the biome.

Terrestrial Biomes

Terrestrial biomes are defined as large geographical areas defined by their climate, soil types, and characteristic vegetation. The North American continent holds examples of the major land biomes found around the world (**Figure 3.9**).

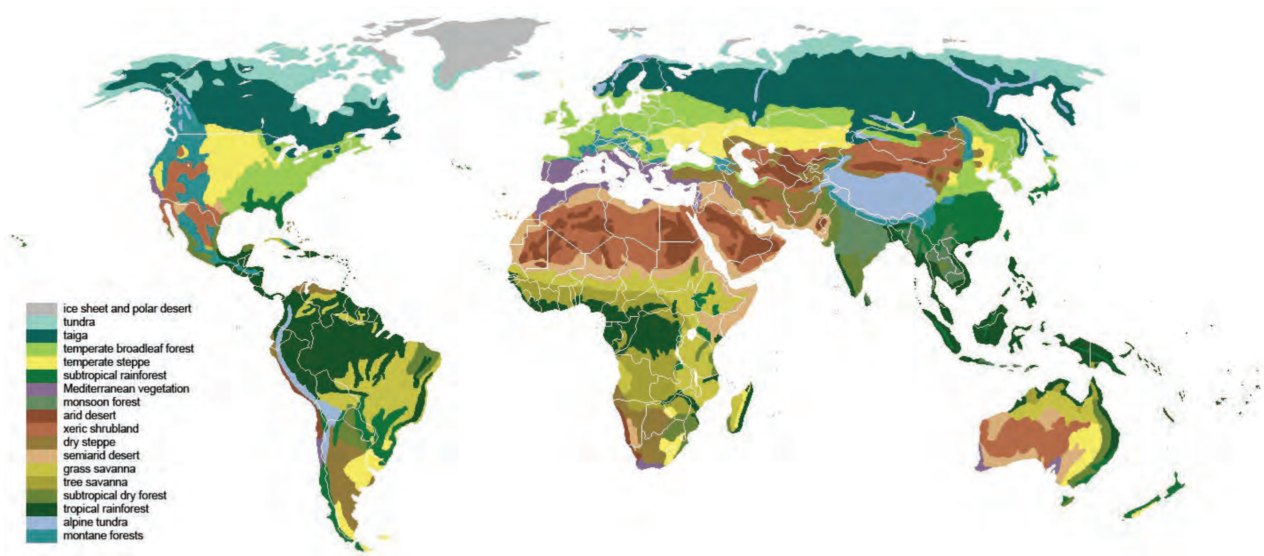

Figure 3.9 The major terrestrial biomes of the world.

Tundra. Arctic tundra encircles the earth south of the ice-covered polar seas in the Northern Hemisphere. Covering nearly 20% of the earth's land surface, it is a brutally cold realm that is characterized by long and even continuous darkness in the winter, but continuous light in the summer.

The tundra receives about 10-50 cm (4-20 inches) of moisture a year, mainly in the form of snow. In what passes for summer, the ground is covered with sedges and short-grasses with patches of lichens and mosses. Since the ground remains frozen (**permafrost**) except for the top several inches in the summer, large woody trees and shrubs cannot establish a foothold on the tundra. A few hardy animals, such as the lemming, ptarmigan, and musk-ox, live on the tundra year-round. The summer months may see the appearance of migratory creatures such as insects, waterfowl, caribou, reindeer, and wolves.

Taiga (Boreal Forest). The taiga, perhaps the largest of the biomes, is a wide band of coniferous forest that stretches across northern Eurasia and North America. The winters there are long and cold as evidenced by a yearly average temperature that ranges only from -5 to +3° C (23 to 37° F). The mean annual precipitation at less than 100 cm (40 inches) supports one of the largest plant formations on earth. The taiga is dominated by evergreen trees—pine, hemlock, cedar, fir, and spruce—which are adapted to withstand cold temperatures and heavy snowfall with their conical shape, needle-like leaves, and flexible limbs. Many herbivores, including hares, rodents, moose, elk, and deer, and such mammalian carnivores as wolves, foxes, wolverines, lynxes, weasels, martens, and omnivorous bears are adapted to year-round life in the boreal forests. Common birds include chickadees, nuthatches, warblers, jays, hawks, owls, and eagles.

In certain locations along the Pacific coast from Alaska down to California, the warm, moisture-laden winds off the Pacific Ocean drop large amounts of snow and rain providing enough moisture to morph what should geographically be taiga into a rare *temperate rainforest*.

Temperature Deciduous Forests. South of the taiga in eastern North America and most of Europe and eastern Asia are (or rather, *were*) great expanses of deciduous (hardwood) forests. Deciduous forests are associated with warmer continental and humid subtropical climates where the winters are mild and the summers warm. The 50-150 cm (20-60 inches) of precipitation is distributed throughout the year, and there is an approximately six month growing season.

Deciduous trees including oak, maple, beech, chestnut, hickory, ash, elm, and basswood, are those that drop their leaves with the onset of winter. Although the large hardwood trees dominate the forest in size and number, smaller plants form an **understory** (layers) beneath them. On sandy soils to the south and along the Gulf Coast, pines (softwoods) replace hardwood species. This is seen in the New Jersey pine barrens, the piney woods of the Deep South, and the tall, long-needled pines of Georgia and other areas of the Atlantic Coastal Plain.

