ENVIRONMENTAL STUDIES

The Earth as a Living Planet

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for Erene and Jackie

Preface

The field of environmental studies integrates many disciplines in the study of our environment. It includes some of the most important applied topics of modern civilization as well as some of the oldest philosophical concerns of human beings—that is, the nature of our relationship to our surroundings. Both applied and basic aspects require a solid foundation in the natural sciences (including biology, geology, geography, oceanography, soil science, hydrology and climatology). We must also be aware of the cultural and historical context in which we make decisions about our environment and understand the ways in which choices are made and implemented. Thus, the field of environmental studies integrates the natural sciences with environmental ethics, environmental economics, environmental law, and planning. *Environmental Studies: The Earth as a Living Planet* attempts to examine the entire spectrum of relationships between people and environment. Because this text is an introduction to environmental studies, you do not need any prerequisites in the sciences or humanities.

The text is divided into three parts. Part One introduces the fundamental principles of environmental studies and examines the physical and biological processes so important to global, regional, and local ecology and geology. In Part Two we discuss the Earth's major resources, including the atmosphere, water, minerals, energy, and biological materials. Part Three examines aspects related to people in the environment—natural hazards, environmental ethics, environmental planning, the urban environment, and environmental law.

Successful completion of this text would not have been possible without the cooperation of many individuals. To all those who so freely offered their help in this endeavor, we offer our sincere appreciation. We wish to thank the following people for their constructive comments in reviewing the manuscript: Stanley Awramik, University of California, Santa Barbara; Charles Beveridge, Frederick Law Olmstead Papers, Department of History, American University; John B. Conway, Washington State University; Ira C. Darling, University of Maine; Margaret B. Davis, University of Minnesota; Anthony Dominski, University of California, Santa Barbara; Lon D. Drake, University of Iowa; Robert N. Ford, Millersville State College; Charles A. S. Hall, Cornell University; Robert E. Hennigan, State University of New York, Syracuse; Jean Hitzeman, State University of New York, Brockport; Sally J. Holbrook, University of California, Santa Barbara; Katherine Keating, Rutgers University; Lynn Margulis, Boston University; Eugene W. McArdle, Northeastern Illinois University; Mark McGinnes, Environmental Defense Center, Santa Barbara; Harold J. Morowitz, Yale University; Roderick Nash, University of California, Santa Barbara; Erene V. Pecan, Santa Barbara Institute for Environmental Studies; Richard C. Pleus, University of Minnesota; Tad E. Reynales, University of California, Santa Barbara; Donald L. Rice, State University of New York, Binghampton; Robert J. Robel, Kansas State University; Dorothy Rosenthal, University of Rochester; Alfred Runte, University of Washington; Jon Sonstelie, University of California, Santa Barbara; Oscar Soulé, Evergreen State College, Olympia, Washington; Alfred Suskie, Mohawk Valley Community College, Utica, New York; Frederick R. Swan, West Liberty State College; Laurence C. Walkter, Stephen F. Austin State University.

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Contents

The study of our environment has expanded rapidly in recent years. Although this study is one of the oldest interests of human beings, it can also be considered one of the newest.

Like other living creatures, human beings live in, depend on, and influence the environment. Thus every human society has beliefs, myths, and attitudes about the environment. Our rapidly expanding technological civilization creates new demands on all aspects of the environment. Because more people are alive today than have ever lived on the Earth at one time, we are using more resources more rapidly than any civilization has used before. We also produce more wastes more rapidly than any previous civilization.

Human beings affect the environment in many ways. Chemicals produced in the United States have been found throughout the oceans and in Antarctic creatures; burning of fossil fuels has increased the carbon dioxide concentration of the atmosphere; industries spew smoke that makes lakes acid, kills fish, and leaves toxic metals on the soil, killing trees. As we change our use of the land, we alter the nature of soils, sediments, and waters, and we increase the rate of extinction of species.