Forest animals are herbivores such as deer, squirrels, and chipmunk, or omnivores including the raccoon, opossum, skunk, and black bear. Large carnivores have been mainly eliminated through the deliberate efforts of humans, but historically included wolves, mountain lions, and bobcats. Some birds—jays, woodpeckers, and chickadees—are year-round residents whereas insectivorous neotropical migrants such as warblers, wrens, thrushes, tanagers, and hummingbirds appear in the spring and depart in the fall. The milder winters also permit the year-round survival of salamanders, frogs, and other amphibians.

Temperate Grasslands. In the semiarid continental climates of the middle latitudes where the soil is rich but the summers hot and dry and only 30-90 cm (12-35 inches) of moisture is the norm, lie the temperate grasslands. Grasses are the dominant vegetation in these areas that are too wet to be a desert but too dry to support trees. Each continent has its own unique grassland system. In North America we have *prairies* (from the French meaning "a meadow grazed by cattle") whereas South America has its *pampas* and *savanna*. Central Eurasia is dominated by the *steppes* whereas Africa has the small *veld* and the larger *savanna*.

The North American prairie biome is composed of three ecosystems. These bands of grass stretch across the midsection of the continent from around western Indiana in the east to the Rocky Mountains in the west and from south-central Canada in the north to Texas and Mexico in the south.

Starting in the east and heading west, we first encounter the *tall grass prairie* ecosystem. Grasses, such as big bluestem, Indian grass and switch grass, receive enough moisture to grow up to six feet tall. These grasses grew so dense that historical accounts describe that when gentle winds rippled the top of the grass, it created the appearance of waves moving across the surface of an inland ocean of green, giving rise to the term *prairie schooner* to describe the wagons of early pioneers to the region. A profusion of perennial herbaceous forbs and wildflowers also dot the tall grass prairie. As we continue west, declining yearly moisture causes tall grass to give way to shorter grass in the *mixed grass* or *transitional prairie* ecosystem. As the designation implies, here we find a mixture of tall grass and short grass species with some forbs and wildflowers mingled in.

At the far western edge of the biome, we find the *short grass prairie* ecosystem nestled in the parching rain shadow of the Rocky Mountains. Semi-desert moisture conditions there permit the growth of only very short bunch grasses. Small herbivores including insects, rabbits, mice, ground squirrels, and prairie dogs, abound, but the large herds of bison and pronghorn antelope which historically dominated these ecosystems are all but gone. Prairie carnivores include snakes, hawks, owls, eagles, badgers, bobcats, coyotes, and foxes. As is so often the case, the large carnivores—bears, wolves, and mountain lions—that also once roamed the prairies have disappeared from their former range.

Wildfires were frequent visitors to the prairies in by-gone times. Ignited by lightning and driven by the relentless prairie winds, these fires would sweep majestically and rapidly across great swaths of the prairie. As contradictory as it sounds, prairie wildfires were not only beneficial, they were essential in maintaining the biological health of the prairie. Fire quickly recycled large amounts of stifling dead plant material into elemental compounds that could more easily be incorporated by prairie plants. Prairie plants and animals suffered little from such fires as they were adapted to them and depended upon them, especially the plants. However, the artificial economic and agricultural ecosystems humans have imposed on the former prairies are not fire friendly; as a result, the natural cycle of growth and fire on the prairies has been suppressed by humans.

Deserts. At around 30 degrees latitude north or south in the interior of the continents lie the world's great deserts. Deserts are dry places receiving less than 25 cm (10 inches) of moisture per year—an amount so low that vegetation is very sparse. In fact, the Sahara of Africa is almost totally devoid of any vegetation whatsoever. With few if any plants present and lacking cloud cover most of the time, temperature changes can be extreme with searing hot days followed by freezing cold nights.

The deserts of North America consist of the hot deserts of the southwest (which include the Mojave, the Sonoran, and the Chihuahuan) and rain shadow deserts created by various mountain ranges. Cacti, shrubs, and other desert plants have few or no leaves at all and other adaptations for dealing with little moisture. Animal life includes many insects, spiders and scorpions, lizards and snakes, rodents such as the kangaroo rat, birds including roadrunners, cactus wrens, vultures, and burrowing owls as well as coyotes, deer, peccaries, and rabbits.

Deserts are increasing in size. In the late 1800s, the amount of desert land on the earth was estimated to be around 9%. Today it is estimated to be 25% and climbing. The main culprits are thought to be extended droughts and overgrazing by livestock.

Chaparral. The chaparral (from the Spanish word meaning "small oak") is a shrubland ecosystem found primarily in California that is shaped and defined by a Mediterranean climate (mild, wet winters and hot, dry summers) and frequent wildfires. Scrub oaks and other low-growing drought resistant shrubs such as manzanita, ceanothus, chamise or greasewood, and mountain mahogany dominant the landscape, often growing so dense that they are all but impenetrable to large animals and humans.

Fire is a frequent visitor to the chaparral and the plants there and the seeds they produce are not only adapted to it but may actually require periodic burns every 10 to 15 years to maintain the ecosystem. As seems to be our need, humans have attempted to suppress wildfires in locations where settlement has encroached on the chaparral. In the face of low humidity, howling winds, and low plant (fuel) moisture, such efforts have failed time and again. In fact, the number of fires is increasing in step with human population growth pushing into the chaparral.

Tropical Forests. Aligned like a green belt along the equator where temperatures are constantly warm (20-25° C [68-77° F]) and rainfall plentiful (100 to 1000 cm [40 to 400 inches] yearly), are the tropical forests. This biome is a heterogeneous collection of several different types of forests.