PART 1

Environment and Life: An Introduction to Natural Processes in the Biosphere

Along with these negative effects, modern civilization has made the environment more liveable in many ways. Since the invention of soap and the first understanding of modern medicine, we have developed better health care, and consequently people are healthier. We have learned to feed more people better than ever before, and more of us can travel further to see national parks and enjoy outdoor recreation than was possible in the past. In recent years, we have learned to live in closer harmony with our environment. For example, we are learning to control pests in a more benign manner than before.

Whether the positive benefits of technology outweigh the negative ones in the long run is an open question. We have many choices, but these choices can lead us in one of two directions. We can move forward to a future in which we live in harmony with our environment, maintaining our renewable resources and conserving and re-using our nonrenewable ones. Or, we can act in ways that will lead to an impoverished landscape, with its problems of pollution, the loss of resources, the exhaustion of soils, forests, and fisheries, and the extinction of many important species. Our choice of direction depends in part on our knowledge and understanding of the environment and in part on our *values*. This is why environmental studies must be seen as a broad and interdisciplinary field encompassing a range of activities—from biological and geological research to environmental ethics, planning, and environmental law. All of our social actions and decisions in regard to the environment require an understanding of basic principles. In Part One we will introduce these basic principles.

Chapter 1 sets down 13 fundamental principles of environmental studies which provide a set of themes for the entire book. You will find it useful to refer to these as you read later chapters.

Chapters 2 through 7 introduce fundamental scientific concepts necessary for the study of the environment. Chapters 2 and 3 consider the biosphere—the place where life exists on our planet. In Chapter 2 we examine climate, weather, geology, and soils, and in Chapter 3 we consider the living part of the biosphere.

In Chapters 4, 5, and 6 we present the basic principles of ecology, the study of the relation between living organisms and their environment. Chapter 4 examines populations, and Chapter 5 covers ecological communities and ecosystems—collections of populations functioning together in an environment. In Chapter 6 we consider the geography of life and the factors that influence the distribution of living creatures on the Earth's surface. There are somewhere between 3 and 10 million species on our planet. Our inability to estimate this number with any greater accuracy shows the complexity of the biosphere and our current state of knowledge.

Chapter 7 introduces the study of human populations. We examine the history of human beings on Earth and the species *Homo sapiens* as an ecological factor. The principles of ecology discussed in Chapters 4, 5, and 6 help us to understand the issues that confront our species within an environment.

Part One provides a foundation on which you can build your own ability to decide what is important in the environment and what we should do to best live within our environment, both local and global.

1 Fundamental Principles

In this chapter we introduce concepts basic to the study of the environment. Although these concepts do not constitute a complete list, they do provide the philosophical framework of this book. The concepts are not to be memorized. Rather, you should understand the general thesis of each concept to help you comprehend the material throughout the remainder of the text.

CONCEPT 1

The Earth is the only suitable habitat we have, and its resources are limited.

The Earth began approximately 4.6 billion years ago when a cloud of interstellar gas known as a solar nebula collapsed, forming protostars and planetary systems. Life on Earth began approximately 2 billion years later and since that time has profoundly affected our planet. Since the evolution of first life, many kinds of organisms have evolved, prospered, and died out, leaving only their fossils to record their place in the Earth's history. Several million years ago, our ancestors set the stage for the eventual dominance of the human race on Earth. It is certain, however, that our sun will eventually die. Then we too will disappear, and the impact of humanity on Earth history may not be particularly significant. However, to us living now and to our children and theirs, our environment is very important.

The Earth is a dynamic, evolving system in which material and energy are constantly being transferred and changing in form. The Earth, with respect to energy, is nearly in a steady state, receiving energy from the sun and releasing it to space. With respect to matter, however, the Earth is almost a closed system. There are a number of natural Earth cycles such as water and rock cycles in which earth materials are continually recycled. For example, the rain that falls today and erodes sediment to be washed to the sea will eventually return to the atmosphere, while the sediment that is deposited will eventually be transformed into solid rock.