- *Tropical rain forests* are found in South America, Africa, Indonesia, and New Guinea. Although rain forests now cover just 2 % of the globe, they are home to anywhere from half to two-thirds of all the living plant and animal species on the planet. It is not only the quantity of life, but diversity as well that makes the rain forests irreplaceable biological gems. Some of the strangest and most beautiful plants and animals are found only in the rain forest and this shady world may well hold hundreds of millions of new species of plants, insects, and microorganisms there still waiting discovery. According to a report by the National Academy of Sciences, a 1,000 hectare (4-square-miles) patch of rain forest can contain up to 1,500 species of flowering plants, 750 species of trees, 125 species of mammals, 400 species of birds, 150 species of butterflies, 100 species of reptiles, and 60 species of amphibians.

  Rain forests are organized into levels or layers (horizontal ecosystems) with an amazing number of plants and animals adapted for life in any particular layer. The canopy layer alone, by some estimates, may be home to 40% of all plant species and a quarter of all insect species on earth. A prospect that prompted American naturalist William Beebe to once declare that "another continent of life remains to be discovered, not upon the earth, but one to two hundred feet above it, extending over thousands of square miles."
- *Moist deciduous* and *semi-evergreen forests* are found in parts of South America, in Central America and around the Caribbean, in coastal West Africa, parts of the Indian subcontinent, and across much of Indochina. These forests experience a cooler winter dry season during which time many tree species drop some or all of their leaves.
- *Montane rain forests*, some of which are known as cloud forests, are found in mountainous areas with cooler climates.
- *Flooded forests* such as freshwater swamp and peat swamp forests, Brazil's Pantanal, the Amazon, and the Florida aquifer system.

Aquatic Biomes

Aquatic biomes may be classified as marine (saltwater) or freshwater. There are also some **estuary ecosystems** near the ocean where the freshwater from the land and the saltwater from the ocean mix producing brackish conditions. Some marine ecosystems, such as coral reefs and estuaries, are exceptionally productive and account for approximately 50% of the earth's primary biological productivity. Because the turn over rate is so high in aquatic systems, they produce about three times more animal production than do terrestrial systems.

Marine ecosystems. The marine biome consists of three major ecosystems: (1) the neritic zone, the shallow coastal waters, (2) the pelagic zone, the open waters above the ocean floor, and (3) the benthic zone, the actual seafloor (**Figure 3.10**).

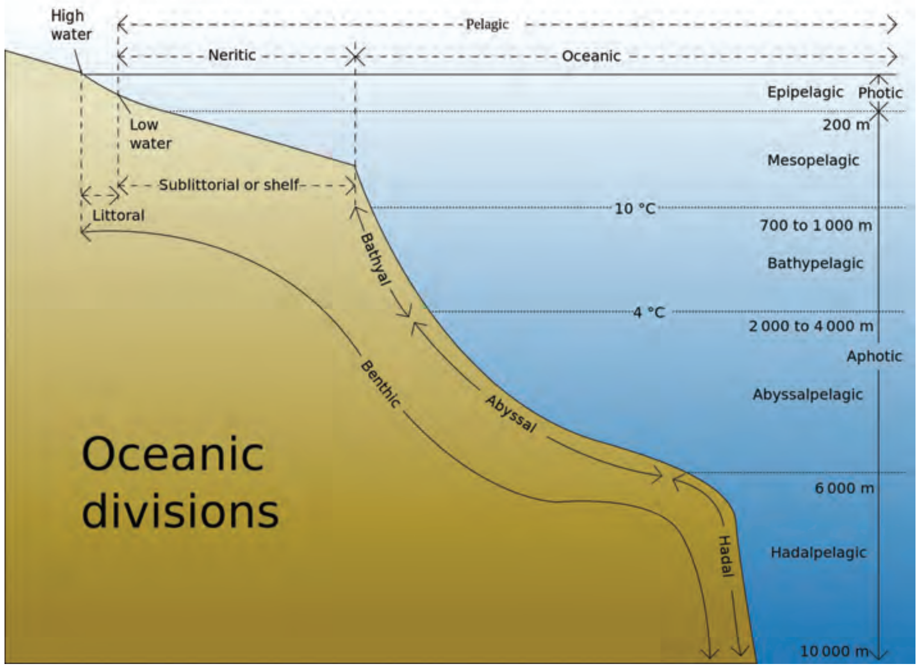

Figure 3.10 Oceanic ecosystems.

Where the ocean meets the land, we find the **intertidal** or **littoral region** of the neritic zone. Slammed by waves and exposed to air during low tides, this region is a very hostile environment where only the most highly adapted plants and animals can survive.

The **neritic zone** extends from the low-tide line outward to the edge of the continental shelf and reaches depths of around 200 meters (656 feet). Low water pressure, a fairly stable temperature, and an abundance of light for photosynthesis make this zone rich with life. In fact, the neritic zone together with estuaries account for essentially the total productivity of the ocean as evidenced by the fact that all the world's great commercial fishing areas are located in the neritic zone.