We must understand the magnitude and frequency of processes that maintain dynamic Earth cycles. For example, if we wish to manage a region's water resources, we must be able to evaluate the nature and extent to which natural processes supply groundwater and surface water. Or, if we are concerned with the disposal of dangerous chemical or radioactive materials in the geologic environment, we must know how the disposal procedure will interact with natural cycles to insure that we or future generations will not be exposed to hazardous materials. Therefore, it is imperative that we recognize Earth cycles and determine the length of time involved in various parts of these cycles. Tables 1.1 and 1.2 list characteristic residence times for some natural cycles and rates of several natural processes.

TABLE 1.1

Residence times of some natural cycles.

Earth Materials	Some Typical Residence Times
Atmosphere circulation	
Water vapor	10 days (lower atmosphere)
Carbon dioxide	5 to 10 days (with sea)
Aerosol particles	
Stratosphere (upper atmosphere)	Several months to several years
Troposphere (lower atmosphere)	One week to several weeks
Hydrosphere circulation	
Atlantic surface water	10 years
Atlantic deep water	600 years
Pacific surface water	25 years
Pacific deep water	1300 years
Terrestrial groundwater	150 years [above 760 m depth]
Biosphere circulation[a]	
Water	2,000,000 years
Oxygen	2000 years
Carbon dioxide	300 years
Seawater constituents[a]	
Water	44,000 years
All salts	22,000,000 years
Calcium ion	1,200,000 years
Sulphate ion	11,000,000 years
Sodium ion	260,000,000 years
Chloride ion	Infinite

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[a]Average time it takes these materials to recycle with the atmosphere and hydrosphere.

Two rather fundamental truths face us: First, the Earth is the only habitable place we have that is now accessible; and second, our resources, even renewable ones, are limited. If we consume the last of our grain and foul our water and air, then these so-called renewable resources may not be as renewable as we would wish. On the other hand, nonrenewable resources such as metals will eventually require large-scale recycling and/or extensive conservation to insure an adequate supply. Furthermore, we must recognize that many materials that are considered pollutants or waste are really resources that are out of place.

TABLE 1.2
Rates of some natural cycles.

Earth Processes	Some Typical Rates
Erosion	
Average U.S. erosion rate[a]	6.1 cm per 1000 years
Colorado River drainage area	16.5 cm per 1000 years
Mississippi River drainage area	5.1 cm per 1000 years
N. Atlantic drainage area	4.8 cm per 1000 years
Pacific slope (Calif.)	9.1 cm per 1000 years
Sedimentation[b]	
Colorado River	281 million metric tons per year
Mississippi River	431 million metric tons per year
N. Atlantic coast of U.S.	48 million metric tons per year
Pacific slope (Calif.)	76 million metric tons per year
Tectonism	
Sea-floor spreading	
N. Atlantic	2.5 cm per year
E. Pacific	7 to 10 cm per year
Faulting	
San Andreas (Calif.)	1.3 cm per year
Mountain uplift	
Cajon Pass, San Bernardino Mts. (Calif.)	1 cm per year

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[a]Thickness of the layer of surface of the continental United State per 1000 years.
[b]Includes solid particles and dissolved salts.

CONCEPT 2

Solutions to environmental problems often involve an understanding of systems and rates of change.

Analysis of many environmental problems and possible solutions often involves an understanding of systems, feedback cycles, and rates of change. For example, to properly manage renewable resources, whether it be timber or whales, one must be familiar with the system and feedback responsible for maintaining that resource as well as the current and past rates of exploitation and projected future harvest. The ocean, for example, is an open system in which there are few boundaries for energy and material. While we may consider many Earth systems such as the oceans or a volcanic system as open, the Earth is probably best regarded as a closed system in terms of resources, particularly renewable resources that are recycled on a rather frequent basis.