Beyond the continental shelf is the open ocean or **pelagic area**. This area contains a number of recognized subzones characterized mainly by their depth:

- *Epipelagic zone* reaches downward to around 200 meters (660 feet) below the surface. This sunlit layer contains practically all the life forms associated with the open ocean and is the home of the primary producers that support all the other living things in this region—microscopic organisms called **phytoplankton**. What phytoplankton lack in size they make up for in numbers, for collectively, these tiny green specks account for about 40% of all the photosynthetic productivity that takes place on the entire planet.
- *Mesopelagic zone*, extending downward from 200 m down to around 1000 m (3300 feet). This region of perpetual twilight is home only to a few animals such as luminescent shrimps, squids, and some fishes.
- *Bathypelagic zone*, from 1000 m down to around 4000 m (13,200 feet). a region of total and never-ending blackness characterized by near-freezing water temperatures, low oxygen, and crushing water pressure. The few animals that live here are delicate, colorless, and usually blind. Most

survive by consuming the snow of **detritus** drifting down from the zones above, but some do prey on others. The legendary giant squid live at this depth where they are occasionally visited by deep-diving sperm whales that hunt them.

- *Abyssopelagic zone*, from 4,000m to just above the seafloor. From the Greek *abyss*, meaning bottomless, a holdover from the times when the deep ocean was thought to have no bottom. The few animals that survive here are delicate, colorless, and often blind.
- *Hadalpelagic zone* is the designation for ocean trenches, the deepest part of the marine environment. This zone extends from a depth of around 6,000 meters (20,000 ft) to the very bottom of a trench.
- *Benthic zone* is the actual seafloor and as with the land, it can be divided into smaller specific ecological zones. At ocean's edge we find the intertidal zone of rocky and soft bottom beaches, mudflats, and sand flats. Moving on out and deeper we encounter either the rocky subtidal zone that is home to kelp forests and coral reefs or the soft bottom subtidal zone where we find habitats such as estuaries, salt marshes, mangrove swamps, and sea grass beds. Starting at the base of the continental slope and rolling on for thousands of miles we find the flat **abyssal plains** of the deep sea floor. The deep sea floor itself is a thick blanket of mud and decaying matter (**ooze**) that have settled down from above and accumulated over millions of years. The crushing water pressure, near-freezing temperatures, velvet blackness, and seeming lack of food led to the belief that nothing could live on the deep seafloor. However, as technology has improved, and biologists have been able to better survey this region, it appears that the number of species living in this alien domain is quite high.

Freshwater Ecosystems. The lakes, ponds, rivers, streams, and wetland swamps and marshes that comprise the freshwater biome are scattered about and occupy a far smaller portion of the planet than either terrestrial biomes or the marine biome. Lakes and ponds cover about 2% of the earth's surface whereas streams and rivers cover about 0.3%.

Large standing bodies of freshwater are called lakes whereas smaller ones are referred to as ponds. Like the ocean, lakes and ponds have three zones (**Figure 3.11**). The **littoral zone** is the shallow edge around the shore where water meets land. The **photic** or **limnetic zone** is the open water from shore to shore and down as far as light penetrates. The **aphotic** or **profundal zone** is area below the limits of light penetration.

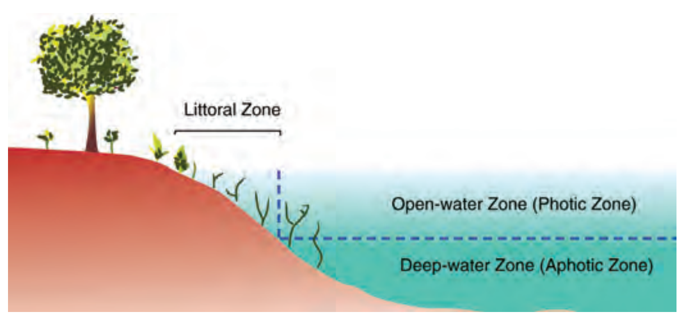

Figure 3.11 Biotic zones found in lakes and ponds.

Unlike the ocean, large temperate lakes undergo seasonal mixing of their zones in a process known as **overturn**. In the late fall, the upper layers become colder and thus denser than the warmer lower layers. This causes the surface waters to sink resulting in a displacement of the deeper layers—fall overturn. In spring, ice that formed on the lake over the winter melts and this cold water sinks below the warmer water in the lower zones again resulting in a rise of the deeper layers—spring overturn. Overturn occurs in temperate lakes but usually not in tropical ones.

In terms of productivity, fast-moving streams are the least productive of the various freshwater ecosystems. The moving water washes away the plankton and the only photosynthesis that supports the system is limited to attached algae and rooted plants along the stream margins.

Lakes can be divided into two categories based on productivity: **eutrophic lakes** and **oligotrophic lakes**. Eutrophic lakes contain an abundant supply of organic matter and minerals and support a rich variety of aquatic life. In oligotrophic lakes, organic matter and mineral nutrients are scarce. Such lakes are often deeper than eutrophic lakes and due to a lack of biological activity, they tend to have very clear, blue water.

Swamps, marshes, bogs, and other wetlands are among the most productive ecosystems on the planet and may be thought of as the freshwater equivalent to terrestrial rain forests and marine coral reefs in that regard. Most lakes are far less productive being limited by a lack of nutrients. Wetlands also play a key role ecologically by providing water storage basins that moderate flooding. Wetlands, however, suffer from the mistaken perception that these areas are useless and unproductive land and as such, they have been and continue to be seriously disrupted and eliminated by human "development."

Planet in Peril

Ecologists define an ecological crisis as a situation in which a species' adaptive capabilities can no longer keep pace with changes in its environment resulting in extinction of that species. Ecological crises may be local or global and last only a few months to millions of years. From the fossil record paleontologists know that world-wide ecological crises resulting in mass extinction has occurred at least five and as many as nine times in the history of the planet. The worst of these mass extinction events seems to have been the "Great Dying' that occurred around 251 million years ago as the Permian Period transitioned into the Triassic Period. During this time, an estimated 70% of all land species and 96% of all marine species became extinct.