There are two types of feedback cycles in systems: positive feedback and negative feedback. Positive feedback is often known as the vicious cycle, whereas negative feedback is self-regulating, inducing the system to approach an equilibrium or steady state. Figure 1.1 illustrates the concepts of positive and negative feedback for the urban environment. Many processes in nature also exhibit feedback cycles. For example, off-road vehicle use may be a positive cycle because as vehicle use increases the number of plants that are uprooted increases, which increases erosion. As this occurs, still more plants are damaged, which further increases erosion until eventually an area intensively used by off-road vehicles may be completely denuded of all vegetation and have a very high

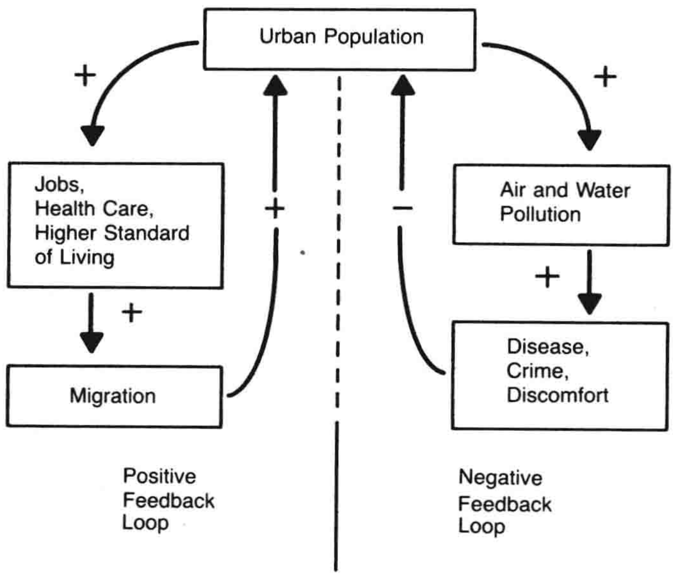

FIGURE 1.1
Idealized diagram of positive and negative feedback loops for an urban population. (Modified after Maruyama, 1963.)

erosion rate. On the other hand, systems such as rivers often display a negative feedback such that a rough steady state is formed. That is, as rivers change in response to an increase in regional rainfall or urbanization, the channel and floodplain system will make changes to accommodate the new, increased amount of water or sediment and within a relatively short time, a new steady state may be established.

Growth rates are important in changes that take place in systems. Exponential growth is particularly significant. Figure 1.2 shows an idealized diagram of an exponential growth curve. Notice that it is shaped like "J"; in the early stages the growth may be quite slow, but then it increases rapidly and then very rapidly. Many systems, both human-induced and natural, may approach the "J" curve for some lengths of time. Involved in exponential growth are two important factors: the rate of growth measured as a percentage, and the doubling time in years, which is the time necessary for the quantity of whatever is being measured to double. A general rule of thumb is that the doubling time is approximately equal to 70 divided by the growth rate. This rule applies to growth rates up to approximately 10 percent. Beyond that, the errors may become quite large.

There are some interesting consequences of exponential growth. For example, if we consider the growth rate of energy consumption, which in the United States has approached 7 percent, then the doubling time will be 10 years. This means that in one decade we will consume as much energy as we have consumed up until that time. A hypothetical story by Albert Bartlett will illustrate this [1]. Consider a hypothetical strain of bacteria that grows with a division time of 1 minute. The growth rate, then, is 1 divided by 60 or 1.66 percent per second, and the doubling time is 60 seconds or 1 minute. Assume that our hypothetical bacterium is put in a bottle at 11:00 A.M., and it is observed that the bottle is full at 12:00 noon. An important question is, When was the bottle half-full? The answer is 11:59 A.M. If you were an average bacterium in the bottle, at what time would you realize that you were running out of space? There is certainly no unique answer to this question, but at 11:58 A.M. the bottle was 75 percent empty, and at 11:57 A.M. it was 88 percent empty. Now assume that at 11:58 A.M. some farsighted bacteria realized that they were running out of space and started looking around for new bottles. Let's suppose that they were able to find three more bottles. How much time did they buy? The answer is 2 additional minutes. They will run out of space at 12:02 P.M.

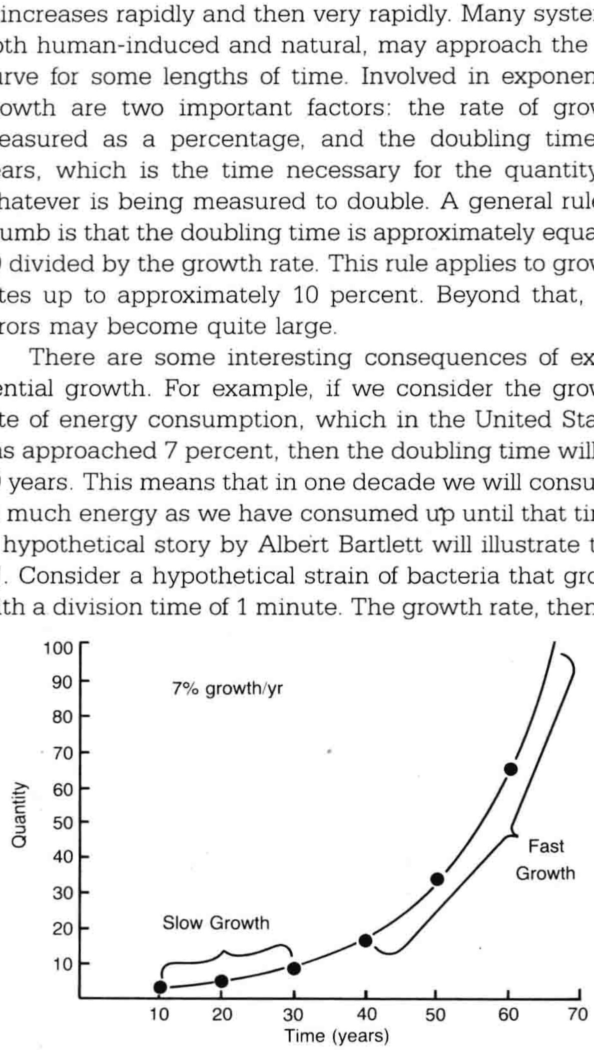

FIGURE 1.2
Idealized diagram of the "J" curve for exponential growth. Notice that in the lower part of the "J" the growth is slow, but past the bend, growth becomes extremely rapid.

The preceding example, while hypothetical, illustrates the power of exponential growth. Many systems in nature display exponential growth for some periods of time, so it is important that we be able to recognize it. In particular, it is important to recognize exponential growth with positive feedback as it may be very difficult to stop positive feedback cycles. Negative feedback, on the other hand, tends toward a steady state and thus is easier to control.

Changes in natural systems may be predictable and should be recognized by anyone looking for solutions to environmental problems (Fig. 1.3). Where the input into the system is equal to the output (Fig. 1.3a), a rough steady state is established and no change occurs. Examples of an approximate steady state may be on a global scale—the balance between incoming solar radiation and outgoing radiation from the Earth, or the system of plate tectonics in which new lithosphere is being created and destroyed at about the same rate—or on the smaller scale of a duck farm in which ducks are brought in and harvested at a constant rate. Another example of change is where the input into the system is less than the output (Fig. 1.3b). Examples of this would be the use of resources such as groundwater or the harvest of certain plants or animals. If the input is much less than the output, then the groundwater may be completely used or the plants and animals may die out. In a system where input exceeds output (Fig. 1.3c), positive feedback may occur, and the stock of whatever is being measured will increase. Examples are the buildup of heavy metals in lakes or the pollution of soil water. By using rates of change or input/output analysis of systems, we can derive an average *residence time* for such factors. The average residence time is a measure of the time it takes for the total stock or supply of a particular material, such as a resource, to be cycled through the pool. To compute the av-