A number of hypotheses have been advanced to explain these mass extinction events:

- Massive and sustained volcanism
- Sea-level rise and fall
- Asteroid and/or comet impacts
- Sustained global warming or cooling
- Oceanic overturn
- Nearby nova, supernova or gamma ray bursts
- Continental drift

A survey by the American Museum of Natural History found that 70% of biologists view the present geologic era as part of a human-induced mass extinction event, possibly one of the fastest ever. This present-day ecological crisis has been dubbed the *Holocene extinction event*. Harvard University biologist E.O. Wilson predicts that human destruction of the biosphere could cause the extinction of one-half of all species within the next 100 years.

Since the beginning, each generation has fought nature. Now, in the life-span of a single generation, we must turn around 180 degrees and become the protector of nature.

—Jacques-Yves Cousteau

What environmental challenges do this planet and its inhabitants face?

Pollution

Many chemicals released into the air, water, and soil by agriculture, industry, and domestic use are toxic to varying degrees and often persistent. These chemicals threaten not only the health of the biosphere but human health as well.

Unfortunately, as some of these toxic chemicals pass through the food chain they become increasingly concentrated in a process called **biological magnification**. The very symbol of our nation, the bald eagle, was nearly exterminated in the late 1960s when it was discovered that the insecticide DDT was magnified in many bird species, especially predator birds. The DDT caused the production of thin, fragile eggshells resulting in the eggs being easily broken. Although DDT was banned from production and sale (at least in this country) in time to save the birds from extinction, it and many other toxic chemicals no longer manufactured still persistently circulate in the ecosystem.

Ozone Hole

The "ozone hole" first appeared over Antarctica in 1975 and each year since, the layer of ozone is thinner and the hole larger. **Ozone** (O_3) is a form of atmospheric oxygen that blocks deadly ultraviolet radiation from the sun. The major factor in ozone depletion is the release of chlorofluorocarbons (CFCs), chemicals used in cooling systems, fire extinguishers, and Styrofoam containers. The CFCs percolate up through the atmosphere and reduce the O_3 form of oxygen to O_2 rendering it ineffective at blocking UV radiation.

Ultraviolet radiation is a serious human health concern. Every 1% drop in atmospheric ozone is estimated to lead to a 2% increase of UV light making it through to the surface which in turn could result in a 6% increase in the incidence of skin cancers. Furthermore, UV radiation has the potential to inflict radiation damage on many animals and could cause disruption of oceanic food chains given the sensitivity of plankton to such radiation.

Global Warming

Glaciologists tell us that by definition, the planet is still technically in an ice age due to the continued presence of large ice sheets both in the Arctic and Antarctic regions. Imbedded within this ice age have been dramatic shifts in the global climate system from warm **interglacial periods** to cold **glacial periods** and back again with the last cold glacial period ending about 12,500 years ago. Modern history and civilization as we know it have developed during the present warm interglacial period.

These interglacial-glacial-interglacial climate oscillations seem to have been occurring for the past 900,000 to 1,000,000 years as part of the current ice age. Clearly the earth has been warming and cooling as a part of a very long-term cycle. As debate rages and disagreement swirls around us regarding global warming, one must not lose sight of the fact that the global warming issue is about the answers to two basic questions: (1) Have human activities accelerated the natural warming of the present interglacial period? And if so, (2) what might be both the short-term and long-term consequences of such human-accelerated global warming?

Why are many scientists and governments so concerned? What is the compelling evidence that human activities are warming the planet?

- The temperature of the troposphere—the thick layer of atmosphere hugging the planet—and land surface are warming, whereas the stratosphere—the layer above the troposphere—is cooling. This has been interpreted as a sign that greenhouse gases are trapping energy and keeping that energy close to the surface of the earth. The Intergovernmental Panel on Climate Change predicts global temperatures are most likely to rise between 3.2 and 7.1 degrees Fahrenheit (1.8 and 4 degrees Celsius) by the year 2100. However, global temperatures during the **Paleocene-Eocene Thermal Maximum** (PETM) some 55-65 million years ago were much warmer than those presently and those predicted for the next century. At the height of the PETM, sea surface temperatures in the oceans rose 9 degrees F (5 degrees C) in the tropics and 11 degrees F (6 degrees C) in the Arctic. The oceans became more acidic, and 30 to 50 percent of the sea floor life went extinct.
- Although the temperature of the planet has fluctuated in the past, it got warmer or cooler over millions of years. What seems apparent is that we are seeing rates of increase in warming that exceed past natural rates by a factor of 100. Thus, humans may be doing in centuries what natural processes do over millions of years. But this begs the question—How do you accurately take the temperature of the entire planet both from the past and during the present?
- Both poles are getting warmer; in Greenland and Antarctica the surface of the ice is dropping, and there is less mass when the ice is measured from space. We know that the ice sheets have come and gone in the past. Why is this any different? The worrisome reason is that in the past, the ice sheets from the two poles didn't move together—one would lead and the other would follow. Presently, both the north and south icecaps are spewing ice into the global ocean and seem to be in an accelerating decline at the same time.
- Sea levels are on the rise. Have sea levels ever been as high as they are now? Yes, roughly 35,000 years ago. A few thousand years later, sea levels began to drop and by about 15,000 years ago, the oceans had declined by almost 500 feet. Then they started to rise and sea levels have slowly been going up ever since.
- Thanks to bubbles of ancient air held in deep ice cores, we know there has been a disturbing increase since the mid-20th century of the so-called **greenhouse gases**, predominantly carbon dioxide but also methane, nitrous oxide, and hydrofluorocarbons in the atmosphere. These gases are easily measured and the scientific community seems in agreement that not only are these gases increasing in concentration (being up around 35% since the beginning of the Industrial Revolution) but that they seem to be increasing at an alarming pace. Aside from the physiological processes of animals, greenhouse gases are released in the greatest amount by the burning of fossil fuels and clearing the land for agriculture. Increases in these gases are thought to lead to the