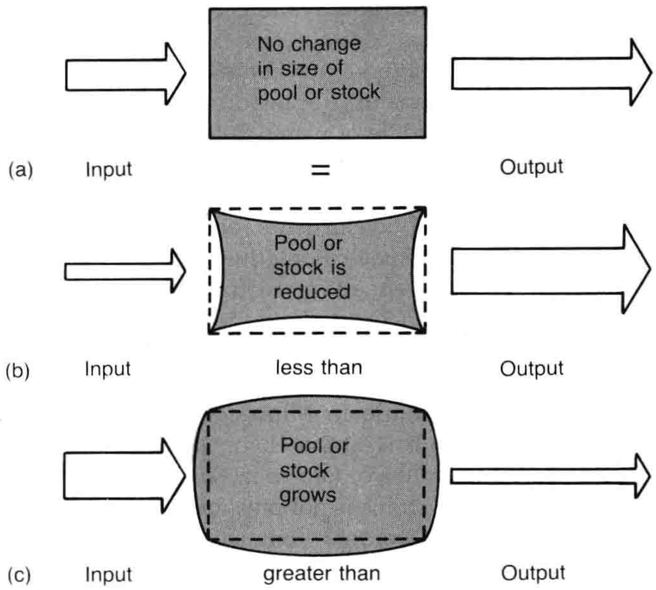

FIGURE 1.3
Idealized diagram of the major ways that a pool or stock of some material may change. (Modified after Ehrlich, Ehrlich, and Holdren, 1977.)

erage residence time, we simply take the total size of the stock or pool and divide it by the average rate of transfer through that pool or stock.

An understanding of changes in systems is primary in many problems in environmental studies. We conclude from our discussion of growth rates and exponential growth that very small growth rates may yield incredibly large numbers in modest periods of time. On the other hand, with other systems it may be possible to compute a residence time for a particular resource and, knowing this, apply the information to develop sound management principles. Recognizing positive and negative feedback systems as well as calculating growth rates and residence times, then, enable us to make predictions concerning resource management.

CONCEPT 3

The Earth, as a planet, has been profoundly altered by life; its atmosphere, oceans, and sediments are strongly modulated by life and are very different from what they would be on a lifeless planet.

The modern atmosphere of the Earth has some peculiar attributes. For example, in it oxygen and methane occur together in concentrations that are close to an explosive combination. That is, a little more methane or a little more oxygen and any spark could produce a large explosion. This means that methane and oxygen occur in concentrations that are far from a chemical equilibrium, an equilibrium that would be reached if the chemical constituents of the oceans, lands, and atmosphere were left together in a closed transparent container and placed out in the sun and under the stars, subject to ordinary Earth days and nights for a very long time. In such a closed container, the methane would inevitably combine with the oxygen to form carbon dioxide and water [2]. This does occur in our present Earth's atmosphere, so there must be a source producing methane as well as oxygen, replenishing what is converted in the air to carbon dioxide and water.

This curious chemical disequilibrium does not occur on Mars and Venus, the two planets in our solar system most like the Earth in size and distance from the sun. Space probes to Mars and Venus, as well as Earth-based observations of these planets with telescopic devices, reveal that the atmospheres of these two planets are similar in composition but are very different from the Earth's. The atmospheres of Mars and Venus are predominantly carbon dioxide, which exists only as a trace constituent (0.03 percent) of the Earth's atmosphere.

The peculiar chemical disequilibrium of the Earth's atmosphere is a result of life acting over long periods of geological time. All of the gases in the Earth's atmosphere are profoundly altered by life, and have been so for several billion years. Moreover, the atmospheric constituency of the Earth appears to have been relatively stable for millions of years, suggesting that life regulates the conditions of its existence by stabilizing the atmosphere as well as by profoundly altering its constitution. This is why we say *the Earth is a living planet.*

Life is thus intimately tied to the cycling of elements through the atmosphere, not only using the gases in the air but controlling the air's constitution. Life is responsible for the kinds of compounds and their concentration, for the amounts that are there at any one time, and the rates at which the compounds enter and leave the atmosphere.

The impact of life on the atmosphere extends beyond the atmosphere's chemistry. Life affects the physical characteristics of the atmosphere and the Earth's surface as well as the rate of heating and cooling—and therefore the temperature—of the Earth's surface and its weather and climate.

The effects of life on the Earth's chemistry are apparent in the soils and rocks and the fresh waters and oceans as well as in the air. As the famous ecologist G. Evelyn Hutchinson observed in 1954, the effects of life on geological processes is indicated in "the presence of great thicknesses of limestone in the sedimentary column" which indicate that "an enormous quantity of carbon dioxide had left the atmosphere" through the process of photosynthesis [3].