warming of the surface of the planet as well as the lower atmosphere by increasing the **greenhouse effect**.

- Ocean chemistry is changing. When carbon dioxide dissolves in seawater, it forms carbonic acid, and in high enough concentrations carbonic acid is corrosive to the shells and skeletons of many marine organisms. If our current trends in burning fossil fuels and generating carbon dioxide continue, the ocean will become more acidic than at any time in the past 65 million years back to the PETM. At that time, high ocean acidity levels are thought to have been one of the contributing factors to a mass extinction event.

The probability and extent of **anthropogenic warming** (human-caused warming) and the future consequences of such planetary warming have become a very controversial and contentious issue worldwide. Multitudes of climatological investigations and observations both ground-based and from satellites have been and continue to be conducted. Data and observations from such studies are then fed into various computer climate models to search for trends and patterns and to predict future outcomes. A great many in the media and popular press have chosen to interpret these data, observations, and climate model results as supporting and verifying an impending global climate catastrophe. In what critics have dubbed the "Chicken Little Approach," these sources then bombard the public almost daily with visual and commentary doom-and-gloom linking possible anthropogenic global warming to melting glaciers, rising sea-levels, drought, wildfires, loss of habitat and diversity, seemingly wild swings in weather patterns, and a host of other perceived planetary ills.

Not only has this issue been popularized, but it has also been politicized. Government leaders of most industrialized countries and the United Nations have chosen to follow the lead of the popular press and conclude humankind faces an inevitable and catastrophic global climate shift. This interpretation of the many climatological studies and computer climate models serves as the driving force for proposed changes in governmental policies, procedures, and laws worldwide. But are these near-hysterical media prophecies and planned profound changes in governmental policies worldwide based on sound science? Critics contend that not only is the popular press behaving irresponsibly but that governments are headed down a path that will result in hundreds of billions to trillions of dollars being spent worldwide in planetary temperature abatement schemes with entire industries possibly laid waste, and even personal freedoms curtailed for no sound scientific reason.

The whole issue of anthropogenic warming and the possible catastrophic climate changes associated with it seem to have become what some have labeled as a "secular religion." And to disagree with its rigid interpretation that a global climate catastrophe is inevitable unless humanity changes its ways, is to be labeled a heretic. However, contrary to what you may have been led to believe, the scientific community worldwide is not unanimously in consensus on the subject of whether anthropogenic warming is actually occurring. In fact, a recent Senate Minority Report reveals that over 700 dissenting scientists from around the globe challenged human-caused global warming claims made by the United Nations Intergovernmental Panel on Climate Change (IPCC). In 2007, the number of dissenting scientists was listed at around 400 worldwide.

Can humankind afford the luxury of waiting for definitive answers to our global warming questions? Dare we wait? But even if through draconian measures we were to roll global emissions of greenhouse gases back to year-2000 levels, would it make any difference? System science such as is being applied to the global warming issue is very complicated because there are multiple possible outcomes. Scientific assessment of the situation requires understanding the relative likelihood of each of these outcomes. From that a value judgment about whether or not the risks are high enough to demand action. (Risk is what can happen multiplied by the probability of it actually happening.) Once science makes the risk levels clear, the risk management will fall to the will of the public and the politicians. As individuals and as a species we should carefully ponder and heed the words of Ken Caldeira when he states:

> *We are at a critical juncture in earth history. If we don't do the right thing and there are geologists around 50 million years from now, they'll be able to look at cores and see the remnants of a civilization that developed advanced technology but didn't develop the wisdom to use it wisely.*

Habitat Destruction

Habitat destruction results when one habitat type is removed and replaced with another habitat type. In the process, plants and animals which previously used the site are displaced or destroyed resulting in an alteration or reduction in the **biodiversity** (the number of different species of plants and animals) of the area involved. Fires, floods, and volcanoes are natural forces that may cause destruction of habitat but the most devastating and widespread demolition of ecological systems is perpetrated by human activities such as land clearing, development and agriculture. The most biologically productive areas are often the hardest hit. Consider that just a few thousand years ago rain forests flourished and formed a wide green belt around the equator. These magnificent verdant gems covered 14 percent of the planet's land surface, or around 2.1 billion hectares (8.2 million square miles). Humans have already destroyed more than half of this forest area, with most damage occurring in the last 100 years. With just 647 million hectares (2.5 million square miles) remaining, we continue, in our ignorance and apathy, to eradicate an estimated 150,000 square km (93,000 square miles) a year. As a result, experts predict that within only a few decades, there will be little undisturbed tropical forest left anywhere in the world.