Locally, life has caused water to be much more varied than it would have been on a lifeless planet: basic-alkaline in some locales, highly acidic in others. Globally, life adds organic acids such as humic acids from decaying tree leaves; the biota also change the proportion of dissolved carbon dioxide, sulphur dioxides, and nitrogen oxides.

Other evidence suggests that many of the important mineral deposits are the result, directly or indirectly, of biological processes. For example, the deposition of copper and other metals can take place in shallow waters lacking oxygen and within a narrow range of acidity. It is life that removes the oxygen from these waters and creates the necessary conditions of acidity.

The effect of life on the Earth is all the more remarkable because living organisms make up only a tiny fraction of the Earth's mass. If the mass of all living things were evenly mixed with the rest of the material of the Earth, the concentration of living material would be two tenths of one part in a trillion, which is a concentration at the border of detectability of our most sophisticated chemical instruments. (The mass of living things is 1.2×10^{12} kilograms; the mass of the Earth is 6×10^{24} kilograms.) Even in relation to the atmosphere, the biota make up a small fraction of the total mass. The mass of the biota equals 0.02 percent of the mass of the atmosphere.

CONCEPT 4

Sustained life on the Earth is a characteristic of ecosystems, not of individual organisms or populations.

We know of no single organism, population, or species that both produces all of its own food and completely recycles all of its own metabolic products. Green plants in light produce sugar from carbon dioxide and water, and from sugar and inorganic compounds make many organic compounds, including protein, and woody tissue. But no green plant alone can degrade woody tissue back to its original inorganic compounds. Those living things that degrade woody tissue, such as bacteria and fungi, do not produce their own food, but instead obtain their energy and chemical nutrition from the dead tissues they feed on. From these observations, we know that for complete recycling of chemical elements to take place there must be several species.

Minimal systems that could have the property for a flow of energy and a complete chemical cycling are apparently composed of at least several interacting populations and their nonbiological environment. The smallest candidates for such minimal systems are what ecologists call *ecosystems*—local communities of interacting populations and their local, nonbiological environment.

The term **ecosystem** is applied to areas of all sizes, from the smallest puddle of water to a large forest. Ecosystems also differ greatly in composition: in the number and kinds of species, in the kinds of and relative proportions of nonbiological constituents, and in the degree of variation in time and space. Sometimes the borders of an ecosystem are well defined, as in the transition from a rocky ocean coast to a forest along the coast of Maine, or in the transition from a pond to the surrounding forest. Sometimes the borders are vague, as in the subtle gradation of forest into prairie in Minnesota and South and North Dakota in the United States, or the transition from grasslands to savannahs or forests in East Africa. What is common to all ecosystems is not physical structure—size, shape, variations of borders—but the existence of the processes we have mentioned, the flow of energy and the cycling of chemical elements.

Ecosystems can be natural or artificial. An artificial pond that is part of a waste treatment plant is an example of an artificial ecosystem. Ecosystems can be natural or managed, and the management can vary over a large range of actions. Agriculture can be thought of as partial management of certain kinds of ecosystems.

Natural ecosystems carry out many "public service" functions for us. Waste water from houses and industries is often converted to drinkable water by passage through natural ecosystems, and pollutants, like those in the smoke from industrial plants or the exhaust from automobiles, are often converted to harmless compounds by forests.

CONCEPT 5

Individual populations are capable of rapid exponential growth, but this is rarely achieved in nature; control of populations is the norm.

Although maximum population size is limited by resources, biological populations are capable of extremely rapid growth. When the increase in the size of a population is a constant percentage of the current population size, the growth is called **exponential** or **geometric.** Laboratory cultures, like yeast in a sugar solution, can increase exponentially for brief periods. Occasionally, natural populations of more complex multicellular organisms are also observed to increase exponentially for brief periods. A pheasant population introduced onto a small island in Puget Sound, Washington, grew exponentially for more than 2 decades (Fig. 1.4); a population of 8 introduced in 1937 grew to 1898 in less than 6 years [4].

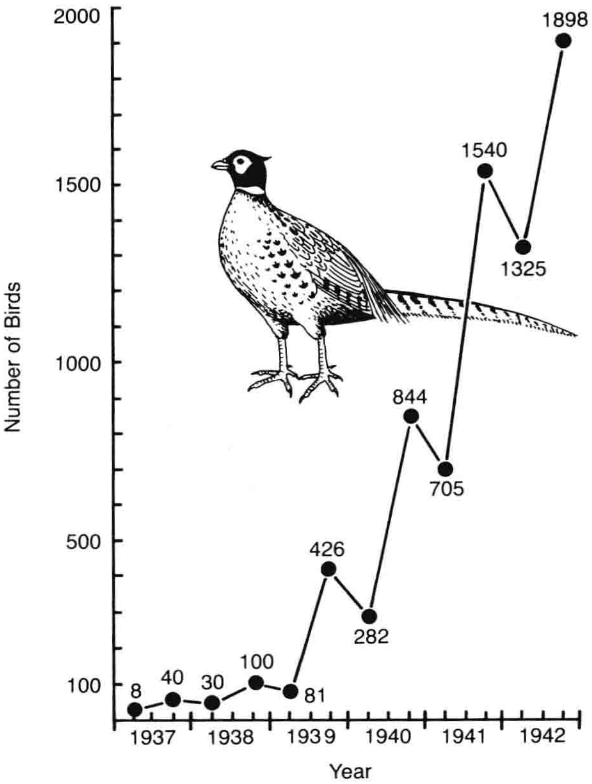

FIGURE 1.4
Growth of a pheasant population on a small island in Puget Sound, Washington, over a 6-year period.

Since the Industrial Revolution, the world's human population has increased at a rate more rapid than an exponential increase; that is, the annual increase in the total number of humans has been an increasingly larger fraction of the current population.

A biological population is characterized by three rates: a rate of birth (reproduction), a rate of growth, and a rate of death. When rapid population growth occurs, eventually a point is reached when the resources available per individual become limiting, and a change occurs in the population rates: births may decrease and/or deaths increase, and/or individual growth decreases.

When a population is self-regulated, it is said to exhibit **density-dependent population control.** Density-dependent population control implies that one or more of the three population rates changes with population size. That is, birth, survival, and growth rates may decrease as the population size increases.

One population may be regulated by another. Trees of different species compete with each other for light, and one species limits the abundance of another. An increase in the size of one population may cause an increase in the incidence of parasitism, such as disease, or an increase in the incidence of predation.

The sizes of populations are also changed by factors that are unrelated to the population's density. For example, a tornado can sweep through a forest and knock down all the trees in its path. The incidence of the tornado is completely independent of the number of trees in the forest. If all trees in the path of the tornado are killed, the death rate is also independent of the size of the population. In this case, the size of a population may be restricted to a relatively narrow range by factors completely unrelated to the population's own size or rates of birth, growth, and death. This is called **density-independent population regulation.**

To summarize, nothing can increase forever. The Earth and the known universe are finite in space, matter, and energy. In a finite universe, there is an upper bound to the size of everything. So, too, are populations limited to a finite range.

CONCEPT 6

Today's physical and biological processes are maintaining and modifying our Earth and have operated throughout much of geologic time. However, the magnitude and frequency of these processes are subject to natural and artificially induced changes.

The concept that present physical and biological processes which are forming and modifying our Earth will help to explain the geologic and evolutionary history of the Earth is known as the doctrine of **uniformitarianism.** Simply stated as "the present is the key to the past," uniformitarianism was first suggested by James Hutton in 1785. Because Charles Darwin was impressed by the concept of uniformitarianism, it pervades his ideas on biological evolution. Today the doctrine is heralded as one of the fundamental concepts of the Earth and biological sciences.

Uniformitarianism does not demand or even suggest that the magnitude and frequency of natural processes remain constant with time. Obviously some processes do not extend back through all of geological time. For example, the processes operating in the oxygen-free environment during the first billion years or so of Earth history must certainly have been quite different from processes we observe today. However, as long as the early continents, oceans, and atmosphere were like modern ones, and so long as the basic factors that rule biological evolution have not changed, then we can infer that present processes also operated in the past. For example, if we study present-day stream channels and learn something about the types of deposits associated with streams, then