The North America prairies once blanketed about 363 million hectares (1.4 million square miles) across the center of the continent. World-wide the rich fertile soil that characterizes grasslands has been their undoing, especially in North America. Now, instead of an ocean of grass stretching from horizon to horizon, cultivation or herds of grazing cattle reach as far as the eye can see and the wildflowers that once dotted the prairies have been replaced by towns, cities, and roads. The prairie that was exists for the most part in only small isolated patches accounting for only 1 to 2% of its former greatness. In its place humans have imposed an artificial ecosystem—the **agroecosystem**. Sadly, global wetlands and coral reefs are meeting the same fate and face the same dismal prospects for long-term sustainability.

A Closing Note
For the Frogs, the Icecaps, and the Rain Forests

With its bright red eyes and toes, green body, and bluish limbs, the red-eyed tree frog is my favorite animal. Truth be told, I have a soft spot in my heart for all things amphibian. That is why continuing global amphibian studies are increasingly distressing to me. At least 32 amphibian species have gone extinct in recent years, and at least another 26 are "missing," not having been seen for many years. The island nation of Sri Lanka has lost as many as 100 species in less than a decade, news that is not all that surprising given that 95% of that nation's rain forests have also disappeared in recent times.

Unfortunately, what is happening to amphibians is but one sad and distressing example of what is happening in general to our planet and the creatures that inhabit it. We all get a nearly daily dose of environmental doom-and-gloom from the media, and I don't mean to add to that,.but what clear-thinking and reasonable person can continue to be bombarded by environmental horror stories without becoming at least mildly concerned about the global environment? However, concern is one thing but acting on those concerns is quite another and many, if not most, people wring their hands in worry with good intentions in their heart but in the end continue to sit on the sidelines and do nothing. Why? Because people are frozen into inactivity in the face of the enormity and complexity of the global environmental problems we and all other life forms face. As individuals, these problems seem too much to bear, let alone solve, so we are content to blame industry or agriculture and wait for the government to do something.

This attitude of inactivity and apathy must change, and there are hopeful signs that more and more people world-wide are beginning to understand that. These are not top down problems, and the solutions to these problems will not shower down on us from above. Rather, meaningful solutions and positive environmental actions will come from people, from the bottom up. What's that you say? You think anything you could possibly do on your own would only amount to a drop in the bucket? It is understandable that you feel that way, but consider this—what is the ocean but a bunch of individual drops put together? There *are* things you can practically and realistically do to make an environmental difference. Research it. Find out what those things are and do at least one or some of them with confidence and pride. Plan your work and then work your plan and let this be your credo (with apologies to the original author who is unknown to me):

> *I am only one, but I am one.*
> *I cannot do everything, but I can do something.*
> *That which I can do, I will do***.**

You have the power to be *One*, we all do. Will you accept the challenge and convince others to do the same? I hope so, not only for the sake of the red-eyed tree frogs, the polar bears, the whales, and the elephants but for all our sakes.

In Summary

- Planet Earth is perfectly constructed with a dynamic physical structure capable of supporting life. Furthermore, it is perfectly positioned from the sun to benefit from the sun's radiation without being destroyed by it.
- At the ecosystem level, ecologists study the interactions between living things and the physical environment in an attempt to understand how biogeochemicals and energy circulate through the system.

- Ecosystems come in several sizes: Macroecosystems are quite large (e.g. the North American deciduous forest), mesoecosystems are medium to small (e.g. a meadow clearing in a forest), and microecosystems are small to tiny (e.g. life under a rotting log in a forest).
- The most important biogeochemical cycles are: the water cycle, the carbon cycle, the nitrogen cycle, the oxygen cycle, and the phosphorous cycle.
- Earth is a closed system when it comes to biogeochemicals but an open system when it comes to energy and energy flow.
- Organisms from different trophic levels feed on each other in sequence forming a food chain (what does eat what). Overlapping and interlocking food chains form food webs (what could eat what).
- Photosynthetic organisms (autotrophs or producers) are the first trophic level. The producers are fed on by the primary consumers (herbivores) which in turn are fed upon by the secondary consumers (carnivores). Omnivores eat both plant material and flesh whereas saprotrophs (scavengers and decomposers) eat dead organisms or the waste given off by living organisms.
- Biological systems are not very efficient. Only about 1% of the solar energy that strikes photosynthetic creatures is converted into food molecules. Much energy is also lost as heat as it flows from one trophic level to the next.
- Ecologists employ a number of different ecological pyramids to graphically represent the relationship between energy and trophic levels of a given ecosystem—biomass pyramids, numbers pyramids, and energy pyramids.
- Biomes are the largest unit of the ecological hierarchy. Biomes are very large areas consisting of many interlocking and overlapping ecosystems. There are two main categories of biomes: terrestrial and aquatic.
- Many species on this planet are in peril of perishing in an ecological crisis that has been dubbed the Holocene extinction event. The factors driving this crisis are directly or indirectly tied to the global activities of humans.

Review and Reflect

1. ***What's in a Quote?*** Provide the ecological details that would explain the Taos Pueblo Indian poem that opens this chapter.
2. ***Spaceship Earth***. Ecologically speaking, our planet has often been described as "Spaceship Earth." Is this indeed the case? Compare and contrast the Earth to the International Space Station.
3. ***Scourge of the Ragu***. The evil Ragu from the planet Remlac wish to destroy all animal life on earth. They do not wish to attack in a direct and costly frontal assault militarily. Rather, they wish to destroy slowly, quietly, and undetected.

   Imagine you are Beldar from Remlac. You have been sent by the Ruling Council of High Ragu to destroy all animal life on earth by disrupting the biogeochemical cycles that regulate and replenish life on this planet. As you sit in your hidden base on the far side of the moon, you possess the technologies to do whatever you wish to any biogeochemical cycle. What cycles would you attack, why would you attack those particular cycles, and how would you attempt to disrupt those particular cycles?

4. ***The Dance of Death***. The graph shown in **Figure 3.12** illustrates a hypothetical relationship between a predator, such as a fox, and its prey, such as rodents. Analyze the graph and answer the questions that follow:

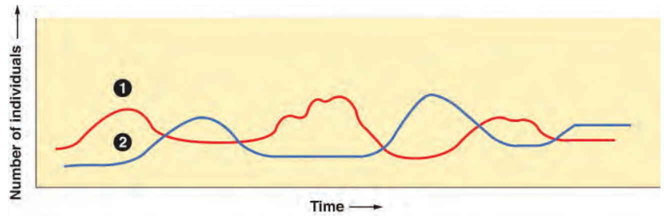

Figure 3.12 A hypothetical predator-prey growth graph.

A. Which line represents the predator and which line represents the prey? Defend your answer.
B. These hypothetical populations are not in sync but neither are such interacting populations in the real world. Why not?
C. If the prey population were to decrease to zero, what would happen to the predator population and why?
D. If the predator population were to decrease to zero, what would happen to the prey population and why?
E. Which population regulates the other? Explain.

5. ***Webs and Pyramids***. Select any ecosystem—terrestrial, marine, or freshwater—of your choice. Prepare a small food web of organisms that inhabit the ecosystem you selected. From your food web then construct both an ecological pyramid of numbers and an ecological pyramid of energy.

Create and Connect

1. ***Alien Realms***. In regions of the deep sea, several strange almost alien ecosystems have been discovered—**hydrothermal vents** and **cold seeps** (sometimes called **cold vents**). Although the physical conditions in and around hydrothermal vents and cold seeps is very different, they are similar in that they are the only ecosystems known that do not depend on photosynthesis for food and energy production.

   Write a short report in which you compare and contrast the physical characteristics of hydrothermal vents and cold seeps and the unique living communities that have developed around each.

Guidelines:

A. Format your report in the following manner:

- *Title page* (including your name and lab section)
- *Body of the Report* (include pictures, charts, tables, etc. here as appropriate). The body of the report should be a minimum of two pages long—double-spaced, 1 inch margins all around with 12 pt font.

- *Literature Cited* A minimum of two references required. Only one reference may be from an online site. The *Literature Cited* page should be a separate page from the body of the report and it should be the last page of the report. Do NOT use your textbook as a reference.

B. The instructor may provide additional details and further instructions.

2. ***A Union Dispute***. What if species formed unions? Imagine that both the union representing predatory species and the union representing prey species are demanding a very large increase in their respective populations. Other groups, such as parasites, are also demanding a seat at the negotiating table. You have been assigned to mediate this dispute. What would your decision be?

3. ***A Local Problem***. Environmental problems and concerns are not far removed from your personal life as you might think or wish them to be. Regardless of how enormous global environmental problems might seem, communities and individuals can and are making a difference. The key is to "Think global but act local." In this investigation, you will evaluate environmental problems in and around your local community and determine the efforts being made by the community to deal with those problems.

Guidelines:

A. Select 1 or more *local* environmental problems you wish to investigate.
B. Prepare a chart listing specific examples of the problem(s) you have chosen to investigate.
C. Collect as much information as possible about each problem and the measures, if any, which have been or will be taken to address those specific problems. As part of this process, you should contact community government officials.
D. Use the Problems Points chart (**Table 3.2**) to rate each environmental problem you investigate.

Table 3.2
Problem Points

Problem Points	Guidelines
0	No problem locally
1	Few mild problems
2	Some problems that could become significant
3	Moderate problems with the potential to become hazardous
4	Severe problems, becoming hazardous
5	Critical problems, hazards existing

E. Use the Solution Points chart (**Table 3.3**) to rate your community's past and present efforts to deal with each problem you investigate.

Table 3.3
Solution Points

Solution Points	Guidelines
0	No pollution awareness or antipollution actions
1	Some community awareness; no community action or legislation
2	Definite awareness, citizens groups; some movement toward legislation
3	Strong awareness; much discussion and news coverage; legislation in process
4	Strong public and private community awareness; legislation in place
5	Community organized to deal with and prevent pollution; legislation enforced

F. Once you have prepared your charts use them to answer the following questions:

a. What environmental issues does your community deal with effectively and what issues are they neglecting or not dealing with effectively?

b. Solution of community environmental problems depends on a triumvirate of community awareness, political action, and individual responsibility. Explain and give an example of each of these pieces to the solution of environmental problems.

c. What suggestions might you offer to reduce or eliminate the environmental problem(s) you investigated?

4. ***Small but Powerful***. It has been said, “We don’t inherit the earth from our ancestors; we borrow it from our children.” This solemn statement begs the question—what can each of us do personally to preserve the purity of this planet and the sanctity of the living things that inhabit it? (See *Closing Note* at the end of this chapter) Identify an environmental issue(s) around your home or on campus and then devise a practical and workable plan to help reduce or eliminate the problem(s). Plan your work then work your plan. HINT: Keep it simple. The simpler your plan, the more likely you are to actually implement it and the more effective your plan will be if and when you do implement it. Remember…You *can* make a difference!